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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 18-1

“Radar Target Detection”
(«Обнаружение РЛ целей»)

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"Analysing and compensating the effects of range and Doppler frequency migrations in linear frequency modulation pulse compression radar"

The pulse compression and Doppler processing (PCDP) method has been extensively used to detect low-speed and uniform-speed targets in linear frequency modulation (LFM) pulse compression radar. However, the PCDP method is affected by range migration (RM) and Doppler frequency migration (DFM) when detecting high-speed and accelerating targets. In this paper, the authors analyse and quantify these effects, and obtain the relationships of the optimal number of pulses and the threshold number of pulses with RM and DFM. It shows that when the number of pulses equals its optimal value, the maximum output signal-to-noise ratio can be obtained; when the number of pulses is greater than its threshold value, the migrations should be compensated. Then the authors propose a method based on the scaling processing and the fractional Fourier transform to remove the two migrations. In the end, the authors give a target detection experiment to show that the proposed method can effectively compensate these migrations. [J1]

"Diversity Gain for MIMO Neyman-Pearson Signal Detection"

For a multiple-input multiple-output (MIMO) system adopting the Neyman-Pearson (NP) criterion, we initially derive the diversity gain for a signal-present versus signal-absent scalar hypothesis test statistic and also for a vector signal-present versus signal-absent hypothesis testing problem. For a MIMO radar system with Mtransmit and Nreceive antennas, used to detect a target composed of Qrandom scatterers with possibly non-Gaussian reflection coefficients in the presence of possibly non-Gaussian clutter-plus-noise, we consider a class of test statistics, including the optimum test for Gaussian reflection coefficients and Gaussian clutter-plus-noise, and apply the previously developed results to compute the diversity gain. It is found that the diversity gain for the MIMO radar system is dependent on the cumulative distribution function (cdf) of the reflection coefficients while being invariant to the cdf of the clutter-plus-noise under some reasonable conditions requiring certain moments of the magnitude of the processed clutter-plus-noise be bounded. If the noise-free received waveforms, due to target reflection, at each receiver span a space of dimension M' ≤ M, the largest possible diversity gain is controlled by the value of min(NM', Q) and the lowest order power in an expansion, about zero, of the cdf of the magnitude squared of a linear transformed version of the reflection coefficient vector. It is shown that the maximum possible diversity gain in any given scenario can be achieved without employing orthogonal waveforms. [J2]

"Multiobjective Optimization of OFDM Radar Waveform for Target Detection"

We propose a multiobjective optimization (MOO) technique to design an orthogonal-frequency-division multiplexing (OFDM) radar signal for detecting a moving target in the presence of multipath reflections. We employ an OFDM signal to increase the frequency diversity of the system, as different scattering centers of a target resonate variably at different frequencies. Moreover, the multipath propagation increases the spatial diversity by providing extra "looks" at the target. First, we develop a parametric OFDM radar model by reformulating the target-detection problem as the task of sparse-signal spectrum estimation. At a particular range cell, we exploit the sparsity of multiple paths and the knowledge of the environment to estimate the paths along which the target responses are received. Then, to estimate the sparse vector, we employ a collection of multiple small Dantzig selectors (DS) that utilizes more prior structures of the sparse vector. We use the ℓ1-constrained minimal singular value (ℓ1-CMSV) of the measurement matrix to analytically evaluate the reconstruction performance and demonstrate that our decomposed DS performs better than the standard DS. In addition, we propose a constrained MOO-based algorithm to optimally design the spectral parameters of the OFDM waveform for the next coherent processing interval by simultaneously optimizing two objective functions: minimizing the upper bound on the estimation error to improve the efficiency of sparse-recovery and maximizing the squared Mahalanobis-distance to increase the performance of the underlying detection problem. We provide a few numerical examples to illustrate the performance characteristics of the sparse recovery and demonstrate the achieved performance improvement due to adaptive OFDM waveform design. [J3]

"Track-before-detect procedures for low pulse repetition frequency surveillance radars"

In this study, the authors present a dynamic programming (DP)-based tracking-before-detect (DP TBD) procedure with reference to a low pulse repetition frequency (PRF) surveillance radar framework. In order to avoid non-linear transformation and meanwhile exploit the ambiguous Doppler information, which is eliminated in most of the literature, the authors model the target dynamics in the measurement coordinates defined by range and apparent Doppler. The target state evolutions in the range-apparent Doppler domain are considered as a hybrid system with the ambiguous number deemed as mode variable. Ambiguity number (or mode) transitions are modelled as state dependent. The authors present a DP TBD method for joint maximum a posteriori(MAP) estimation of the target trajectory in the range-apparent Doppler maps and the corresponding ambiguity sequence, both assumptions of known and unknown nuisance parameters (target power and noise variance) are considered. The detection and tracking performance of the proposed procedure are investigated under several system settings. The effect of the prior uncertainty of the nuisance parameters on the performance is also studied. [J4]

"Target detection in high-resolution sea clutter via block-adaptive clutter suppression"

Attentions have been focused on the moving target detection in a high-resolution sea clutter. This study commences with a proposal of median-based estimator to estimate the power spectrum of high-resolution sea clutter by the time series observed in adjacent range cells and time intervals. The estimator provides a robust estimation when just a few aberrant time series happen in observation. Based on the estimator, a block-adaptive clutter suppression filter (BACSF) is designed to suppress the clutter prior to the pulse integration. Then, the residual clutter, the output of the BACSF, is modelled as spherically invariant random vector. Upon applying an adaptive normalised matched filter (ANMF) to the residual clutter, a residual clutter's ANMF detector is derived. Moreover, in high-resolution radar background, considering that the approximately stationary intervals of sea clutter and residual clutter are much shorter than the coherent processing interval, another heuristic block-ANMF detector is proposed. It can integrate more pulses and can achieve better performance than the ANMF detector does. This study concludes with the experiments of simulated target against the real sea clutter. The experimental results demonstrate that, when target's Doppler frequency is beyond strong clutter region, the ANMF detector and block-ANMF detector perform better in the residual clutter than in the clutter. [J5]

"Adaptive subspace detector for multi-input multi-output radar in the presence of steering vector mismatch"

This study studies the problem of adaptive target detection by multi-input multi-output (MIMO) radar with multiple antennas at each of the receiver sites. MIMO radar has been postulated to have a number of advantages over its monostatic counterpart. However, many previous publications have not necessarily made valid assumptions in assessing performance potential. Here, the authors consider the issue of the overall MIMO radar system steering vector which should be aligned with the desired pointing direction. However, misalignment can occur because of calibration errors, receiver channel imperfections and beam pointing errors. To account for this misalignment, the steering vector is assumed to belong to a known linear subspace. At the design stage, the authors resort to a generalised likelihood ratio principle and Rao test criterion. Subsequently, MIMO versions of the subspace generalised likelihood ratio test (MIMO-SGLRT), the subspace adaptive beam-former orthogonal rejection test (MIMO-SABORT) and the subspace Rao (MIMO-SRao) detector are developed to improve the robustness of MIMO radar detection performance for the case of steering vector mismatch. The constant false alarm rate properties of the three detectors are demonstrated. Finally, the performance of the MIMO-SGLRT, MIMO-SABORT and MIMO-SRao detectors in both the matched and mismatched steering vector cases are numerically evaluated. The results show the robustness of the proposed detectors to steering vector mismatch. [J6]

"An Improved Scheme for Target Discrimination in High-Resolution SAR Images"

To design a highly automatic and practical method for target discrimination in synthetic aperture radar images, we propose in this paper an improved scheme consisting of the framework and algorithms for target discrimination. Our main contribution in this scheme comprises four aspects. First, an integrative frame sequentially combining the algorithm based on feature extraction and the knowledge of target group has been presented. Second, three new features for target discrimination have been introduced. Third, a genetic algorithm-based feature-selection algorithm has been presented. The results show that this algorithm can evaluate the goodness-of-feature better. Finally, to improve the accuracy of the discriminator, we have designed a weighted quadratic distance discriminator, which has been observed to improve the performance of target discrimination. We have analyzed the performance of the proposed scheme comprehensively and specifically using some measured data, and carried out comparisons of the existing algorithms. The results show that the proposed scheme could improve the application ability in target discrimination. [J7]

"Ground Moving Targets Imaging Algorithm for Synthetic Aperture Radar"

It is well known that the motion of a target induces range migration, especially for high-resolution synthetic aperture radar (SAR) systems. Ground moving target imaging necessitates the correction of the unknown range migration. To finely refocus a moving target, one must accurately obtain the motion parameters for compensating the target trajectory. However, in practice, these parameters usually cannot be precisely estimated. This paper proposes a new imaging approach for ground moving targets without a priori knowledge of their motion parameters. In the devised method, the azimuth compression function is constructed in range frequency domain, which can eliminate the coupling effect between range and azimuth. Theoretical analysis confirms that the methodology can precisely focus targets without interpolation procedure. The effectiveness of the proposed imaging technique is demonstrated by both simulated and real airborne SAR data. [J8]

"Physical Limitations on Detecting Tunnels Using Underground-Focusing Spotlight Synthetic Aperture Radar"

This paper examines the feasibility of underground-focusing spotlight synthetic aperture radar (UF-SL-SAR) systems for tunnel detection applications. A general formulation is reviewed for generating UF-SL-SAR imaging by using multiple frequencies across a wide band and by focusing in space to subsurface points using well-known ray refraction at the nominal ground surface. A full-wave finite-difference frequency-domain model is used to consider wave propagation in realistic soil with loss- and frequency-dependent dielectric constant and a randomly rough ground surface, both of which serve to obscure and distort the returned tunnel target signal. Imaging results are presented for two representative soil scenarios: dry sand and moist clay loam. Considering the ground surface ray refraction for focusing greatly improves the SAR image relative to conventional SAR focusing at the ground surface. Using UF-SL-SAR, a small shallow tunnel is reasonably imaged for the sand case, despite the roughness of the ground interface. However, for higher conductivity moist clay loam, the clutter from the rough surface overwhelms the significantly attenuated target signal, which must propagate through the lossy intervening soil. It is demonstrated that, despite ideal focusing, the tunnel is successfully imaged only for the sand case. [J9]

"An Improved Radon-Transform-Based Scheme of Doppler Centroid Estimation for Bistatic Forward-Looking SAR"

For high-quality synthetic aperture radar (SAR) processing, Doppler centroid estimation is an essential procedure. An incorrect Doppler centroid would cause a loss of SNR, an increase in the azimuth ambiguity level, a shift in the location of the target, etc. An improved Radon-transform-based Doppler centroid estimation scheme of bistatic forward-looking SAR is proposed in this letter. First, this scheme performs edge detection on the range-compressed data and then does the coarse and fine Radon transforms to estimate the Doppler centroid. Simulations and real-data experiments validate the effectiveness of this method. [J10]

"Adaptive OFDM Radar for Target Detection in Multipath Scenarios"

We develop methods for detecting a moving target in the presence of multipath reflections, which exist, for example, in urban environments. We take advantage of the multipath propagation that increases the spatial diversity of the radar system and provides different Doppler shifts over different paths. We employ a broadband orthogonal frequency division multiplexing (OFDM) signal to increase the frequency diversity of the system as different scattering centers of a target resonate variably at different frequencies. To overcome the peak-to-average power ratio (PAPR) problem of the conventional OFDM, we also use constant-envelope OFDM (CE-OFDM) signaling scheme. First, we consider a simple scenario in which the radar receives only a finite number of specularly reflected multipath signals. We develop parametric measurement models, for both the OFDM and CE-OFDM signaling methods, under the generalized multivariate analysis of variance (GMANOVA) framework and employ the generalized likelihood ratio (GLR) tests to decide about the presence of a target in a particular range cell. Then, we propose an algorithm to optimally design the parameters of the OFDM transmitting waveform for the next coherent processing interval. In addition, we extend our models to study the aspects of temporal correlations in the measurement noise. We provide a few numerical examples to illustrate the performance characteristics of the proposed detectors and demonstrate the achieved performance improvement due to adaptive OFDM waveform design. [J11]

"Combination of Advanced Inversion Techniques for an Accurate Target Localization via GPR for Demining Applications"

We used advanced ground-penetrating radar (GPR) inversion techniques for detecting landmines in laboratory

conditions. The radar data were acquired with a calibrated vector network analyzer combined with an off-ground monostatic horn antenna, thereby setting up a stepped-frequency continuous-wave radar. Major antenna effects and interactions with the soil and targets were filtered out using frequency-dependent complex antenna transfer functions. The proposed strategy first exploits inversion approaches that are able to give an accurate characterization of the antenna-soil interaction and a reliable estimate of the soil permittivity. The outcomes of this first phase are at the basis of the application of a microwave tomographic approach based on the Born approximation to achieve the imaging of the subsurface. The algorithms were applied for imaging three landmines of different sizes and buried at different depths in sand. Although the radar system was off the ground, the results showed that it was possible to reconstruct all mines, including a shallow plastic mine as small as 5.6 cm in diameter. This last mine was invisible in the raw radar data, and the use of common GPR imaging techniques did not lead to satisfactory results. The proposed integrated method shows great promise for shallow subsurface imaging in a demining context, particularly because it automatically provides accurate information on the shallow soil dielectric permittivity. [J12]

"Analysis of polarimetric techniques using high-resolution polarimetry data in an automatic target recognition context"

In recent years, large numbers of radar images are collected but there is neither time nor enough manpower to go through each collected image. Researchers in the automatic target recognition (ATR) field have developed automated algorithms and tools to analyse each image and obtain higher recognition rate and fewer false alarms but there is still a need for improvement in these aspects. In this study, we have investigated various polarimetric and non-polarimetric techniques and recommended the best ATR approach among those analysed for higher recognition rate and least false alarm rate. The experimental results show that self-organising map (SOM) feature extraction technique with a two-dimensional Fourier transform (2DFFT) algorithm has a better classification rate and a lower false alarm rate. The classifier used here was AND Corporation's holographic neural technology (UNeT) classifier. The SOM technique using |HH|, |HV| and |W| achieved 98.9% correct classification over the detected targets and reduced the false alarm rate to 8.2%. An ATR system trained with both target and not-a-target class data produced a lower false alarm rate compared with ATR systems trained with target samples alone. This study will help in selection of appropriate methods for future ATR system implementations. In addition, it will assist image analysts (IAs) in choosing appropriate techniques and training datasets to perform their operational tasks. [J13]

"Ambiguity Function Analysis of Wireless LAN Transmissions for Passive Radar"

Wireless transmission is becoming an increasingly widely available source of transmissions for passive radar detection. In this paper, we present a detailed analysis of the ambiguity function (AF) of a range of typical IEEE 802.11 signals obtained during a series of experimental trials. Theoretical analysis has been used to identify the average properties of basic signal types in terms of resolution and sidelobe levels in both the range and Doppler domains. The theoretical model of a range of typical 802.11 transmissions has been verified and range and Doppler resolutions have been investigated for a range of transmission types. It has been found that using Doppler with a suitable integration time can enable detection of typical personnel targets. A number of issues relating to the use of these transmissions have been identified during this study. [J14]

"New Parameter Estimation and Detection Algorithm for High Speed Small Target"

Target detection and parameter estimation are the principal problems of radar applications. The detection and parameter estimation for high-speed small targets are challenging for narrowband radar since the target may only occupy one range cell with small reflectivity. In addition, the high speed makes the target shift through range cells during the observation period, which makes it difficult to improve the target's reflecting energy coherent accumulation and signal-to-noise ratio (SNR). An algorithm for high-speed small target detection and parameter estimation with narrowband radar is proposed in this paper. Firstly three target motion parameters, i.e., the cross-range frequency modulation rate, ambiguous Doppler frequency, and fold factor are estimated one by one. Then based on the estimated parameters, a target detection method is proposed. In addition, we also analyze the detection performance under estimation error. After that, an improved method for fold factor estimation is presented. Simulation results have proved the validity of the proposed algorithm. [J15]

"Application of clutter reduction techniques for detection of metallic and low dielectric target behind the brick wall by stepped frequency continuous wave radar in ultra-wideband range"

A study of clutter reduction techniques for detection of metallic and non-metallic (low dielectric constant) targets behind a brick wall with the help of ultra-wideband (UWB) through wall imaging system is presented. It is known that sometimes the clutter level is comparable to the level of target reflection that makes it difficult to detect the

target correctly. Detection of low dielectric constant materials becomes more difficult due to low reflection from such targets. Therefore there is a need to analyse various clutter removal techniques and check the performance of these techniques for enhancement of target signal-to-clutter ratio. For this purpose, an UWB stepped frequency wave radar is indigenously assembled with the use of vector network analyser, which works in the frequency range of 3.95??5.85 GHz. An experiment is carried out for detection of metal as well as Teflon (low dielectric constant) targets with the application of clutter reduction techniques. The authors have considered statistical-based techniques like singular value decomposition, principle component analysis, factor analysis and independent component analysis (ICA) for clutter removal. It is observed that the signal-to-clutter ratio for metal target detection is quite enhanced by all the four techniques, whereas only ICA is able to enhance the signal-to-clutter ratio for a low dielectric constant target like Teflon. [J16]

"Geometry-Induced Range-Dependence Compensation for Bistatic STAP with Conformal Arrays"

Radar space-time adaptive processing (STAP) is a well-suited technique to detect slow-moving targets in the presence of a strong interference background. We consider STAP for a radar operating in a bistatic radar configuration and collecting returns with a conformal antenna array (CAA). The statistics of the secondary data snapshots used to estimate the optimum weight vector are not identically distributed with respect to range, thus preventing the STAP processor from achieving its optimum performance. The compensation of the range-dependence (RD) requires the knowledge of the locus of the clutter signature. We use a new RANSAC-based method for estimating this locus or, equivalently, the flight configuration parameters. Based on this knowledge, we perform an RD compensation of the snapshots to obtain an accurate estimate of the clutter covariance matrix. End-to-end performance analysis in terms of signal-to-inference-plus-noise ratio loss shows that our method yields promising performance. [J17]

"Detection and Tracking of Coordinated Groups"

In this paper, we describe models and algorithms for detection and tracking of group and individual targets. We develop two novel group dynamical models within a continuous time setting using stochastic differential equations (SDE) that aim to mimic behavioural properties of groups. We also describe a possible way of modeling interactions between closely spaced targets using repulsive forces. These can be combined with a group structure transition model to create realistic evolving group models. We use a Markov chain Monte Carlo (MCMC)-particles algorithm to perform sequential inference. Computer simulations demonstrate the ability of the algorithm to detect and track targets within groups as well as to infer the correct group structure over time. The group tracking model is also applied to two sets of real ground moving target indicator (GMTI) radar data with group targets. The results show significant improvement in tracking accuracy over tracking without group models. [J18]

"Time Reversal Detection in Clutter: Additional Experimental Results"

Time reversal (TR) is a promising technique in detecting weak targets immersed in clutter. This paper reports a series of electromagnetic (EM) domain experiments on TR detection using a single antenna pair in a controlled scattering environment. The TR likelihood ratio detector is compared with the conventional energy detector and the matched filter. The EM experiments demonstrate the superiority of TR detection over conventional detection in rich multipath scattering environments. [J19]

"Signal fusion-based target detection algorithm for spatial diversity radar"

Signal fusion-based radar target detection algorithms are studied in this article for spatial diversity multiple input multiple output (MIMO) radar based on the generalised likelihood ratio test (GLRT) algorithm, under the assumption that covariance matrices of clutter signals received by different radar sites are different. Two signal fusion-based target detection algorithms are proposed, which can be applied in signal fusion networks (SFNs) with typical structures, at a low communication and computation cost. Simulation experiments in several scenarios indicate that two proposed signal fusion algorithms have better detection performances than decision fusion algorithms. [J20]

"Range-Spread Target Detection using Consecutive HRRPs"

In this paper, a heuristic detector is proposed to detect range-spread targets in white Gaussian noise using multiple consecutive high- resolution range profiles (HRRPs) received from a high-resolution radar (HRR). The detector consists of refiners of HRRPs and a cross-correlation integrator of refined HRRPs. Based on the fact that strong scattering cells are sparse in target HRRPs, nonlinear shrinkage maps are designed to refine received HRRPs before integration, by which most of the noise-only cells in received HRRPs are suppressed while strong scattering cells most probably relevant to target signature are preserved. Since the target's

scattering geometry is almost unchanged except for range walking during integration, the refined target HRRPs from consecutive pulses are highly similar while refined noise-only HRRPs are dissimilar due to randomicity. The modified correlation matrix of multiple refined HRRPs is used to measure their similarity. The test statistic, a weighted integration of the entries of the modified correlation matrix, is constructed for target detection. The proposed detector does not depend on a strict target return model and can work in mild conditions. The real target data and simulated noise are used to evaluate the detector, and the experimental results show that it achieves better detection performance than some existing methods. [J21]

"Road Intensity Based Mapping Using Radar Measurements With a Probability Hypothesis Density Filter"

Mapping stationary objects is essential for autonomous vehicles and many autonomous functions in vehicles. In this contribution the probability hypothesis density (PHD) filter framework is applied to automotive imagery sensor data for constructing such a map, where the main advantages are that it avoids the detection, the data association and the track handling problems in conventional multiple-target tracking, and that it gives a parsimonious representation of the map in contrast to grid based methods. Two original contributions address the inherent complexity issues of the algorithm: First, a data clustering algorithm is suggested to group the components of the PHD into different clusters, which structures the description of the prior and considerably improves the measurement update in the PHD filter. Second, a merging step is proposed to simplify the map representation in the PHD filter. The algorithm is applied to multi-sensor radar data collected on public roads, and the resulting map is shown to well describe the environment as a human perceives it. [J22]

"Sandglass transformation for synthetic aperture radar detection and imaging of ship at low signal-to-clutter-plus-noise ratio"

Space/air-borne synthetic aperture radar (SAR) detection and imaging of moving ships at sea are important for ocean reconnaissance and fishery monitoring. A novel algorithm based on sandglass transformation to detect weak ships and form high-quality images under the conditions of low signal-to-clutter-plus-noise ratio is presented here. It requires no prior information about motion parameters of targets. The sandglass transformation can decouple the time and lag time in the instantaneous autocorrelation function of a linear frequency modulated (LFM) signal. Thus the cross-range signals of ship in the approximate form of LFM signals can be integrated coherently via the two-dimensional fast Fourier transformation. The proposed algorithm can not only achieve high-energy accumulation gain, but also suppress the interference of cross terms effectively without loss of resolution. Hence, it is effective to detect weak ships and generate high-resolution images. Numerical and experimental results confirm the effectiveness of the proposed algorithm. [J23]

"Multiple-input multiple-output radar search strategies for high-velocity targets"

The radar detection of high-velocity targets with a multiple-element antenna array is considered. The detection performance of multiple-input multiple-output (MIMO) radar with orthogonal waveforms is compared with that of a radar using a directed beam. An analytical expression for the probability of detection for a radar with a multiple-element array is derived. For high-velocity targets, the decrease in probability of detection because of the longer integration time required for MIMO radar is quantified. It is shown that for lower-velocity targets, sector search using orthogonal waveforms results has similar detection range performance to that of scanning directed beams. For higher-velocity targets, the use of scanning directed beams yields larger detection range. [J24]

"Predicting Millimeter Wave Radar Spectra for Autonomous Navigation"

Millimeter Wave (MMW) radars are currently used as range measuring devices in applications such as automotive driving aids (Langer and Jochem, 1996), (Rohling and Mende, 1996), the mapping of mines (Brooker et al., 2005) and autonomous field robotics (Brooker, 2001), (Langer, 1996). This recent interest is largely due to the advantages MMW radars offer over other range measuring sensors, as their performance is less affected by dust, fog, rain or snow and ambient lighting conditions. MMW radars can provide received signal strength values, at all discrete range intervals, within the working range of the radar (Clark and Durrant-Whyte, 1997), (Scheding et al., 2002). The received power versus range spectra hence contain useful range to target information, but are also corrupted by noise. User defined stochastic algorithms can then be implemented, which exploit this rich data to improve object detection and mapping performance. This is in contrast to many other range measuring devices which typically internally threshold received signals, to provide single hard decisions only, on the estimated range to objects (Mullane, 2007). This paper addresses the issues of predicting the power-range spectra from MMW radars which use the Frequency Modulated Continuous Wave (FMCW) range estimation technique. This is important for two reasons. First, in automotive and autonomous robotic applications, such sensors are used in conjunction with vehicle navigation and map state estimation filters. This is so that (typically

uncertain) vehicle motion knowledge can be optimally fused with the noisy sensor information, to infer estimates of the state of interest (typically, the vehicle's pose (position and orientation) and/or information of the surrounding object locations). Hence, it is essential that predicted power versus range spectra can be computed, to apply a Bayesian recursive estimation framework, based on previous measurements, and uncertain vehicle motion information. Second, it- is extremely useful to be able to simulate MMW radar data, given certain environmental configurations. This aids the development of reliable object detection algorithms, based on theoretical sensor and noise models, which can then be applied more effectively to real MMW radar data. [J25]

"On the Role of Phase Stability in SAR Multibaseline Applications"

This paper is meant to present a statistical analysis of the role of propagation disturbances (PDs), such as those due to atmospheric disturbances or to residual platform motion, in multibaseline synthetic aperture radar (SAR) interferometry (InSAR) and tomography (T-SAR) applications. The analysis will consider both pointlike and distributed targets in such a way as to cover all the cases that are relevant in the applications. In order to provide a tool for the evaluation of the impact of PDs on the analysis of an arbitrary scenario, a definition of signal-to-noise ratio (SNR) will be introduced that accounts for both the presence of PDs and the characteristics of the imaged scene. In the case of pointlike targets, it will be shown that such definition of SNR allows reusing well known results following after the Neyman-Pearson theory, thus providing a straightforward tool to asses phase-stability requirements for the detection and localization of multiple pointlike targets. In the case of distributed targets, instead, it will be provided a detailed analysis of the random fluctuations of the reconstructed scene as a function of the extent of the PDs, of the vertical structure of the imaged scene, and of the number of looks that are employed. Results from Monte Carlo simulations will be presented that fully support the theoretical developments within this paper. The most relevant conclusion of this paper is that the impact of PDs is more severe in the case where the imaged scene is characterized by a complex vertical structure or when multiple pointlike targets are present. As a consequence, it follows that the T-SAR analyses require either a higher phase stability or a more accurate phase calibration with respect to InSAR analyses. Finally, an example of phase-stability analysis and phase calibration of a real data set will be shown, based on a P-band data set relative to the forest site of Remningstorp, Sweden. [J26]

"Optimal Waveform Design for Improved Indoor Target Detection in Sensing Through-the-Wall Applications"

This paper deals with waveform design for improved detection and classification of targets behind walls and enclosed structures. The target impulse response is incorporated in an optimum design of the transmitted waveform which aims at maximizing the signal-to-interference and noise ratio (SINR) at the receiver output. The interference represents signal-dependent clutter which, along with the wall, degrades the receiver performance compared to the free-space and zero-clutter case. Computer simulations show sensitivity of the optimum waveform to target orientation but depict an SINR enhancement over chirped waveform radar emissions at all aspect angles. Numerical electromagnetic modeling is used to provide the impulse response of typical indoor stationary targets, namely, tables, chairs, and humans. [J27]

"Bird-aircraft strike avoidance radar"

Avian radar system has been developed for bird-aircraft strike hazard avoidance. Two representative systems, which are countrywide and airport-based avian radar systems, are surveyed to summarize the state-of-the-art in this research field. Avian radar experimental system built by Beihang University is introduced in detail, including system architecture, performance analysis, and processing algorithm for bird target detection and tracking. This radar is operated in horizontal and vertical positions alternatively for scanning, and some experimental data are collected, respectively, at reservoir and airport. After processing of background subtraction, noise suppression, target information extraction, tracking and data fusion, a fused image containing bird targets and aircraft is provided. Finally, improvement suggestions on radar antenna, processing algorithms and risk assessment models of bird-aircraft strikes are given. Moreover, a scheme for practical systems applications at airport is proposed. [J28]

"Multihit mode direct-detection laser radar system using a Geiger-mode avalanche photodiode"

In this paper, a direct-detection laser radar system that uses a Geiger-mode avalanche photodiode (GAPD) of relatively short dead time (45 ns) is described. A passively Q-switched microchip laser is used as a laser source and a compact peripheral component interconnect system, which includes a time-to-digital converter (TDC), is set up for fast signal processing. With both the GAPD and the TDC functioning multistop acquisition, the system operates in a multihit mode. The software for the three-dimensional visualization and an algorithm for the removal of noise are developed. It is shown that the single-shot precision of the system is 10cm(sigma)and

the precision is improved by increasing the number of laser pulses to be averaged so that the precision of 1cm(sigma)was acquired with more than 150 laser pulses scattered from the target. The accuracy of the system is measured to be 12 cm when the energy of the emitted laser pulse varies with a factor of 7. [J29]

"Accurate K-distributed clutter model for scanning radar application"

The correct formulation of the likelihood ratio test (LRT)-based detection schemes for a target in the presence of clutter needs a faithful and mathematically tractable clutter model. The state-of-art detection methods usually assume that the land and sea clutter in whose presence a target signal to be detected as K-distributed form of non-Gaussian clutter and uses an LRT detector obtained for the same. However, the macroscopic phenomena of clutter generation in a search radar and also the detailed studies on the measured clutter data show a significant texture fluctuation caused by the continuous antenna scanning motion. Incorporation of the scanning effect in the clutter model introduces challenges in modelling the varying texture and formulating a suitable detection scheme. Here the authors propose a clutter model for such scanning radar applications taking the effect of scanning on the clutter correlation into consideration. A method of fitting the proposed model to measured data and a method of simulating the clutter as per the proposed model are also presented. The proposed model is found to be attractive for an LRT detector design. Further in this study, the proposed clutter model is also validated through a real experimental data which show an excellent match between the simulated and measured data of both sea and land clutters. The close agreement between the model and the measurement clearly illustrates the validity and applicability of the model. [J30]

"Ship Detection Using TerraSAR-X Images in the Campos Basin (Brazil)"

The very large extent of the Brazilian coast (~8000 km) and the growing maritime vessel traffic demand that research be made on ancillary methods to monitor and control ship's traffic in national waters. An important tool for this purpose is the use of orbital synthetic aperture radar (SAR) imagery, particularly due to its ability to work day and night and to suffer almost no interference of cloud coverage. In this letter, we investigate some ship detection concepts, as applied to TerraSAR-X (TSX) ScanSAR images (16-m resolution), in VV and HH polarization. Ocean clutter statistical parameters are estimated, and the Kolmogorov-Smirnov test is used to verify the goodness of fit for the K-distribution to TSX images. A constant false alarm rate (CFAR) target detection algorithm is developed, and its performance is verified. Incidence angle, CFAR's window size, and probability of false alarm influence are further analyzed. [J31]

"A Novel, Fast, Approximate Target Detection Technique for Metallic Target Below a Frequency Dependant Lossy Halfspace"

The extinction pulse (E-Pulse) technique has been widely applied to problems involving radar target identification. In this paper a fast approximate target detection and recognition scheme based on the E-Pulse technique is proposed and applied to a subsurface target detection and recognition scenario. Previous studies have demonstrated that the target resonances for subsurface targets are closely related to the target resonances for a target within a homogenous environment. In the proposed method, the target resonance for the target in the homogenous medium will be used to construct the E-Pulse for target detection and recognition purposes. The details of the proposed method will be described in this paper. The obvious example of a target below a dielectric halfspace is the use of ground penetrating radar (GPR) for detecting and recognizing unexploded ordnance (UXO). However, instead of a GPR related scenario, a numerical example of a biomedically related problem, of a hip prosthesis model sited within a halfspace of homogenous human tissue model with realistic dielectric properties will be used to demonstrate the feasibilities of the proposed technique for target detection and recognition. The reasons for the choice of this particular example will also be explained in the paper. [J32]

"Automatic target detection in simulated ground clutter (Weibull distributed) by multilayer perceptrons in a low-resolution coherent radar"

This study presents the problem of detecting known targets (Swerling 0 model) in simulated ground clutter (land cultivated). As a modelled low-resolution coherent radar system is used, the clutter is modelled by a complex-valued time-correlated Weibull distribution. The research exposed in this study looks for two objectives. First, finding a detection scheme that permits the final user (radar operator) determine if a target is present or not, and its position, size and shape. And second, designing a detection scheme as robust as possible against clutter and target condition changes and approximating the specification and measurement of the radar performance by using clutter models. However, these tasks are really complicated, because high-level clutter echoes are received. A detection scheme based on neural networks is proposed, where feedforward multilayer perceptrons are used. The performance obtained with this detection scheme is discussed from subjective (visual analysis of the achieved detection scans) and objective (receiver operating characteristics) points of view. Finally, this

scheme is compared with a coherent detector commonly used when Weibull-distributed clutter is present, the target sequence known a priori detector. This comparison empirically demonstrates the performance improvement achieved by the proposed detector comparing with the commonly used. [J33]

"Analysis of the KK-distribution with medium grazing angle sea-clutter"

Robust maritime surveillance with radar requires an accurate description of the backscatter from the sea. An estimated probability distribution of the backscatter is commonly used to determine the threshold for separating targets from clutter at a given false alarm rate. Data collected at medium to high grazing angles by the Defence Science Technology Organisation (DSTO) Ingara fully polarimetric X-band radar demonstrate that the commonly used K-distribution is not always adequate for modelling the probability distribution. This is especially the case for the horizontal polarisation and in regions of high backscatter where target detection can be a problem. An alternative proposed as a more accurate model in this region is known as the KK-distribution. The analysis presented in this study describes this model with the addition of multiple looks and a thermal noise component to produce greater accuracy in the mean and underlying shape. The threshold required to achieve a constant false alarm rate is then studied and compared with the K-distribution. [J34]

"Clutter modelling for space-time adaptive processing in airborne radar"

The presence of clutter can be highly detrimental to detection of targets in airborne radar systems. Space-time adaptive processing (STAP) attempts to alleviate the problem by exploiting angle-Doppler inter-relationships to suppress clutter. The requirements for modelling of clutter data that are suitable for the application of STAP are considered in this study. Examples of clutter generated using the ELMBAARC program in bistatic and monostatic applications are provided. Modelling of internal clutter motion is considered, together with its effect on the clutter domain in angle-Doppler space. Modelling of non-homogeneous clutter is also considered. [J35]

"Radar Micro-Doppler Signature Analysis with HHT"

Radar micro-Doppler signature analysis of vibrating targets with the joint time-frequency methods can provide useful information for target detection, classification, and recognition. We employ a well-known method for nonlinear and nonstationary signals, Hilbert-Huang transform (HHT) as a new approach in micro-Doppler analysis. Simulation and experimental results show that it can achieve better performance than the traditional Cohen's class time-frequency methods. [J36]

"Rapid Evaluation of Airborne Intercept Radar Detection for Swerling I Targets"

A very simple approximation for evaluating the probability of detection of the modes of airborne intercept radars, for use in large scale air engagement simulations, is developed. The approximation has two parameters, the values of which are generated using numerical optimisation. The results are generally applicable to binary integration processing. [J37]

"Using Target RCS when Tracking Multiple Rayleigh Targets"

Closely-spaced (but resolved) targets pose a challenge for measurement-to-track data association algorithms. Since the Mahalanobis distances between measurements collected on closely-spaced targets and tracks are similar, several elements of the corresponding kinematic measurement-to-track assignment cost matrix are also similar. Lacking any other information upon which to base assignments, it is not surprising that data association algorithms make mistakes. Given this problem many in the target tracking community have speculated that measurement-to-track data association could be improved through the use of features. Since the radar cross section (RCS) naturally occurs with the detection and kinematic measurement and does not require use of high-energy/high-resolution waveforms, it is typically a favored feature for radar systems. To gain insight into its impact on measurement-to-track data association, the benefits of RCS-assisted tracking are analytically assessed in several simple cases. Both the rigorous hypothesis probability approach and several less rigorous ad hoc approaches (which are commonly used in practice) are treated. Results vary between the approaches, but the conclusion is that the benefit of RCS-assisted tracking is limited. In fact applying it blindly in every dwell can actually degrade measurement-to-track data association. For this reason the steps required to incorporate RCS-assisted tracking in a beneficial manner are also identified. [J38]

"A Qualitative Inverse Scattering Method for Through-the-Wall Imaging"

Imaging methods that are able to detect targets located behind a wall and monitor their motion have recently gained an increasing attention. To pursue this aim, we propose a qualitative inverse scattering approach based on the linear sampling method, which is a computationally effective nonapproximated shape-reconstruction

strategy. In particular, we describe the formulation of the method for the through-the-wall scenario for both the case of static and dynamic targets. The results of a numerical analysis are reported as a preliminary assessment of the achievable performances. [J39]

"HFSW Radar Model: Simulation and Measurement"

High-frequency surface-wave (HFSW) radars are usually used to remotely measure oceanographic parameters. These systems can also potentially detect targets beyond the conventional microwave radar coverage. In this paper, the backscattered Doppler spectrum made up of the sea clutter, ship echoes, and the background noise has been modeled. Taking into account the propagation and the signal-processing effects, a range-Doppler image has been generated. This model can be used for different purposes like the (theoretical) evaluation of detection performance. This paper gives an overview of the theoretical elements for modeling the backscatter signal. The processing effects on the range-Doppler image and the time-evolving target signature are also introduced. Some of the simulated elements and the obtained range-Doppler images are compared with real data. Finally, from this model, the detection capabilities of HFSW radars are evaluated. [J40]

"Tracking Small Targets in Heavy-Tailed Clutter Using Amplitude Information"

Harbor surveillance above and below the sea surface depends on sensors such as surveillance radar and multibeam sonar. These sensors attempt to detect and track moderately observable targets such as small boats or human divers in environments which often are characterized by heavy-tailed backgrounds. Target tracking in heavy-tailed environments is challenging even for moderate signal-to-noise ratios (SNRs) due to the increased frequency of target-like outliers. A tracking method operating in such an environment should exploit as much of the data as possible to ensure robustness. Still, conventional tracking methods rely on kinematic measurements such as range, bearing, and Doppler only. The performance of the tracking method can be improved by using the backscattered signal strengths together with the kinematic measurements. This is done in the probabilistic data association filter with amplitude information (PDAFAI). We propose new conservative amplitude likelihoods for the PDAFAI with improved robustness compared to existing methods. The first likelihood works by incorporating the uncertainty of the background estimate. The second likelihood explicitly treats the background as heavy tailed using the -distribution. Extensive and realistic Monte Carlo simulations show that both our conservative likelihoods give significant reductions in track loss. Furthermore, we provide a quantitative evaluation of the difficulties encountered by tracking methods in heavy-tailed clutter. To the best of our knowledge, such an analysis does not yet exist in the open literature. [J41]

"Spectroscopic Calibration Correlation of Field and Lab-Sized Fluorescence LIDAR Systems"

A method has been developed to correlate spectral signatures obtained with various fluorescence LIght Detection And Ranging (LIDAR) systems. A calibrated fluorescence reference target was used to calibrate the spectral response of the LIDAR transmitter channels and obtain their transfer functions. Two LIDAR systems have been spectrally characterized, and corrected signatures for two bioaerosols are presented. The first LIDAR system is the Standoff Integrated Bioserosol Active Hyperspectral Detection field LIDAR developed by Defence R&D Canada. This standoff system uses a 351-nm pulsed laser in a monoaxial design. The second system is a lab-sized aerosol chamber designed to characterize fluorescent aerosols under controlled environmental conditions. The chamber was designed according to classical short-range biaxial LIDAR principles, with the purpose of duplicating the results obtained with field LIDAR systems. Aerosols generated within the chamber are probed by a 355-nm pulsed laser, and autofluorescence spectra are measured with a spectrometer and an intensified charge-coupled device camera. This chamber is used to collect the reference spectra of various fluorescing aerosols and simulants of biological agents. One of the main objectives in using this chamber is to produce and compile a library of instrument-free fluorescing spectra that can be transferred to other LIDAR-based bioaerosol sensors with known optical transfer functions. [J42]

"Multihypothesis Viterbi Data Association: Algorithm Development and Assessment"

Two algorithms for tracking in clutter, based on the Viterbi algorithm are presented: single-target Viterbi data association (ST-VDA) and multihypothesis VDA (MH-VDA). MH-VDA is designed specifically for multiple-target tracking (MTT), although ST-VDA still achieves good performance on MTT problems. The basic philosophy of both methods is to set up an optimisation problem for the sequence of measurement-to-target associations rather than directly seeking the target state estimates. The joint optimisation problem for the data association sequence is decomposed into a sequence of scalar optimisation problems by means of an approximate forward dynamic programming recursion to which the Viterbi algorithm is applicable. Once the data association problem is solved, the target state estimates can be retrieved by backtracking. The operation of the algorithms is easily visualised as a search on a trellis for the optimal path. For ST-VDA, nodes in the trellis correspond to

measurements. For MH-VDA, nodes correspond to multitarget data association hypotheses. Conventional measurement gating is extended to work within this context. Results from simulations that compare the performance of ST-VDA and MH-VDA with four, standard, zero-scan-back tracking approaches are given. The performance assessment includes metrics for track loss and track swaps in a multiple crossing target context. The Viterbi data association (VDA) algorithms are shown to outperform the alternative algorithms. In particular the ST-VDA is found to have the best track swap performance, while MH-VDA has the lowest track loss figure. Average state estimation errors for both VDA algorithms are only about 10% larger than a Kalman filter with known data associations. While both variants of VDA are essentially batch processing approaches, the simulation results indicate that the algorithms can be implemented with a fixed processing lag of only a few scans without significant loss in performance. [J43]

"Reducing the Waveform Cross Correlation of MIMO Radar With Space-Time Coding"

Multiple-input-multiple-output (MIMO) radar is attractive for target detection, parameter identification, and target classification due to diversity of waveform and perspective. However, the mutual interference among the waveforms may lead to performance degradation in resolving spatially close returns. In this paper, we consider the use of space-time coding (STC) to mitigate the waveform cross-correlation effects in MIMO radar. First, it turns out that a joint waveform optimization problem can be decoupled into a set of individual waveform design problems. Second, a number of monostatic waveforms can be directly used in a MIMO radar system, which offers flexibility in waveform selection. We provide conditions for the elimination of waveform cross correlation, and discuss four kinds of space time codes. In addition, we also extend the model to partial waveform cross-correlation removal based on waveform set division. Numerical results demonstrate the effectiveness of STC in MIMO radar for waveform decorrelation. [J44]

"Including Spatial Correlations in the Statistical MIMO Radar Target Model"

Previous studies of statistical MIMO radar detection performance have used a target model that consists of a large number of point scatterers located within a rectangular target area. These point scatterers have scattering amplitudes that are complex random variables and are spatially uncorrelated, so that the target is a white noise process in space. Spatial correlations are introduced into the target model in this paper, and the impact of these correlations on MIMO radar system detection performance is analyzed. [J45]

"An Impulse Response Function for Evaluation of UWB SAR Imaging"

Based on analysis of a point target imaged by different synthetic aperture radar (SAR) systems, the commonly used impulse response function in SAR Imaging (IRF-SAR)-a two-dimensional (2-D) sincfunction-is shown to be inappropriate for ultrawideband-ultrawidebeam (UWB) SAR systems utilizing a large fractional signal bandwidth and a wide antenna beamwidth. As a consequence, the applications of the 2-D sincfunction such as image quality measurements and spatial resolution estimations are limited to narrowband-narrowbeam (NB) SAR systems exploiting a small fractional signal bandwidth and a narrow antenna beamwidth. In this paper, a more general IRF-SAR, which aims at UWB SAR systems, is derived with an assumption of flat two-dimensional (2-D) Fourier transform (FT) of a SAR image and called IRF-USAR. However, the derived IRF-USAR is also valid for NB SAR systems. [J46]

"Systems-of-Systems Analysis of Ballistic Missile Defense Architecture Effectiveness Through Surrogate Modeling and Simulation"

Traditionally, the analysis of Ballistic Missile Defense System (BMDS) effectiveness has been limited in fidelity due to the inherent complexity of the subject. Indeed, the BMDS battle management process involves monitoring and controlling the actions of many interacting participants (e.g. radar sensors, communications networks and interceptor missiles) in a process whereby a target moves from launch through sensor detection through intercept kill assessment. Because the actions of each participant may evolve independently, the battle management process functions as a true system-of-systems (SoS). Proper SoS analysis requires architecture level engineering, dealing with component functional allocation and inter-component interaction rather than the internal workings of individual participants. Although prior work has been identified that addresses BMD effectiveness at the SoS level, each method sacrifices analysis fidelity of both process elements and individual participants to enable timely decision making. This paper proposes a modeling and simulation (M&S) framework that supports architecture level analysis of the BMDS. The key innovation is the application of neural network surrogate models, which are representations of other high- or medium-fidelity M&S tools, and can be executed rapidly with negligible loss in fidelity. Surrogate models were created of a BMDS analysis tool that included multisensor target tracking and fusion codes. Results will show the benefit of integrating M&S to architecture level analysis. Specific examples include sensitivity of operational level metrics to formation of an integration

tracking picture, and the enabling architecture level decision making. [J47]

"NEW: Network-Enabled Electronic Warfare for Target Recognition"

Network-enabled electronic warfare (NEW) is the development of modeling and simulation efforts that explore the advantages and limitations of NEW concepts. The advantages of linking multiple electronic support measures (ESM) and electronic attack (EA) assets to achieve improved capabilities across a networked battle force have yet to be quantified. In this paper, we utilize radar sensors as ESM and EA assets to demonstrate the advantages of NEW in collaborative automatic target recognition (CATR). Signal (waveform) design for radar sensor networks (RSN) in NEW is studied theoretically. The conditions for waveform coexistence and the interferences among waveforms in RSN are analyzed. We apply the NEW to CATR via waveform diversity combining and propose maximum-likelihood (ML)-ATR algorithms for nonfluctuating targets as well as fluctuating targets. Simulation results indicate that our NEW-CATR performs much better than the single sensor-based ATR algorithm for nonfluctuating and fluctuating targets. [J48]

"Nonparametric detection of frequency modulated signals using fractional Fourier transform"

A detection scheme for unknown nonlinear frequency modulated signals in white Gaussian noise is developed using the fractional Fourier transform and two-dimensional order-statistic filter. The simulation experiment and comparison with other methods available are shown, and the effectiveness of the proposed method is reported. [J49]

"CFAR detection of range-spread target in white Gaussian noise using waveform entropy"

A detection scheme for a range-spread target in white Gaussian noise is developed. The detector is based on waveform entropy of the arithmetic average of multiple successive high-resolution range profiles, and has the precious property of a constant false-alarm rate (CFAR). The proposed detector is compared with the conventional detectors based on measured data, and good performance is reported. [J50]

"Noncausal Adaptive Spatial Clutter Mitigation in Monostatic MIMO Radar: Fundamental Limitations"

The problem of a point target detection masked by clutter distributed over range and Doppler, including the range and Doppler of the target, is considered for a multimode propagation scenario commonly encountered in quasimonostatic HF over-the-horizon radars (OTHR). Here, a clutter signal spread in Doppler frequency due to propagation via a disturbed ionospheric layer competes with a target and narrowband clutter returns propagating via a stable ionospheric layer with the same group delay (radar range). Mitigation over all ranges of spread clutter propagating via a Г‚Вїmixed modeГ‚Вї path with indistinguishable direction-of-arrival (DoA) relative to the target requires (potentially adaptive) transmit beamforming to exploit the direction-of-departure (DoD) difference, which varies as a function of radar range. This range-dependent beamforming can be implemented only via the use of multiple-input multiple-output radar technology. In this paper, we explore the fundamental limitations that exist for the maximal dimension of the area in range-Doppler space occupied by spread clutter and the required properties (cardinality) of the orthogonal waveform set for efficient spread clutter mitigation. [J51]

"Time Reversal in Multiple-Input Multiple-Output Radar"

Time reversal explores the rich scattering in a multipath environment to achieve high target detectability. Multiple-input multiple-output (MIMO) radar is an emerging active sensing technology that uses diverse waveforms transmitted from widely spaced antennas to achieve increased target sensitivity when compared to standard phased arrays. In this paper, we combine MIMO radar with time reversal to automatically match waveforms to a scattering channel and further improve the performance of radar detection. We establish a radar target model in multipath rich environments and develop likelihood ratio tests for the proposed time-reversal MIMO radar (TR-MIMO). Numerical simulations demonstrate improved target detectability compared with the commonly used statistical MIMO strategy. [J52]

"Accurate UWB Radar Three-Dimensional Imaging Algorithm for a Complex Boundary Without Range Point Connections"

Ultrawide-band pulse radars have immeasurable potential for a high-range-resolution imaging in the near field and can be used for noncontact measurement of industrial products with specular or precision surfaces, such as reflector antenna or aircraft fuselage, or identifying and locating the human body in security systems. In our previous work, we developed a stable and high-speed 3-D imaging algorithm, Envelope, which is based on the principle that a target boundary can be expressed as inner or outer envelopes of spheres, which are determined

using antenna location and observed ranges. Although Envelope produces a high-resolution image for a simple shape target that may include edges, it requires an exact connection for observed ranges to maintain the imaging quality. For complex shapes or multiple targets, this connection becomes a difficult task because each antenna receives multiple echoes from many scattering points on the target surface. This paper proposes a novel imaging algorithm without range point connection to accomplish high-quality and flexible 3-D imaging for various target shapes. The algorithm uses an accurate estimation for the direction of arrival using signal amplitudes and realizes direct mapping from observed ranges to target points. Several comparative studies of conventional algorithms clarify that our proposed method accomplishes accurate and reliable 3-D imaging even for complex or multiple boundaries. [J53]

"Multiple-Input Multiple-Output Radar for Lesion Classification in Ultrawideband Breast Imaging"

This paper studies the problem of applying multiple-input multiple-output (MIMO) radar techniques for lesion classification in ultrawideband (UWB) breast imaging. Ongoing work on this topic has suggested that benign and malignant masses, which usually possess remarkable architectural differences, could be distinguished by exploiting their morphology-dependent UWB microwave backscatter. We have previously approached this problem by deriving the complex natural resonances of the late-time target response, where the damping factors vary with the border profiles of anomalies. In this paper, we investigate the potential advantage of MIMO radar to enhance the resonance scattering phenomenon in breast tissue discrimination. MIMO radar can choose freely the probing signals transmitted via its antennas to exploit the independence between signals at the array elements, thereby enhancing the performance of target classification. Based on the observed damping factors and the receiver operating characteristics at different classifiers, which correspond to various diversity paths in the MIMO radar system, two data-fusion rules are proposed for robust lesion differentiation. Finally, numerical examples are provided to demonstrate the efficacy of the proposed imaging technique. [J54]

"MIMO Radar Waveform Constraints for GMTI"

Ground moving-target indication (GMTI) provides both an opportunity and challenge for coherent multiple-input multiple-output (MIMO) radar. MIMO techniques can improve a radar's angle estimation and the minimum detectable velocity (MDV) for a target. However, the challenge of clutter mitigation places significant constraints on MIMO radar waveforms. In this paper, the loss of target return because of clutter mitigation (signal-to-noise ratio (SNR) loss) is the driving performance metric. The ideal, orthogonal repeated-pulse waveform is shown not to exist. Pulse-to-pulse time-varying waveforms, such as Doppler-division multiple access (DDMA), are shown to offer SNR loss performance approaching ideal MIMO systems. [J55]

"Performance of MIMO Radar With Angular Diversity Under Swerling Scattering Models"

The performance of statistical multiple-input multiple-output (MIMO) radar configurations that use distributed antennas is analyzed in this paper. Statistical MIMO radars exploit angular diversity to mitigate the impact of radar cross section (RCS) fluctuations. The fluctuations can be modeled with the Swerling scattering model consisting of four different cases with either fast or slow target RCS fluctuations. In this paper, the performance of different statistical MIMO radar configurations is compared in the different Swerling cases. Both target detection and direction of arrival estimation tasks are considered. We derive the optimal test statistics for target detection for non-orthogonal waveforms in all the Swerling cases in single-pulse as well as multi-pulse scenarios. We derive a closed-form density function for the test statistics under null and alternate hypotheses in the Swerling cases 1 and 2. For orthogonal waveforms in cases 3 and 4, the density function is given as a convolution involving a transcendental function. A suboptimal detector having a closed-form density function in cases 3 and 4 when the waveforms are orthogonal is introduced as well. In the direction finding task, confidence bounds of the squared estimation error of the different configurations are compared. The comparison is done in terms of the confidence bounds as the Cramer-Rao bounds are not defined for all the cases and configurations. The pros and cons of the angular diversity and each radar configuration are pointed out in different fluctuation scenarios. [J56]

"Optimal Joint Target Detection and Parameter Estimation by MIMO Radar"

We consider multiple-input multiple-output (MIMO) radar systems with widely spaced antennas. Such antenna configuration facilitates capturing the inherent diversity gain due to independent signal dispersion by the target scatterers. We consider a new MIMO radar framework for detecting a target that lies in an unknownlocation. This is in contrast with conventional MIMO radars which break the space into small cells and aim at detecting the presence of a target in a specified cell. We treat this problem through offering a novel composite hypothesis testing framework for target detection when 1) one or more parameters of the target are unknown and we are interested in estimating them, and 2) only a finitenumber of observations are available. The test offered optimizes

a metric which accounts for both detection and estimation accuracies. In this paper, as the parameter of interest we focus on the vector of time-delays that the waveforms undergo from being emitted by the transmit antennas until being observed by the receive antennas. The analytical and empirical results establish that for the proposed joint target detection and time-delay estimation framework, MIMO radars exhibit significant gains over phased-array radars for extended targets which consist of multiple independent scatterers. For point targets modeled as single scatterers, however, the detection/estimation accuracies of MIMO and phased-array radars for this specific setup (joint target detection and time-delay estimation) are comparable. [J57]

"ISAR Imaging for Avian Species Identification With Frequency-Stepped Chirp Signals"

Imaging an avian target by inverse synthesis aperture radar (ISAR) is a novel and important technological approach of solving the problem of avian detection. However, the ISAR images of birds obtained with the conventional range-Doppler algorithm could be contaminated due to serious micro-Doppler effects, which are generated by the birds' flapping wings. In this letter, a novel imaging method of birds is proposed, which is simple to comprehend and operate, and avoids lots of complications and computation burdens. In the method, the moving status of bird is identified first via finding the variety of moving average values of the cross-correlation coefficient of the adjacent high-resolution range profiles. The usage of moving average values is attributed to the characters of the bird's flapping. The parts of respective flapping spectrogram can then be eliminated, and the parts of the residual spectrogram, i.e., the respective gliding spectrogram, can be connected to prepare for the cross-compression. In this letter, the minimum waveform entropy criterion and genetic algorithm are employed in the spectrogram connection to compensate the phase error. Finally, the feasibility and effectiveness of the methods are verified by simulation results. [J58]

"Track-Before-Detect Strategies for STAP Radars"

In this correspondence we propose track-before-detect (TBD) strategies for space-time adaptive processing (STAP) radars. As a preliminary step we introduce the target and noise models in discrete-time form. Then, resorting to generalized likelihood ratio test (GLRT)-based and ad hoc procedures we derive detectors for two different scenarios (a point better clarified in the body of the correspondence). The preliminary performance assessment, conducted resorting to Monte Carlo simulation, shows that the proposed procedures might be viable means to implement early detection and track initiation of weak moving targets. [J59]

"Alternative Methodologies for the Internal Quality Control of Parallel LiDAR Strips"

Light Detection and Ranging (LiDAR) systems have been widely adopted for the acquisition of dense and accurate topographic data over extended areas. Although the utilization of this technology has increased in different applications, the development of standard methodologies for the quality control (QC) of LiDAR data has not followed the same trend. In other words, a lack in reliable, practical, cost-effective, and commonly acceptable QC procedures is evident. A frequently adopted procedure for QC is comparing the LiDAR data to ground control points. Aside from being expensive, this approach is not accurate enough for the verification of horizontal accuracy, unless specifically designed LiDAR targets are used. This paper is dedicated to providing accurate, economical, and convenient internal QC procedures for the evaluation of LiDAR data, which is captured from parallel flight lines. The underlying concept of the proposed methodologies is that, in the absence of systematic and random errors in system parameters and measurements, conjugate surface elements in overlapping strips should perfectly match each other. Consistent incompatibilities and the quality of fit between conjugate surface elements in overlapping strips can be used to detect systematic errors in the system parameters/measurements and to evaluate the noise level in the LiDAR point cloud, respectively. Experimental results from real data demonstrate that all the proposed methods, with one exception, produce compatible estimates of systematic discrepancies between the involved data sets, as well as good quantification of inherent noise. [J60]

"Polarimetric MIMO Radar With Distributed Antennas for Target Detection"

Multiple-input-multiple-output (MIMO) radar systems with widely separated antennas enable viewing the target from different angles, thereby providing spatial diversity gain. Polarimetric design of the transmit waveforms based on the properties of the target scattering matrix provides better performance than transmitting waveforms with only fixed horizontal or vertical polarizations. We propose a radar system that combines the advantages of both systems by transmitting polarized waveforms from multiple distributed antennas, in order to detect a point-like stationary target. The proposed system employs 2-D vector sensors at the receivers, each of which measures the horizontal and vertical components of the received electric field separately. We design the Neyman-Pearson detector for such systems. We derive approximate expressions for the probability of false alarm (PFA) and the probability of detection (PD). Using numerical simulations, we demonstrate that optimal

design of the antenna polarizations provides improved performance over MIMO systems that transmit waveforms of fixed polarizations over all the antennas. We also demonstrate that having multiple widely separated antennas gives improved performance over single-input-single-output (SISO) polarimetric radar. We also demonstrate that processing the vector measurements at each receiver separately gives improved performance over systems that linearly combine both the received signals to give scalar measurements. [J61]

"Performance Metrics for Single-Photon Laser Ranging"

Airborne laser swath mapping systems collect thousands of range measurements per second, enabling high-resolution surface mapping. Low-signal-to-noise-ratio (LSNR) detection techniques allow for implementation of light detection and range (LIDAR) instrumentation aboard platforms with stringent power, size, and weight restrictions. The University of Florida has developed the coastal area tactical-mapping system, which is a prototype LSNR LIDAR system that is capable of single-photon laser ranging. Laser pulses of 532 nm, 3.5 ??J, and 480 ps are transmitted at 8 kHz, with the outgoing footprint split into a 10 ?? 10 array of elements. Backscattered photons are imaged back onto separate anodes of a multistop microchannel plate photomultiplier tube. A 2-GHz event timer processes returns over the array. Ranges for known targets are accumulated for repeated laser shots, and statistical analysis is applied to evaluate performance metrics that are related to minimum separation distance, bathymetric mapping depth, and atmospheric scattering. An LSNR detection paradigm based on Poisson statistics has enabled topographic target detection and shallow-water bathymetry. Quantitative results are used to draw conclusions about feature detection in topographic and bathymetric mapping scenarios. [J62]

"Polarimetric Characterization and Temporal Stability Analysis of Urban Target Scattering"

This paper studies the polarimetric-dispersion properties of urban targets and their evolution along time in terms of the geometrical configuration. The relations between target geometry and the scattering behavior have been defined through the analysis of large stacks of simulated images. Scattering maps and synthetic aperture radar (SAR) images have been synthesized with the numerical tool GRaphical Electromagnetic COmputing SAR for different qualitative models of two real buildings. Ground-based SAR (GB-SAR) data acquired in a subsidence measurement campaign has been used to assess the simulator's realism. These data have permitted the identification of the critical simulation parameters and their range of recommended values for realistic simulations. In the context of very high resolution images, the results derived from this study may be crucial for making progress in urban-image postprocessing. As the different resolution cells comprise few scattering centers showing a quasi-deterministic scattering behavior, nonprobabilistic models based on target's geometry seem more suited for scattering modeling. In these models, the geometry-scattering (GS) links precisely inferred from simulated images can be very important. In addition to change detection and land classification, GS models may help in improving the interpretation of subsidence results with differential interferometry. Certainly, new processing algorithms can be developed exploiting the available scattering data with more physical sense. In addition, they can take more advantage of the fine resolution and polarimetric capabilities of the new sensors, like TerraSAR-X or RADARSAT-2. [J63]

"Real-Time Noncoherent UWB Positioning Radar With Millimeter Range Accuracy: Theory and Experiment"

In this paper, we propose a novel architecture for ultra-wideband (UWB) positioning systems, which combines the architectures of carrier-based UWB systems and traditional energy detection-based UWB systems. By implementing the novel architecture, we have successfully developed a standalone noncoherent system for positioning both static and dynamic targets in an indoor environment with approximately 2 and 5 mm of 3-D accuracy, respectively. The results are considered a great milestone in developing such technology. 1-D and 3-D experiments have been carried out and validated using an optical reference system, which provides better than 0.3-mm 3-D accuracy. This type of indoor high-accuracy wireless localization system has many unique applications including robot control, surgical navigation, sensitive material monitoring, and asset tracking. [J64]

"Ambiguity Functions for Spatially Coherent and Incoherent Multistatic Radar"

The ambiguity function is a key tool for determining the target resolution capability of a radar system. Recently, multistatic radar systems have been proposed where target detection is jointly performed on a vector of captured signals arising from multiple spatially dispersed transmitters and/or receivers. In the work presented here, expressions for the ambiguity functions of such systems are derived based on corresponding statistically optimal multistatic detectors, which themselves depend on the spatial coherence of target fluctuations observed by each receiver. These expressions allow the ambiguity in resolving target position and velocity vectors in two or three dimensions to be determined for any transmitted waveform and multistatic topology. New plots are introduced to

illustrate the resulting ambiguity responses by example, and the dependency on spatial, target, and waveform parameters is discussed. [J65]

"Envelope-Law and Geometric-Mean STAP Detection"

Two detectors for space-time adaptive processing (STAP) are proposed here. These are variants that use envelope-law and geometric-mean (GM) (or logarithmic) processing, both being well-known concepts from conventional constant false alarm rate (CFAR) square-law radar detection. The variants are based on normalized adaptive matched filter (NAMF) STAP processing, and their CFAR property is established. Threshold setting for the detectors for specified false alarm probability (FAP) is accomplished using fast simulation based on importance sampling. Performance analyses of these detectors reveal almost indistinguishable loss in detection probability in homogeneous Gaussian interference compared with conventional square-law STAP detector versions. In addition, they exhibit robust detection performance in the presence of interfering targets in the training data for both nonfluctuating as well as fluctuating target models. Comparisons are made with the corresponding envelope-law and GM variants of the adaptive matched filter (AMF) detector previously proposed in a recent paper. [J66]

"A Polarimetric Target Detector Using the Huynen Fork"

The contribution of synthetic aperture radar polarimetry in target detection is described and found to add valuable information. A new target detection methodology that makes novel use of the polarization fork of the target is described. The detector is based on a correlation procedure in the target space, and other target representations (e.g., Huynen parameters or ?? angle) can be employed. The mathematical formulation is general and can be applied to any kind of single target; however, in this paper, the detection is optimized for the odd and even bounces (the first two elements of the Pauli scattering vector) and for the oriented dipoles. Validation against real data shows significant agreement with the expected results based on the theoretical description. [J67]

"Joint Detection Estimation Problem of Monopulse Angle Measurement"

Estimation of the direction of arrival (DOA) of a signal source by means of a monopulse estimation scheme is one of the oldest and most widely used high-precision techniques in operational tracking systems. Although the statistical performance of this estimation technique has been extensively investigated, it has never been analyzed from the viewpoint of the joint detection-estimation problem. As a consequence the historical form of the (detector-angle estimator) solution has become the usual form implemented in operational tracking systems and may restrict their accessible performance. Indeed, the application of the optimal detection theory reveals alternative (detector-angle estimator) solutions providing other relevant trade-offs in detection-estimation performances that are worth considering to optimize the performance of the tracking system according to the scenario. Both stochastic signal model (Rayleigh-type signal source) and deterministic signal model (signal source of unknown amplitude) have been investigated, leading to a novel but equally simple (detector-angle estimator) solution through which analytical statistical prediction has been derived. Comparison of detection-estimation performances of new and usual solutions is presented. [J68]

"Correcting Airborne Laser Scanning Intensity Data for Automatic Gain Control Effect"

The intensity data recorded by airborne laser scanning (ALS) systems are useful for several applications, e.g., automatic point classification, change detection, and environmental studies. Before the intensity values can be used for any specific application, it has to be calibrated for atmospheric effect, range, energy loss, and incidence angle. Some ALS systems use automatic gain control (AGC). AGC is useful for getting laser returns even from low-reflectance surfaces (e.g., dark roofs), but it also changes the recorded intensity during the data acquisition, even within one surface type. This means that the same asphalt road might have totally different intensity values depending on the surrounding environment, which has affected the state of the AGC level. Therefore, it is important to correct the intensity values to neglect the effect of AGC in order to be able to get a normalized intensity value, which is only affected by the target characteristics. A first approach to correct the intensity values for AGC is reported in this letter. The same area was flown with AGC on and off, which allowed the modeling to take place. The results showed that the model produces values that agreed with an R2of 0.76 to the intensities obtained when AGC was turned off. [J69]

"Target Motion Ambiguities in Single-Aperture Synthetic Aperture Radar"

A simple approach to the detection and estimation of target motion based on phase measurements from a single-aperture synthetic-aperture radar (SAR) is presented. In this analysis the SAR is treated as a pure range-measuring device. Each stationary object in a scene produces a unique range-time history in the radar. Thus,

ideal SAR processing is reduced to finding the response to the set of matched filters associated with stationary targets. For this purely geometrical model, it is shown that there exists a class of moving targets that are absolutely indistinguishable from a stationary target. These are targets that move in such a way that the range to the SAR is always identical to the range from the SAR to some stationary target. Moreover it turns out that most moving targets are also indistinguishable from some other moving targets. The idealized SAR is only sensitive to a single velocity component of the target, and thus most solutions are degenerate. Theoretical limits of the detection of motion are established that are dependent on SAR parameters and observation time. Fast-moving (e.g. spaceborne) SARs can detect along-track motions with less ambiguity than a slow-moving SAR. It is shown that most moving targets do produce apparent motion in sequences of multilook SAR imagery. These apparent motions can be used to estimate the measurable component of target velocity. [J70]

"Sequential Track Initialization with Page's Test"

A new track initialization method for remote sensing systems that uses the amplitudes of the measurements to provide some statistical separation between true and false contacts is presented. In the proposed method the data are partitioned into Hough transform bins, and Page's test is performed on the data in each bin. The new method embodies the best ideas of existing sequential and batch methods, exploits both the amplitude and the temporal information in the data, and minimizes the average latency for initializing target tracks for a specified false track initialization rate. Analytic performance predictions for the proposed method for the Swerling I signal model with Poisson clutter are developed and compared with the theoretical performance of a commonly used "M of N" method. The new method provides substantial improvement in the false track initialization rate and the average latency for initializing target tracks. [J71]

"Low Observable Targets Detection by Joint Fractal Properties of Sea Clutter: An Experimental Study of IPIX OHGR Datasets"

We exploit the joint fractal properties of sea clutter extracted from detrended fluctuation analysis (DFA) for targets detection. We find that two specific fractal statistics, i.e., the intercept at the crucial scale and the Hurst exponent of optimal scales provide valuable information for targets detection. The first statistic measures the discrepancy between sea clutter and low observable targets at the crucial fractal scale, and the second one evaluates the average fractal difference within the optimal multi-scales. A target detection method integrating these two statistics is proposed, which is validated by real-life IPIX radar datasets. We find that this joint fractal detection approach achieves more accurate results for low observable targets detection. [J72]

"Matched-Illumination Waveform Design for a Multistatic Through-the-Wall Radar System"

We present the matched illumination waveform design for improved target detection in through-the-wall radar imaging and sensing applications. We consider a multistatic radar system for detection of stationary targets with known impulse responses behind walls. The stationary and slowly moving nature of typical indoor targets relaxes the orthogonality requirement on the waveforms, thereby allowing sequential transmissions from each transmitter with simultaneous reception at multiple receivers. The generalization of the matched illumination waveform design concept from a monostatic to a multistatic setting casts the indoor radar sensing problem in terms of multiple-input multiple-output (MIMO) operations and puts in context the offering of MIMO to urban sensing and imaging of targets in enclosed structures. Numerical electromagnetic modeling is used to provide the impulse response of typical behind-the-wall stationary targets, namely tables and humans, for different target orientations and at various incident and reflection angles. Simulation results depict an improvement in the signal-to-clutter-and-noise-ratio (SCNR) at the output of the matched filter receiver for multistatic radar as compared to monostatic operation. [J73]

"Iterative Adaptive Approaches to MIMO Radar Imaging"

Multiple-input multiple-output (MIMO) radar can achieve superior performance through waveform diversity over conventional phased-array radar systems. When a MIMO radar transmits orthogonal waveforms, the reflected signals from scatterers are linearly independent of each other. Therefore, adaptive receive filters, such as Capon and amplitude and phase estimation (APES) filters, can be directly employed in MIMO radar applications. High levels of noise and strong clutter, however, significantly worsen detection performance of the data-dependent beamformers due to a shortage of snapshots. The iterative adaptive approach (IAA), a nonparametric and user parameter-free weighted least-squares algorithm, was recently shown to offer improved resolution and interference rejection performance in several passive and active sensing applications. In this paper, we show how IAA can be extended to MIMO radar imaging, in both the negligible and nonnegligible intrapulse Doppler cases, and we also establish some theoretical convergence properties of IAA. In addition, we propose a regularized IAA algorithm, referred to as IAA-R, which can perform better than IAA by accounting for

unrepresented additive noise terms in the signal model. Numerical examples are presented to demonstrate the superior performance of MIMO radar over single-input multiple-output (SIMO) radar, and further highlight the improved performance achieved with the proposed IAA-R method for target imaging. [J74]

"Extending Loffeld's bistatic formula for the general bistatic SAR configuration"

This study derives an accurate bistatic point target reference spectrum based on a zeroth-order polynomial model. The spectrum contains only two hyperbolic square root terms that are very analogous in form to the analytical monostatic spectrum. The new formulation can be considered as an improvement of the Loffeld's bistatic formula (LBF) and allows it to handle a wider range of bistatic configurations. The original LBF works well only in the case where the contributions of transmitter and receiver to the total Doppler modulation are approximately equal. An earlier paper on the extended LBF (EBLF) uses time bandwidth product (TBP) to weight the azimuth phase modulation from each platform. However, this extension is valid only in the low squint bistatic geometry. Both LBF and ELBF are expanded up to the quadratic term to derive an approximate bistatic spectrum; however, they do not show a good focusing performance in the more complex bistatic geometry, for example, the high squint case. This is due to the inaccurate individual time-Doppler correspondences. In this study, a norm in Euclidean space is defined to derive the optimal individual time-Doppler correspondences. Using the accurate individual time-Doppler correspondences, a zeroth-order polynomial model can be used to readily derive a more accurate bistatic spectrum. Two simulation experiments in the high squint geometry are used to verify the accuracy of this new formulation. The first experiment uses a parallel-track spaceborne/spaceborne configuration, and the second experiment involves an orthogonal-track airborne/airborne case. [J75]

"Experimental Verification of SAR-GMTI Improvement Through Antenna Switching"

Recently, theoretical investigations have shown that switching between parts of the transmit and/or receive aperture in a pulse-to-pulse cycle may improve the ground moving target indication (GMTI) performance of a two-channel radar system. This paper intends to verify these findings experimentally for the switching concept for the first time. Accordingly, six different GMTI modes were implemented in the system PAMIR (phased-array multifunctional imaging radar) of the Fraunhofer Institute for High Frequency Physics and Radar Techniques (Fraunhofer FHR) including three switching modes. An experiment was conducted using six cooperative vehicles following a predefined scenario to compare the GMTI performance and, in particular, the positioning accuracy of the different GMTI modes. The results of this experiment as well as the underlying signal processing are presented in this paper. The analysis is based on a multilook constant false-alarm rate detection scheme. Due to the heterogenous nature of the considered scene, the well-known test statistic for homogeneous terrain had to be extended accordingly, and a novel test statistics is proposed. [J76]

"Simulation and Analysis of Human Micro-Dopplers in Through-Wall Environments"

We present a simulation methodology for generating micro-Doppler radar signatures of humans moving behind walls. The method combines primitive-based modeling of humans with finite-difference time-domain (FDTD) simulation of walls. Realistic motions of humans are generated from computer animation data. The time-varying human radar cross section is simulated using the primitive-based prediction technique. The scattered returns of humans behind walls are then simulated by a hybrid of the human simulation model with the through-wall propagation data generated from FDTD. The resulting simulator is used to investigate the effects of walls of both homogeneous and inhomogeneous types on human micro-Dopplers. It is found that while through-wall propagation affects the magnitude response of the Doppler spectrogram in the form of attenuation and fading, it only introduces very minor distortions on the actual Doppler frequencies from the body parts. This is corroborated by measurement data collected using a Doppler radar, as well as by a point-scatterer analysis of refraction and multipath introduced by walls. [J77]

"Stealth technology for wind turbines"

Currently, a large proportion of proposed UK wind farms have either concerns raised at the pre-planning stage or formal objections made by radar operators on the basis of the potential for wind turbines to cause interference to radar systems. The current generation of on and off-shore three-bladed horizontal axis wind turbines have radar signatures consistent with their often very large physical size and hence considerable potential to reduce the ability of ground-based radars to detect targets in the vicinity of the farm. The impact of wind farms, particularly on ground-based aviation radars such as those operated for air defence and military and civil air traffic control purposes is likely to become particularly acute as European Union member governments strive to meet the requirements for energy generation under the Renewables Obligation. In addition, the increasing number of offshore wind farm projects proposed has the potential to cause interference to marine radars such as

coastal vessel traffic services and those on-board vessels for navigational purposes. This study considers the options available for the reduction of turbine radar signature and presents solutions for each of the main external turbine components. The radar signature reduction approaches are based on existing technologies developed for aerospace stealth applications. However, the realisation of these for the purposes of reducing wind turbine radar signatures is a novel development, particularly in the solutions proposed. The reduction of wind turbine-induced radar interference is a growing area of research. [J78]

"Target Localization Accuracy Gain in MIMO Radar-Based Systems"

This paper presents an analysis of target localization accuracy, attainable by the use of multiple-input multiple-output (MIMO) radar systems, configured with multiple transmit and receive sensors, widely distributed over an area. The Cramer-Rao lower bound (CRLB) for target localization accuracy is developed for both coherent and noncoherent processing. Coherent processing requires a common phase reference for all transmit and receive sensors. The CRLB is shown to be inversely proportional to the signal effective bandwidth in the noncoherent case, but is approximately inversely proportional to the carrier frequency in the coherent case. We further prove that optimization over the sensors' positions lowers the CRLB by a factor equal to the product of the number of transmitting and receiving sensors. The best linear unbiased estimator (BLUE) is derived for the MIMO target localization problem. The BLUE's utility is in providing a closed-form localization estimate that facilitates the analysis of the relations between sensors locations, target location, and localization accuracy. Geometric dilution of precision (GDOP) contours are used to map the relative performance accuracy for a given layout of radars over a given geographic area. [J79]

"A Quasi-Planar Conical Antenna With Broad Bandwidth and Omnidirectional Pattern for Ultrawideband Radar Sensor Network Applications"

A quasi-planar conical antenna with broad bandwidth (more than 10:1) and omnidirectional radiation pattern has been designed. In order to achieve mechanical stability, conical radiator is realized through thin metallic coating over a cavity etched into a dielectric slab. Due to dielectric loading, the conical antenna in this paper is quasi-planar, low-cost, light, mechanically robust, and easy to fabricate, integrate, and re-configure. A simulation tool based on the Method of Moments is developed to analyze the quasi-planar antenna. With simulation results as the guideline, the dielectric loading's material and geometries are optimized to attain wideband input impedance and omnidirectional radiation pattern. Three antenna prototypes are fabricated by using high density polyurethane foam as the dielectric loading material. Simulation and measurement data show excellent agreements. Input impedance bandwidths of all the three prototypes are greater than 10:1; and all of them show omnidirectional patterns in the azimuth plane. These quasi-planar conical antennas can be readily applied to ultrawideband communication and radar applications. In this paper, an ultrawideband radar sensor network testbed is constructed using one of the three prototype designs. Target localization is successfully demonstrated by five radar nodes with the aid of grid based location estimation algorithm. [J80]

"Tracking of Metallic Objects Using a Retro-Reflective Array at 26 GHz"

The detection and tracking of targets in highly cluttered environments often poses a difficult engineering challenge as the strong clutter backscatter contained in the scene makes it difficult to distinguish the target of interest. A design concept to aide in standoff detection and tracking of large metallic objects in a warehouse setting is presented. This includes the design and implementation of an active retro-reflective array system that is able to determine the precise location and identification of an object. To accomplish this, a unique series fed grounded coplanar waveguide patch antenna is designed and implemented with minimal cross coupling among elements. This compact array has a relatively large radar cross-section (RCS) while maintaining the desired retro-reflectivity. Additionally, a tilted beam is incorporated in the linear series-fed array to isolate the large RCS of the planar array structure at boresight from the desired modulated, retro-reflective RCS. This method for enhanced detection is implemented at 26 GHz. The incorporation of the high-speed PIN switches into the array structure provide the tag with a unique identification. Measurement results for the modulated RCS from such an array in a cluttered environment are presented. [J81]

"Inverse synthetic aperture radar image focusing using fast adaptive joint time-frequency and three-dimensional motion detection on experimental radar data"

This study presents two algorithms for enhancing the capabilities of the adaptive joint time-frequency (AJTF) approach and the three-dimensional (3D) motion detection method, respectively, on inverse synthetic aperture radar (ISAR) imaging. The first method is a modified AJTF motion compensation algorithm that is able to employ more than two prominent point scatterers for translation and rotation motion compensation, respectively. The second algorithm enhances a current 3D motion detection method. This algorithm improves the computation time

for identifying 3D motion in ISAR images and selects the imaging time intervals with the least 3D motion. With these enhanced detection algorithms, the authors have the ability to distinguish the time intervals when the target undergoes smooth two-dimensional (2D) motion from those containing more chaotic 3D motion. As a result, the authors can reliably detect those time intervals where 2D target motions are predominant to form well-focused ISAR images that are used in automatic target recognition applications. [J82]

"Coherent Detection of Swerling 0 Targets in Sea-Ice Weibull-Distributed Clutter Using Neural Networks"

The detection of Swerling 0 targets in movement in sea-ice Weibull-distributed clutter by neural networks (NNs) is presented in this paper. Synthetic data generated for typical sea-ice Weibull parameters reported in the literature are used. Due to the capability of NNs for learning the statistical properties of the clutter and target signals during a supervised training, high clutter reduction rates are achieved, reverting on high detection performances. The proposed NN-based detector is compared with a reference detector proposed in the literature that approximates the Neyman-Pearson (NP) detector. The results presented in the paper allow empirically demonstrating how the NN-based detector outperforms the detector taken as reference in all the cases under study. It is achieved not only in performance but also in robustness with respect to changes in sea-ice Weibull-distributed clutter conditions. Moreover, the computational cost of the NN-based detector is very low, involving high signal processing speed. [J83]

"Detection Algorithms to Discriminate Between Radar Targets and ECM Signals"

We address adaptive detection of coherent signals backscattered by possible point-like targets or originated from electronic countermeasure (ECM) systems in presence of thermal noise, clutter, and possible noise-like interferers. In order to come up with a class of decision schemes capable of discriminating between targets and ECM signals, we resort to generalized likelihood ratio test (GLRT) implementations of a generalized Neyman-Pearson rule (i.e., for multiple hypotheses). The adaptive detectors rely on secondary data, free of signal components, but sharing the statistical characterization of the noise in the cell under test. The performance assessment focuses on an adaptive beamformer orthogonal rejection test (ABORT)-like detector; analytical expressions for the probability of false alarm, the probability of detection of the target, and the probability of blanking the ECM (coherent) signal are given. More remarkably, it guarantees the constant false alarm rate (CFAR) property. The performance assessment shows that it can outperform the adaptive sidelobe blanker (ASB) in presence of ECM systems. [J84]

"Space-Time Coding for MIMO Radar Detection and Ranging"

Space-time coding (STC) has been shown to play a key role in the design of MIMO radars with widely spaced antennas: In particular, rank-one coding amounts to using the multiple transmit antennas as power multiplexers, while full-rank coding maximizes the transmit diversity, compromises between the two being possible through rank-deficient coding. In detecting a target at known distance and Doppler frequency, no uniformly optimum transmit policy exists, and diversity maximization turns out to be the way to go only in a (still unspecified) large signal-to-noise ratio region. The aim of this paper is to shed some light on the optimum transmit policy as the radar is to detect a target at an unknown location: To this end, at first the Cramer-Rao bounds as a function of the STC matrix are computed, and then waveform design is stated as a constrained optimization problem, where now the constraint concerns also the accuracy in target ranging, encapsulated in the Fisher Information on the range estimate. Results indicate that such accuracy constraints may visibly modify the required transmit policy and lead to rank-deficient STC also in regions where pure detection would require pursuing full transmit diversity. [J85]

"High Resolution Angle-Doppler Imaging for MTI Radar"

To reduce the need for training data or for accurate prior knowledge of the clutter statistics in space-time adaptive processing (STAP), we consider high resolution angle-Doppler imaging by processing each range bin of interest independently. Specifically, we use a weighted least-squares-based iterative adaptive approach (IAA) to form angle-Doppler images of both clutter and targets for each range bin of interest. The resulting angle-Doppler images can be used with localized detection approaches for moving target indication (MTI). We show via numerical examples that the robust and nonparametric IAA algorithm can be used to enhance the MTI performance significantly as compared with existing approaches. [J86]

"Examination of the Effect of Array Weighting Function on Radar Target Detectability"

A methodology is described to assess the detectability of targets by an airborne fire control radar (FCR) operating in a medium pulse-repetition frequency (PRF) mode in the presence of strong ground clutter as a

function of the transmitting and receiving antenna array weighting functions and proportion of failed array elements. It describes the radar, antenna, and clutter modelling processes and the method by which target detectability is quantified. The detectability of targets in clutter is described using a detectability map, which provides a useful means of comparing target detectability as clutter conditions change. It concludes that the best target detectability is to be achieved using those weighting functions on transmit and receive which result in the lowest average sidelobe levels but that the margins between the more highly tapered weighting functions were small. Furthermore, it concludes that target detectability degrades as the proportion of failed elements increases. A failure of 5% of the elements gave modest, though meaningful, degradations in target detectability and would therefore form a suitable upper limit. [J87]

"Wavefront Reconstruction Method for Subsurface Radar Imagery Acquired Along Circular and Planar Scan Trajectories"

Subsurface radar (SR) techniques are used in situations where the scan area consists of a material that has different dielectric properties to the one where the radar elements are located. For many SR applications, the targets are at a shorter distance than in airborne/seaborne radar scenarios. Additionally, the data acquisition process may be performed along nonconventional scan trajectories in order to suit the geometry of the scan area. This paper presents a novel reconstruction technique for SR data collected along circular and semi-elliptical scan trajectories. The spectrum of the collected data is processed in order to locate the spatial origin of the reflections and remove the artifacts introduced by the scan trajectory. Sampling constraints and the behavior of the point-spread function (PSF) in both scan geometries are discussed and illustrated. The proposed algorithm was tested using simulated examples and experimental data collected from phantoms that mimic the dielectric properties of two novel SR applications: breast cancer detection and wood inspection. The proposed method yielded promising results in terms of both spatial accuracy and focal quality. [J88]

"MIMO Radar Moving Target Detection in Homogeneous Clutter"

A multiple-input multiple-output (MIMO) radar approach employing widely dispersed transmit and receive antennas is studied for the detection of moving targets. The MIMO radar transmits orthogonal waveforms from the different transmit antennas so these waveforms can be separated at each receive antenna. For a moving target in colored Gaussian noise-plus-clutter, we quantify the gains from having widely dispersed antennas that allow the overall system to "view" the target simultaneously from several different directions. The MIMO radar performance is contrasted with that of a traditional phased-array approach, which employs closely spaced antennas for this purpose. The MIMO radar approach is well suited to handle targets that have small radial velocities for scenarios in which colocated sensors cannot separate the target from the background clutter. Both a centralized processing and a simple distributed processing form of the MIMO radar approach are developed and studied, and the gains from the centralized version, which come at the price of additional complexity, are clearly demonstrated and explained intuitively. The constant false alarm rate (CFAR) property of an adaptive version of the MIMO moving target detector is also demonstrated for homogeneous clutter. [J89]

"Airport Surveillance Processing Chain for High Resolution Radar"

The paper focuses on the design of the digital processing chain of a surface movement radar (SMR) for airport traffic in the frame of A-SMGCS (advanced-surface movements guidance and control system); in order to reach, or exceed, the demanding requirements for the A-SMGCS surveillance function, special attention has to be paid to SMR processing, whose main functional blocks are the CFAR (constant false alarm rate) processor, the plot extractor, and the track-while-scan (TWS). A description of these processing functions, tailored to a noncoherent, high-resolution radar, and of their implementation is provided. The performance evaluation is accompanied by trials on recorded data, as obtained from a national research and development project called fast prototyping (FP) project (2001–2003) and its subsequent activities. The aim of the work presented here is to give a system view of the radar processing chain for high-resolution SMR, being rather different than standard surveillance radar. [J90]

"Facet Model of Moving Targets for ISAR Imaging and Radar Back-Scattering Simulation"

A facet model of targets is proposed to simulate inverse synthetic aperture radar (ISAR) images and radar back-scattering of moving targets with rigid and nonrigid motions. Targets are composed of solid objects which are modeled by triangular facets. It is shown that a facet can be treated as an equivalent point-scatterer whose radar cross section (RCS) and position depend on the shape of the triangle, the frequency, and the angle of incidence. A shadowing algorithm is also developed to detect the facets which actually have influence on the signal received by the radar. Besides, a facet division algorithm is implemented to improve the result of the shadowing algorithm and to have at least one facet per resolution cell. Finally, we apply our simulator to obtain

the ISAR images of a ship and a helicopter and to calculate the micro-Doppler signature of a human. [J91]

"Finding Underground Targets by Means of Change-Detection Methods in Huynen Spaces"

A different and useful approach is presented for detecting new events in a scene, such as the presence or absence of landmines or perhaps the movement of people, vehicles, or structures. The approach rests on the radar examination of an area several times, once, before there are targets present, and the other (or others) after. The change detection algorithm notices if there are any changes after the first view. In the present approach the prospective target is represented, not in terms of three complex elements of a scattering matrix, but in terms of phenomenologically-based Huynen parameters. Each element of the Huynen parameter set conveys a different type of physical and geometrical attribute about the scatterers, thus the potential for significant false-alarm mitigation is increased. We provide results of the application of this approach on fully polarimetric signatures of simulated pairs of buried cylindrical targets. These results indicate the following. 1) Huynen parameters are more effective for change detection than the scattering matrix elements because of their ability to generate higher unambiguous autocorrelation peaks and fewer dominating cross-correlation curves. 2) A large number of symmetries are observed in the plots of the Huynen parameters for both one and two buried cylinders. These symmetries may eventually lead to further classification insights. 3) By using standard Prony methods, relevant resonance frequencies are extracted from the parameter plots, from which the height of either one of the cylinders is estimated. 4) The diameter of either cylinder can also be obtained by a simple procedure based on ray-tracing and time delays. Numerical calculations substantiate all the above assertions. [J92]

"Countering stealth with passive, multi-static, low frequency radars"

The potential of passive, multi-static radars as covert sensors for the detection of low flying, stealth air targets are illustrated by multi-static RCS analysis, coverage simulations for low flight levels and measurement results obtained with an experimental passive radar using digital audio broadcast signals (DAB). The measurement sensor is described and future perspectives are pointed out. [J93]

"Adaptive Detection Application of Covariance Matrix Estimator for Correlated Non-Gaussian Clutter"

In the clutter-dominated disturbance modeled as spherically invariant random vectors with the same covariance matrix and possibly correlated texture components, we propose an estimator of covariance matrix, which exploits all secondary data fully and introduces a constraint of matrix trace. Moreover, its adaptive target detection application is investigated. For match between the estimated clutter group size and the actual one, the adaptive normalized matched filter (ANMF) with the new estimator of any number of iterations theoretically ensures the constant false alarm rate (CFAR) property, with respect to the normalized clutter covariance matrix and the statistics of the texture. Furthermore, the simulation results show that it still guarantees the approximate CFAR property for mismatch cases and has an acceptable loss with respect to its nonadaptive counterpart in cases of relevant interest for radar applications. Finally, the effectiveness of ANMF with the proposed estimator is confirmed by Monte Carlo simulation. [J94]

"Estimating Unknown Clutter Intensity for PHD Filter"

In most of the existing probability hypothesis density (PHD) filters, the clutter is modeled as a Poisson random finite set (RFS) with a known intensity. The clutter intensity is characterized as a product of the average number of clutter (false alarm) points per scan and the probability density of clutter spatial distribution. The PHD filter is generalized to the problem of multi-target tracking (MTT) in clutter with an unknown intensity. In the proposed approach, the unknown clutter intensity is first estimated for the PHD filter. Estimation of the clutter intensity involves the estimation of the average clutter number per scan and the estimation of the clutter density. The clutter density is estimated as finite mixture models (FMM) via either expectation maximum (EM) or Markov chain Monte Carlo (MCMC) algorithm. Then, the estimated intensity is used directly in the PHD filter to perform multi-target detecting and tracking. Monte Carlo (MC) simulation results show that the proposed approach outperforms the naive PHD filter of assuming uniform clutter distribution significantly especially when the nominal clutter model is obviously different from the ground truth. [J95]

"Multi-Channel SAR-GMTI Method Robust to Coregistration Error of SAR Images"

High accuracy in complex images coregistration is essential in ground moving target indication (GMTI) processing of synthetic aperture radar (SAR) data, normally termed SAR-GMTI. The clutter suppression performance is proportional to the coregistration accuracy. In this correspondence, we propose a new SAR-GMTI approach, which is robust to the SAR images coregistration error. The observed clutter-plus-noise vector is built using the neighboring pixels as the first step, thus the corresponding covariance matrix, termed as joint

covariance matrix, can be estimated. The joint noise subspace is obtained by eigen-decomposing of the joint covariance matrix. The clutter is suppressed successfully by a projecting operation, i.e., a projection of the joint observed vector into the resulting joint noise subspace. The information of neighboring pixels is substantially exploited in the clutter suppression, resulting in the robustness, even at the presence of large coregistration error. Both the simulated and real multi-channel airborne data are used to validate the proposed approach. [J96]

"Radar Backscatter from Conducting Polyhedral Spheres"

Electromagnetic backscatter characteristics of conducting polyhedral spheres, constructed of 12 pentagons and a large number of hexagons, were investigated. The polyhedral structures were classified by their number of vertices and by the width of the conducting edges in their frames. Polyhedral spheres with 60, 80, 180, 240, 320, 500, 540, 960, and 1500 vertices were evaluated for their ability to scatter electromagnetic waves back to a source. The edge widths were varied between the limits of (1) nearly zero, to produce a wire-frame sphere; and (2) full surface closure of the polygon holes in the sphere, to form solid conducting structures. Using Method-of-Moments simulations with the WIPL-D code, the monostatic scattering properties of these spheres were studied over a wide range of structural and frequency parameters. The spherical wire frames had up to a 10 dB larger radar cross section than the completely solid spheres. This result provides models for new light-weight radar cross section targets used as satellite-calibration spheres with enhanced radar cross section for easier detection, low mass for easier launch, and low drag cross section for long orbit life. With selected edge widths, the monostatic radar cross section becomes vanishingly small at specific anti-backscatter frequencies, for conducting spherical shells with a regular pattern of polygon holes. These shells can be placed around solid spheres to nearly eliminate radar reflection from the composite object at specific frequencies. The polyhedral conducting-mesh (PCM) spheres with vanishing radar cross section at a desired frequency have applications for isotropic scattering sources that reflect no energy back to the electromagnetic source. the anti-backscatter polyhedral conducting-mesh spheres may provide insight for future stealth applications with spherical targets. [J97]

"An Experimental Study of WiMAX-Based Passive Radar"

Passive radars using illuminators of opportunity have attracted much attention in recent years. The worldwide inter-operability for microwave access (WiMAX) signal is a new illumination source for passive radar. This paper presents a study to understand and to demonstrate the feasibility of using WiMAX signals for passive radar. The study includes WiMAX signal analysis, the design and implementation of a WiMAX-based passive radar demonstrator, the associated radar signal processing scheme, and the field measurements. Results based on field measurements for various moving targets provide some useful references about the performance and potential capability of using WiMAX signals for passive radar applications. [J98]

"Detection of Turbulence with Airborne Weather Radars using Space-Time Filtering"

Detection of hazardous atmospheric zones with a high level of turbulence is a crucial problem for airborne weather radars. Usually it is solved via estimation of the spectrum width of weather echoes. Unfortunately atmospheric turbulence is not the only phenomenon that increases the spectrum width in airborne weather radars. Spectrum spreading of the same kind is introduced by the finite value of the antenna beamwidth because each scatterer within a resolution volume has its own Doppler shift even if it is not involved in turbulent motion. Implementation of space-time (2D) filtering in airborne weather radars to discriminate these two phenomena is considered in the correspondence. A dual channel (monopulse) antenna system is proposed for the realization of the 2D filter. It is shown that the filter can suppress reflections from weather targets with a low level of atmospheric turbulence and its output can be used to detect the presence of a pronounced turbulence via a simple threshold test. [J99]

"Idealized Bistatic RADAR GMTI Detection with Space-Time Processing"

In a recent paper by the author a novel approach was utilized for determining upper-bound ground moving target indication (GMTI) radar detection performance with two-dimensional space-time processing. That model utilized an idealized clutter model and other simplifying assumptions to clarify the method. The method is extended here to the general bistatic case. It is shown that the elements of the clutter covariance matrix can be obtained from cross-correlations of the convolutions of (appropriately transformed) transmit and receive aperture functions at different times and locations. A simulation based on this theory was developed that accommodates arbitrary transmitter-receiver geometry. When this general bistatic model is specialized to the monostatic case, it is shown to agree both theoretically and computationally with the earlier results. [J100]

"Ultrawideband Random Noise Radar Design for Through-Wall Surveillance"

We have developed an ultrawideband (UWB) random noise radar for through-wall surveillance applications. The operating frequency is in the ultrahigh frequency range, and the entire system is built around the concept of software defined radio. The radar receiver performance is statistically evaluated using both simulation studies and actual measurement results. We also discuss the phenomena of interference level and radar cross section (RCS) of the human target using the receiver operating characteristics (ROC). Experimental results presented show that random noise radars are useful for detecting and tracking humans obscured by building walls. [J101]

"Observability and Performance Analysis of Bi/Multi-Static Doppler-Only Radar"

Bi/multi-static radars using cooperative or noncooperative transmitters have attracted wide attention. This paper analyzes the method of locating a moving target from corrupted Doppler frequency measurements obtained by single or multiply receivers located together and with corresponding cooperative or noncooperative transmitters distributing in remote places. Both the observability requirements in two dimensions and the expressions for the Cramer-Rao bound are derived. Further analysis with simulation results reveals the relationship between the performance and the number of transmitters and the sensitivity between the performance and the time integration. It is shown that the bi/multi-static radars can exploit only Doppler information to locate a moving target effectively. [J102]

"Air target detection using airborne passive bistatic radar"

Passive bistatic radar (PBR) research has traditionally focused on using a static ground based receiver for air target detection. Reported are the initial findings from a novel airborne PBR experiment using commercial FM transmissions between 88 and 108 MHz, as illuminators of opportunity. A two-channel PBR system was designed, constructed and installed on a light aircraft and the system flown with the intention of detecting low altitude commercial air targets in the vicinity of London s Heathrow and Gatwick airports. Analysis of the data has shown that the system has successfully detected high velocity air targets on established air routes around the southeast of England. These encouraging results provide the proof of concept necessary to stimulate further development of the radar demonstrator to give improved target localisation and sensitivity. [J103]

"Automatic Target Recognition using Multipolar Bistatic Synthetic Aperture Radar Images"

Radar is a coherent sensor, which makes it suitable for the retrieval of the polarization information of the scattering process. Different algorithms have been proposed in the last few decades regarding how to analyze multipolar radar information. The extra information retrieved from the multipolar data has been shown to give more information regarding the physical features of the scatterer than the single polarization data. A few papers in the open literature have reported initial results regarding the use of monostatic multipolar data in radar-based automatic target recognition (ATR). However, a detailed report regarding the advantages of using multipolar data for ATR has not yet come in the open literature. Nor has there been any report on the use of multipolar data for bistatic radar-based ATR exercises. The work presented here deals with the task of using multipolar data for bistatic ATR A group of algorithms have been proposed and analyzed for the task of multipolar bistatic synthetic aperture radar (SAR) ATR Most of these algorithms are the contributions of the present work. For validating the algorithms, a simulated multipolar bistatic dataset has been used. It is also shown that using multipolar data not only improves the absolute performance of an ATR algorithm, it also makes it statistically more robust. Finally, the paper discusses a new algorithm to use multipolar data to avoid the decreased performance of an ATR algorithm that may arise from an uncalibrated bistatic multipolar radar system. [J104]

"GMTI Tracking via the Gaussian Mixture Cardinalized Probability Hypothesis Density Filter"

The cardinalized probability hypothesis density (CPHD) filter is a recursive Bayesian algorithm for estimating multiple target states with a varying target number in clutter. In particular the Gaussian mixture variant (GMCPHD), which provides closed-form prediction and update equations for the filter in the case of linear Gaussian systems, is a candidate for real time multi-target tracking. The following three issues are addressed. First we show the equivalence between the GMCPHD filter and the standard multi hypothesis tracker (MHT) in the case of a single target. Second by using a Gaussian sum approach, we extend the GMCPHD filter to incorporate digital road maps for road constrained targets. The use of such external information leads to more precise tracks and faster and more reliable target number estimates. Third we model the effect of Doppler blindness by a target state-dependent detection probability, which leads to a more stable target-number estimation in the case of low-Doppler targets. [J105]

"Reduced Order Jammer Cancellation Scheme Based on Double Adaptivity"

A doubly adaptive scheme is presented for detection and jammer cancellation by airborne/spaceborne radar equipped with a limited number of receiving channels. In this case where, to guarantee the desired performance

in the protection against multiple jammers with a wide range of possible direction of arrivals (DOAs), a number of auxiliary antenna beams greater than the number of channels would be required. For these systems an adaptive auxiliary beam selection technique is proposed to decide which is the most effective subset of auxiliary antennas in each condition, assuming a slowly changing jamming environment. This leads to a doubly adaptive jammer cancellation scheme: we first perform an adaptive selection of the best set of auxiliary beams, and then we apply an adaptive scheme for jammer cancellation and target detection by using only the best set of beams. This especially applies to the case of adaptive radar obtained as a retrofit of existing monopulse radar sensors or of design retrofit for single channel spaceborne radar with a redundant channel. A closed form analytical expression is provided for the detection performance of the proposed reduced degree of freedom (DOF) scheme based on double adaptivity, which provides a complete characterization of the properties of this detection scheme. Based on the derived expression of the detection performance, the proposed scheme is compared with an ideal scheme with a number of channels equal to the number of auxiliary antennas, showing that the proposed approach has near-optimal performance. Finally the implementation issues of the doubly adaptive scheme are discussed, together with its limitations. [J106]

"Time-frequency-based detection of fast manoeuvring targets"

The time-frequency representation (TFR) is a powerful tool for analysis of non-stationary signals. In the past decades, TFRs have been primarily devoted to the analysis tasks in the sense that they were introduced so as to depict time-frequency structure of time-varying signals and non-stationary processes in the time-frequency plane. Also, there has been a permanent interest in tackling decision problems by means of TFRs. In this study the authors, present a time-frequency-based detection scheme in the high-frequency surface-wave radar (HFSWR) for the detection of manoeuvring air targets in the presence of noise. Performance of the proposed method is evaluated by using both synthetic and experimental data. In addition, the proposed time-frequency detection scheme is examined in detail with various signal-to-noise ratio. This time-frequency-based detection method is then compared to the Fourier-based detector. Results clearly demonstrate that the time-frequency-based detector can significantly improve detection performance in the HFSWR, as well as add new physical insight, compared to the conventional Fourier-based detector, currently used by HFSWRs. [J107]

"Micro-Doppler parameter estimation from a fraction of the period"

Radar micro-Doppler (m-D) signatures are of great potential for identifying properties of unknown targets. All the techniques developed for extracting m-D features for the past decade rely primarily on the assumption that the time series of the signal contains at least one oscillation or more during the coherent integration time or imaging time. However, many applications in real-world scenarios involve short duration signals and often require the detection and the estimation of m-D characteristics. Short duration signals may contain only a fraction of an oscillation. In this study, the authors develop two techniques to estimate the m-D parameters from a fraction of the period. In these scenarios, the coherent integration will cover only 1/4 and 1/2 of the oscillation. The performance of the proposed methods are evaluated using both synthetic and experimental data. [J108]

"Time-Reversal Ground-Penetrating Radar: Range Estimation With Cramйr-Rao Lower Bounds"

In this paper, first, a new range-estimation technique using time reversal (TR) for ground-penetrating-radar (GPR) applications is presented. The estimator is referred to as the TR/GPR range estimator. The motivation for this paper comes from the need of accurately estimating the location of underground objects such as landmines or unexploded ordinance for safe clearance. Second, the Cramer-Rao lower bound (CRLB) for the performance of the TR/GPR range estimator is derived and compared with the CRLB for the conventional matched filter (MF). The CRLB analysis shows that the TR/GPR range estimator has the potential to achieve higher accuracy in estimating the location of the target than that of the conventional MF estimator. Third, the proposed TR/GPR estimator is tested using finite-difference time-domain simulations, where the surface-based reflection GPR is modeled using an electromagnetic transverse-magnetic (TM) mode formulation. In our simulations, the TR/GPR estimator outperforms the conventional MF approach by up to 5-dB reduction in mean square error at signal-to-noise ratios ranging from -20 to 20 dB for dry-soil environments. [J109]

"Adaptive tomographic sensors for below ground imaging"

Herein, ground penetrating radar and tomography are combined to detect and identify hidden targets, such as underground facilities and bard and deeply buried targets. Past experiences in below-ground imaging is described, current measurement results are presented, and future plans are discussed. [J110]

"Passive Coherent Location as Cognitive Radar"

Cognitive Radar describes a generic radar system that is capable of adapting its transmission waveforms and

cooperation with other sensors in order to achieve superior detection, recognition, and tracking of targets. For example, the sensors of a cognitive radar system might use the illumination signals to carry broadcast data, allowing the sharing of target information. Herein, we postulate that it would be possible to implement a cognitive version of Passive Coherent Location (PCL) which has much in common with the broad cognitive radar concept, but adapts only to the waveforms it senses in the environment, and exploits those that are most useful to it for target detection. In addition, it would model the terrain to improve coverage and provide countermeasures against direct signal saturation. By its name, PCL does not transmit, but relies on emissions from other radiating systems, such as broadcast services, other radars, cellular radio, WiFi, and so on. It is clear that such a system, consisting of multiple, cooperating receivers, can achieve excellent performance in the presence of deliberate jamming, difficult terrain, and attempts at target stealth. In the civilian radar domain, the technology offers opportunities for bandwidth conservation. [J111]

"Space-time clutter rejection and target passive detection using the APES method"

A new method to reject ground clutter using the Amplitude and Phase EStimation (APES) method is proposed. The theoretical approach is followed by the application of this method to the rejection of such an interference in the frame of a bistatic passive radar using digital video broadcasting-terrestrial (DVB-T) transmitters. [J112]

"Low Probability of Intercept Antenna Array Beamforming"

A novel transmit array beamforming approach is introduced that offers low probability of intercept (LPI) for surveillance radar systems employing phased array antennas. Radar systems are often highly visible to intercept receivers due to the inherent two-way versus one-way propagation loss. In this paper, the traditional high-gain antenna beam scanned across a search region is replaced with a series of low-gain, spoiled beams. Keeping the transmit antenna gain low reduces the radar visibility, but the radar's antenna performance remains unchanged as the original high-gain beam can be formed by processing the set of spoiled beams. Large transient power density radiated in a traditional scan is replaced with low power density persistently radiated at the target throughout the scan time. The detection performance of the radar is not affected since the total energy on the target is the same. Derivation of the complex weights to synthesize the high-gain patterns from the low-gain basis patterns is presented for both one-way and two-way beam patterns. [J113]

"Human motion estimation with multiple frequency modulated continuous wave radars"

Human motion estimation is an important issue in automotive, security or home automation applications. Radar systems are well suited for this because they are robust, are independent of day or night conditions and have accurate range and speed domain. The human response in a radar range-speed-time measurement behaves like an extended target where legs and arms coincide. A mutually non-coherent radar sensor network makes it possible to estimate additional information of the extended target response. To keep the system low cost the network uses commercial off-the-shelf (COTS) radar sensors without synchronisation of frequency or phase between the radar sensors. This article presents the results of human motion estimation with a mutually non-coherent radar sensor network. The calibration, radar processing, parameter estimation and classification of extended human objects are described. The swinging and rotating moving body parts give elliptical shapes in the differential range-speed responses. A model fit gives the legs and arms parameters on which classification is possible. [J114]

"A New CFAR Ship Detection Algorithm Based on 2-D Joint Log-Normal Distribution in SAR Images"

The characteristic difference between targets and clutter is analyzed. Considering the ship target's gray intensity distribution and its shape difference compared to the clutter, in this letter, a new algorithm is presented based on correlation. The algorithm utilizes the strong gray intensity correlation in the ship target; also, the joint gray intensity distribution using 2-D joint log-normal distribution of a pixel with neighboring pixels in the clutter is modeled, which can be used for correlation-based joint constant false alarm rate detection. Using this algorithm, the false alarms caused by speckle and local background nonhomogeneity can be greatly reduced. The detection performance is much better. [J115]

"Detection of Moving Targets by Focusing in UWB SAR-Theory and Experimental Results"

Moving-target detection in ultrawideband (UWB) synthetic aperture radar (SAR) is associated with long integration time and must accommodate azimuth focusing for reliable detection. This paper presents the theory on detection of moving targets by focusing and experimental results on single-channel SAR data aimed at evaluating the detection performance. The results with respect to both simulated and real data show that the ability to detect moving targets increases significantly when applying the proposed detection technique. The

improvement in signal-to-clutter noise ratio, which is a basic requisite for evaluating the performance, reaches approximately 20 dB, using only single-channel SAR data. This gain will be preserved for the case of multichannel SAR data. The reference system for this study is the airborne UWB low-frequency SAR Coherent All RAdio BAnd Sensing II. [J116]

"Estimating Surface Water Speeds With a Single-Phase Center SAR Versus an Along-Track Interferometric SAR"

Synthetic aperture radar (SAR) single-aperture systems are designed to image fixed scenes. Dual-antenna along-track interferometric (ATI) SAR systems are designed to detect moving targets and estimate their motion parameters. Although SAR systems are not designed to characterize moving targets, for localized targets, such as vehicles or ships, this problem has been addressed in the literature with some success. Distributed moving targets are hard to characterize, even for ATI systems. Estimating surface water speeds is an ideal example of this since the water returns are generated from weak returns randomly distributed in both time and space. The question asked here is can one measure surface water speeds with a single-phase center SAR system? The answer presented is a qualified yes, with the aid of an upper bound on the water speed, but not with the same accuracy as an ATI system. This upper bound and the collection geometry provide design criteria for the filtering of the phase information. Time-frequency (TF) methods provide another speed estimate as well as a rough profile of the speed across the water channel. A robust nonparametric TF method was developed and applied to estimate the speed. Comparisons between the ATI estimate and single-phase estimates are made using data from an X-band ATI-SAR system. [J117]

"Passive bistatic noise radar using DVB-T signals"

This study presents a new approach to passively detect targets using noise-like emitters of opportunity. This method combines the Wiener filtering to achieve clutter rejection and a proposed adaptation to noise-like signals of the amplitude and phase estimation (APES) method. This theoretical approach is confirmed by the detection of a helicopter by a bistatic radar using a digital video broadcasting terrestrial (DVB-T) transmitter. [J118]

"Time-orthogonal waveform diversity and joint domain localised algorithm for distributed aperture radars"

Distributed aperture radars represent an interesting solution for target detection in strong interference environments. Distributed apertures provide improved angular resolution or are able to view a target from multiple look-angles, thereby exploiting scintillation. However, because of the large distances between array elements, both target and interfering sources are in the near field of the antenna array. Furthermore, because of the relative motion between antenna elements and interference sources, the clutter Doppler frequency is not stationary. Recent works have demonstrated the benefits of combining frequency diversity and space-time adaptive processing (STAP) for distributed aperture radars. In this study a new waveform diversity system model is developed. Using orthogonal signalling, the receivers can treat the incoming signals independently, solving several bistatic problems instead of the initial multistatic problem. The authors also apply adaptive techniques to counteract the range dependency of the clutter Doppler frequency. In particular, the authors apply the joint domain localised algorithm, specifically chosen because of its need for only limited secondary data. [J119]

"MIMO Radar Detection and Adaptive Design Under a Phase Synchronization Mismatch"

We consider the problem of target detection for multi-input multi-output radar with widely separated antennas in the presence of a phase synchronization mismatch between the transmitter and receiver pairs. Such mismatch often occurs due to imperfect knowledge of the locations and local oscillator characteristics of the antennas. First, we introduce a data model using a von Mises distribution to represent the phase error terms. Then, we employ an expectation-maximization algorithm to estimate the error distribution parameter, target returns, and noise variance. We develop a generalized likelihood ratio test target detector using these estimates. Based on the mutual information between the radar measurements and received target returns (and hence the phase error), we propose an algorithm to adaptively distribute the total transmitted energy among the transmitters. Using Monte Carlo simulations, we demonstrate that the adaptive energy allocation, increase in the phase information, and realistic measurement modeling improve the detection performance. [J120]

"Hybrid Detection Approach for STAP in Heterogeneous Clutter"

We address the problem of radar target detection under clutter heterogeneity. Traditional approaches, designated as the two-data set (TDS) algorithms, require a training data set in order to estimate the interference covariance matrix and implement the adaptive filter. This training data is usually drawn from range gates adjacent to the cell

under test (CUT) that are deemed to be statistically homogeneous with it. When the training data exhibits statistical heterogeneity with respect to the test data, the performance of the TDS detectors degrades. The single-data set (SDS) detectors have been proposed to deal with this problem by operating solely on the test data. In this paper, we present a general hybrid approach that combines the SDS and TDS algorithms, taking the degree of heterogeneity into account. This makes the SDS and TDS detectors special cases of the more general hybrid formulation. We derive the hybrid detectors and propose the use of the generalised inner product as a heterogeneity measure. We analyse the new hybrid detectors and give expressions for the probabilities of false alarm and detection when the clutter is assumed homogeneous, and we assess their performance under heterogeneity using Monte Carlo simulations. The results show that the new detectors outperform both the TDS and SDS algorithms under both homogeneous and heterogeneous interference. [J121]

"Predicting Small Target Detection Performance of Low-SNR Airborne Lidar"

Recent technological advances in the performance of small micro-lasers and multi-channel multi-event photo-detectors have enabled the development of experimental airborne lidar (light detection and ranging) systems based on a low-SNR (LSNR) paradigm. Due to dense point spacing (tens of points per square meter) and sub-decimeter range resolution, LSNR lidar can likely enable detection of meter-scale targets that would go unnoticed by traditional lidar technology. Small vehicle obstructions and other similar targets in the beach and littoral zones are of particular interest, because of LSNR lidar's applicability to the near-shore environment and the general desire to improve detection of antivehicle and antipersonnel obstacles in the coastal zone. A target detection procedure is presented that exploits the detailed information available from LSNR lidar data while diminishing the effect of spurious noise events. Consideration is given to detection in both topographic and bathymetric scenarios. Data sets for target detection analysis are supplied by a numerical sensor simulator developed at the University of Florida. Target detection performance is evaluated as a function of environmental characteristics, such as water clarity and depth, and system parameters, specifically transmitted pulse energy and laser pulse repetition frequency. Analysis of results with regards to consideration for future system design is discussed. [J122]

"Light-Stripe-Projection-Based Target Position Designation for Intelligent Parking-Assist System"

This paper proposes a novel light-stripe-projection-based target position-designation method for an intelligent parking assist system, providing an economical free-space-based target position-designation method for poorly lit indoor parking spaces without degradation of the external appearance when integrated into a vehicle's body. The proposed method can be applied by adding a low-cost light plane projector to existing backward-parking cameras. Light stripe features are detected by the difference between an image with the light plane projector on and off. Three-dimensional information of the parking area is reconstructed using the light-stripe-projection theory. By orientation normalization and depth-map construction, free spaces are detected, and the nearest is selected as the target position. Experimental results show that the proposed method can successfully designate the target position, in spite of poor lighting conditions and the black reflective surface of adjacently parked vehicles. [J123]

"Adaptive Target Detection With Application to Through-the-Wall Radar Imaging"

An adaptive detection scheme is proposed for radar imaging. The proposed detector is a postprocessing scheme derived for one-, two-, and three-dimensional data, and applied to through-the-wall imaging using synthetic aperture radar. The target image statistics depend on the target three-dimensional orientation and position. The statistics can also vary with the standoff distance of the imaging system because of the change in the corresponding scene image resolution. We propose an iterative target detection scheme for the cases in which no or partial a priori knowledge of the target image statistics is available. Properties of the proposed scheme, such as conditions of convergence and optimal configurations are introduced. The detector performance is examined under synthetic and real data. The latter is obtained using a synthetic aperture through-the-wall radar indoor imaging scanner implementing wideband delay and sum beamforming. [J124]

"Detection in Gamma-Distributed Nonhomogeneous Backgrounds"

We propose a new technique for target detection in RADAR range-Doppler maps in the presence of nonhomogeneous backgrounds with gamma-distributed fluctuations. This technique is based on a cell-averaging (CA) constant false alarm rate (CFAR) detection test for which the ratio threshold and the set of values involved in the detection test are adaptively optimized in order to improve the false alarm regulation and the detection probability in nonhomogeneous backgrounds. This technique is compared with standard detection techniques on a synthetic range-Doppler map which demonstrates the relevance of the proposed approach in nonhomogeneous gamma-distributed backgrounds. [J125]

"SAR Processors Based on Signal or Interference Subspace Detector"

In this paper, we present a new synthetic aperture radar (SAR) processor relying on subspace detectors. The scattering pattern of the constituent element of the man-made target (MMT) to detect is used to improve the detection capabilities. In the particular case of foliage penetration (FOPEN), we propose to reduce the probability of false alarms by considering the scattering pattern of almost vertical trunks (modeled here as dielectric cylinders). New subspace detectors are derived to look for either an interference or a target element in a noisy environment. A new processor based on these subspace detectors is successively applied to simulated data. In addition, results obtained with real data reveal a significant improvement in the detection capabilities both in comparison with a classical SAR processor and with the subspace signal detector SAR (SSDSAR) processor (without interference model). [J126]

"Non-parametric Bayesian super-resolution"

Super-resolution of signals and images can improve the automatic detection and recognition of objects of interest. However, the uncertainty associated with this process is not often taken into consideration. This is important because the processing of noisy signals can result in spurious estimates of the scene content. This study reviews a variety of super-resolution techniques and presents two non-parametric Bayesian super-resolution algorithms that not only take uncertainty into account, but also retain knowledge about the output uncertainty in the form of a full probability distribution. One of the two Bayesian techniques is based on an analytical calculation re-interpreted as super-resolution, and the other is a novel numerical algorithm. Although the algorithms are presented as stand-alone techniques for image analysis, such Bayesian super-resolution algorithms can increase automatic target recognition performance over standard super-resolution. [J127]

"Collaborative mobile target imaging in UWB wireless radar sensor networks"

Wireless sensor networks (WSN) have thus far been used for detection and tracking of static and mobile targets for mission critical surveillance applications. However, detection and tracking do not suffice for a complete and accurate target classification. In fact, surveillance target imaging yields the most valuable information. Current techniques mainly aim to provide images of static environment in a sensor network. Nevertheless, imaging of mobile targets requires networked and collaborative detection, tracking and imaging capabilities. With this regard, ultra-wideband (UWB) radar technology stands as a promising approach for networked target imaging due to its unique features such as having no line-of-sight (LoS) requirement. However, UWB wireless radar sensor network (WRSN) is yet to be developed for imaging of mobile targets. In this paper, an architecture and a new collaborative mobile target imaging (CMTI) algorithm for WRSN are presented. The objective is to efficiently obtain an accurate image of mobile targets based on the collaborative effort of deployed radar sensor nodes. CMTI enables detection, tracking and imaging of mobile targets as a complete WRSN solution. Performance evaluations reveal that CMTI yields high quality radar image of mobile targets inWRSN with very low communication overhead regardless of the target shape and velocity. [J128]

"Inter-Track Interference Mitigation for Bit-Patterned Magnetic Recording"

In bit-patterned magnetic recording (BPMR), inter-track interference (ITI) becomes a major impairment due to the small track pitch. One way to mitigate the ITI is to equalize the read channel to a two dimensional (2D) partial-response (PR) target. However, we find that the channel detection on the center track cannot take advantage of the 2D target without good estimation of the data on the sidetracks. Therefore, we propose a multi-track detection technique, where the detection on the center track is aided by the information obtained from the detection of the sidetracks. This technique works with any equalizer capable of equalizing the channel to a 2D target. We apply this method to joint-track equalized and 2D equalized BPMR channels. Our simulation results show that the proposed technique provides a significant performance improvement. [J129]

"Tensor Algebra and Multidimensional Harmonic Retrieval in Signal Processing for MIMO Radar"

Detection and estimation problems in multiple-input multiple-output (MIMO) radar have recently drawn considerable interest in the signal processing community. Radar has long been a staple of signal processing, and MIMO radar presents challenges and opportunities in adapting classical radar imaging tools and developing new ones. Our aim in this article is to showcase the potential of tensor algebra and multidimensional harmonic retrieval (HR) in signal processing for MIMO radar. Tensor algebra and multidimensional HR are relatively mature topics, albeit still on the fringes of signal processing research. We show they are in fact central for target localization in a variety of pertinent MIMO radar scenarios. Tensor algebra naturally comes into play when the coherent processing interval comprises multiple pulses, or multiple transmit and receive subarrays are used (multistatic configuration). Multidimensional harmonic structure emerges for far-field uniform linear

transmit/receive array configurations, also taking into account Doppler shift; and hybrid models arise in-between. This viewpoint opens the door for the application and further development of powerful algorithms and identifiability results for MIMO radar. Compared to the classical radar-imaging-based methods such as Capon or MUSIC, these algebraic techniques yield improved performance, especially for closely spaced targets, at modest complexity. [J130]

"High-speed multi-target detection with narrowband radar"

High-speed multi-target detection is a challenging problem in radar applications. Typically, targets with high speed go through several range cells in the observation period, which makes it more difficult to obtain each target's power coherently accumulated for target detection. In this study, novel multi-target detection with a narrowband radar system is proposed. In order to remove range migration and obtain coherent integration of the target energy, the Keystone transform is applied to the moving targets. However, because of the high target velocity and the low radar pulse repetition frequency phase ambiguity will occur, so the range migration will not be corrected properly. Then the phase ambiguity function of the kth target is compensated, and the envelope of the kth target concentrates in a certain range cell. Following by frequency modulation rate search a quadratic phase term is compensated, and the signal energy is finally coherently accumulated by FT analysis. The target is detected if the ratio of peak value to noise is higher than a predetermined threshold. For target detection in low signal-to-noise ratio (SNR), the Clean technique is applied. The proposed algorithm is verified by simulation and raw radar data results. [J131]

"Hybrid direct data domain sigma-delta space-time adaptive processing algorithm in non-homogeneous clutter"

The need to deal with non-homogeneous clutter has driven much of the recent research in space-time adaptive processing (STAP). An extension of the low-complexity, sigma-delta (ΣΔ) algorithm incorporating the direct data domain (D3) processing is presented. The new algorithm is practical and improves target detection in nonhomogeneous clutter environments. The algorithm employs a hybrid approach, combining D3processing with the more traditional statistical approach, thereby obtaining advantages of both. First, a modified D3algorithm, which maximises signal-to-interference-plus-noise ratio (SINR), is presented. Then this D3algorithm is used as an adaptive transformer to create sum (Σ) and difference (Δ) beams. The residual interference after the D3processing is further cancelled by ΣΔ STAP. The proposed hybrid algorithm using D3-ΣΔ STAP is tested in nonhomogeneous clutter modelled using spherically invariant random variables (SIRV) and artificially injected discrete interferers. Performance of the proposed methods is compared with those of traditional statistical approaches, illustrating significant benefits of hybrid processing in non-homogeneous scenarios. [J132]

"Uniformly most powerful invariant detection in spherically invariant random vector distributed clutter"

This study deals with the problem of detecting a radar target with unknown complex amplitude in the presence of clutter modelled as a spherically invariant random vector (SIRV). It is proved that, under a quite mild technical condition, the normalised matched filter (NMF) is the uniformly most powerful invariant (UMPI) detector in SIRV disturbance. The developed proof is based on the theory of total positive functions of order two. [J133]

"Special Issue on Remote Sensing of Building Interior"

The 15 papers in this special issue focus on remote sensing of building interior and can be categorized into: 1) system design and instrumentation; 2) advanced imaging techniques for elimination of glint from large flat wall structures; 3) radar polarimetry; 4) passive microwave radiometry; 5) advanced forward models based on high-frequency methods as well as full-wave solutions based on finite-difference time-domain technique for large-scale problems; and 6) detection and identification techniques of behind the wall stationary and moving concealed and unconcealed targets. [J134]

"Space-Based Motion Estimators-Evaluation With the First RADARSAT-2 MODEX Data"

Synthetic aperture radar (SAR)-based motion estimation algorithms, which have been developed and validated for airborne SAR data, are now being extended to the RADARSAT-2 Moving Object Detection Experiment (MODEX). Several modifications of the classical along-track interferometry (ATI) approach are considered. Some of the first MODEX results are presented, demonstrating the estimation of target position and velocity from a commercial satellite using ATI methods. [J135]

"Use of a Frequency-Hopping Radar for Imaging and Motion Detection Through Walls"

A small frequency-agile radar has been developed and configured into different systems for performing imaging of static and dynamic targets through common building materials. Radar operating parameters are defined through software control, allowing radar system operations to be tailored to operational needs. Field testing has shown the radar's ability to detect stationary individuals concealed behind concrete walls at significant ranges. [J136]

"Converting Bearings-?nly Measurements to Cartesian Coordinates"

The lack of range information for passive measurements complicates sensor registration, requires one to address the arctangent function's singularities, and prevents one from applying existing polar to Cartesian conversion mappings. Consequently, a coordinate conversion method is developed for passive measurements using an integral representation. In addition, the existing coordinate conversion methods are shown to differ only by a constant multiplying each converted measurement and in the eigenvalues of the corresponding covariance matrix. [J137]

"New SAR Processor Based on Matched Subspace Detectors"

This paper deals with a new synthetic aperture radar (SAR) processor based on a subspace detector designed for man-made target (MMT) detection. As MMTs are more accurately described by a set of canonical elements than with isotropic points, we develop a new algorithm which aims at using new models, instead of the isotropic point model commonly used in SAR processors. A subspace detector matched to canonical elements is included in the SAR processing. The implementation and the optimization of subspace detector SAR (SDSAR) algorithm is described. Simple examples of MMT detection in simulations and real data with a target hidden in a forest show the power of our approach. The SDSAR algorithm is shown to be the first robust and tractable algorithm relying on realistic scattering assumptions about the target. [J138]

"Fault Tolerant Maximum Likelihood Event Localization in Sensor Networks Using Binary Data"

This paper investigates Wireless Sensor Networks (WSNs) for achieving fault tolerant localization of an event using only binary information from the sensor nodes. In this context, faults occur due to various reasons and are manifested when a node outputs a wrong decision. The main contribution of this paper is to propose the Fault Tolerant Maximum Likelihood (FTML) estimator. FTML is compared against the Centroid (CE) and the classical maximum likelihood (ML) estimators and is shown to be significantly more fault tolerant. Moreover, this paper compares FTML against the SNAP (Subtract on Negative Add on Positive) algorithm and shows that in the presence of faults the two can achieve similar performance; FTML is slightly more accurate while SNAP is computationally less demanding and requires fewer parameters. [J139]

"Target Detection in Single- and Multiple-View Through-the-Wall Radar Imaging"

A detector of targets behind walls and in enclosed structures is presented. The detector is applied to through-the-wall radar images obtained by wideband delay and sum beamforming. We consider the detection problem using single- and multiple-view imaging. The statistics of noise, clutter, and target images are examined and formulated using sample scenes. The effects of wall parameter errors on the image statistics are shown. An iterative detection scheme, which adapts itself to the image statistics, is presented. The proposed detection schemes are evaluated using real data. [J140]

"Target Detection in Clutter Using Adaptive OFDM Radar"

We address the problem of detecting a target moving in clutter environment using an orthogonal frequency division multiplexing (OFDM) radar. The broadband OFDM signal provides frequency diversity to improve the performance of the system. First, we develop a parametric model that accounts for the measurements at multiple frequencies including the Doppler shift. Then, we present a statistical detection test and evaluate its performance characteristics. Based on this, we propose an algorithm to adaptively design the parameters for the next transmitting waveform. Numerical examples illustrate our analytical results, demonstrating the achieved performance improvement due to the OFDM signaling method and adaptive waveform design. [J141]

"Through-Wall Imaging of Moving Targets Using UWB Random Noise Radar"

For a through-wall ultrawideband (UWB) random noise radar using array antennas, subtraction of successive frames of the cross-correlation signals between each received element signal and the transmitted signal is able to isolate moving targets in heavy clutter. Images of moving targets are subsequently obtained using the back projection (BP) algorithm. This technique is not constrained to noise radar, but can also be applied to other kinds of radar systems. Different models based on the finite-difference time-domain (FDTD) algorithm are set up to

simulate different through-wall scenarios of moving targets. Simulation results show that the heavy clutter is suppressed, and the signal-to-clutter ratio (SCR) is greatly enhanced using this approach. Multiple moving targets can be detected, localized, and tracked for any random movement. [J142]

"RKHS Bayes Discriminant: A Subspace Constrained Nonlinear Feature Projection for Signal Detection"

Given the knowledge of class probability densities, aprioriprobabilities, and relative risk levels, Bayes classifier provides the optimal minimum-risk decision rule. Specifically, focusing on the two-class (detection) scenario, under certain symmetry assumptions, matched filters provide optimal results for the detection problem. Noticing that the Bayes classifier is in fact a nonlinear projection of the feature vector to a single-dimensional statistic, in this paper, we develop a smooth nonlinear projection filter constrained to the estimated span of class conditional distributions as does the Bayes classifier. The nonlinear projection filter is designed in a reproducing kernel Hilbert space leading to an analytical solution both for the filter and the optimal threshold. The proposed approach is tested on typical detection problems, such as neural spike detection or automatic target detection in synthetic aperture radar (SAR) imagery. Results are compared with linear and kernel discriminant analysis, as well as classification algorithms such as support vector machine, AdaBoost and LogitBoost. [J143]

"GPR Response From Buried Pipes: Measurement on Field Site and Tomographic Reconstructions"

The identification of the physical nature of an object or target causing a ground-penetrating radar (GPR) anomaly, as well as the estimation of a target's dimensions and geometry, is rather challenging. To improve target identification, basic studies are still required, and they can be addressed primarily using a laboratory- or field-based physical model. The field model (test site) is usually expensive and difficult to build, but it provides data for controlled target properties and geometry from a natural environment that are essential for testing processing techniques. In this paper, we present the results from a field experiment where GPR data were collected on plastic and metallic pipes. The main objective is the comparison of the classical migration technique with a microwave tomography approach for reconstructing the geometrical target properties. The use of the microwave tomography approach will allow us to obtain more focused and stable images of the buried objects compared to the ones obtained using classical migration techniques. [J144]

"Mine Classification With Imbalanced Data"

In many remote-sensing classification problems, the number of targets (e.g., mines) present is very small compared with the number of clutter objects. Traditional classification approaches usually ignore this class imbalance, causing performance to suffer accordingly. In contrast, the recently developed infinitely imbalanced logistic regression (IILR) algorithm explicitly addresses class imbalance in its formulation. We describe this algorithm and give the details necessary to employ it for remote-sensing data sets that are characterized by class imbalance. The method is applied to the problem of mine classification on three real measured data sets. Specifically, classification performance using the IILR algorithm is shown to exceed that of a standard logistic regression approach on two land-mine data sets collected with a ground-penetrating radar and on one underwater-mine data set collected with a sidescan sonar. [J145]

"Phase of Target Scattering for Wetland Characterization Using Polarimetric C-Band SAR"

Wetlands continue to be under threat, and there is a major need for mapping and monitoring wetlands for better management and protection of these sensitive areas. Only a few studies have been published on wetland characterization using polarimetric synthetic aperture radars (SARs). The most successful results have been obtained using the phase difference between HH and VV polarizations, phiHH- phiVV, which has shown promise for separating flooded wetland classes. Recently, we have introduced a new decomposition, the Touzi decomposition, which describes target scattering type in terms of a complex entity, the symmetric scattering type. Huynen's target helicity is used to assess the symmetric nature of target scattering. In this paper, the new complex-scattering-type parameters, the magnitude alphasand phase Phialphas, are investigated for wetland characterization. The use of the dominant-scattering-type phase Phialphasmakes it possible to discriminate shrub bogs from poor (sedge or shrub) fens. These two classes cannot be separated using phiHH- phiVV, or the radiometric scattering information provided by alphas, the Cloude alpha, the entropy H, and the multipolarization HH-HV-VV channels. phialphas, which cannot detect deep (45 cm below the peat surface) water flow in a bog, is more sensitive to the shallower (10-20-cm) fen beneath water, and this makes possible the separation of poor fens from shrub bogs. Phialphasalso permits the discrimination of conifer-dominated treed bog from upland deciduous forest under leafy conditions. Target helicity information is exploited to introduce a new parameter, the target asymmetry. The latter is shown very promising for detection of forest changes between leafy and no-leaf

conditions. The analysis of low-entropy marsh scattering showed that both the scattering-type magnitude and phas--e alphasand Phialphas, respectively, as well as the maximum polarization intensity of the dominant scattering m, are needed for a better understanding of marsh complex scattering mechanisms. The unique information provided by the new roll-invariant decomposition parameters are demonstrated using repeat-pass Convair-580 polarimetric C-band SAR data collected in June and October 1995 over the RAMSAR Mer Bleue wetland site near Ottawa (Canada). [J146]

"Radar Optimal Times Detection Allocation in Multitarget Environment"

This paper deals with the problem of the management of electronically steered antenna (ESA) in multitarget environments. Radars are used to detect, locate and identify targets. In this paper we focus on the detection of several aerial targets in a fixed given time. The difficulty of such detection lies in the fact that targets may be located anywhere in the space, but radars can only observe a limited part of it at a time. As a result, it is necessary to change their axis position over time. This paper describes the main steps to derive an optimal radar management in this context: the modeling of the radar, the determination of a criterion based on the target detection probability and the temporal optimization process leading to sensor management strategy. An optimization solution is presented for several contexts and several hypotheses about prior knowledge concerning the targets' locations. First, we propose a method for the optimization of the radar detection probability in a single target environment. It consists in the decomposition of the detection step into an optimal number of independent elementary detections. Then, in a multitarget context with deterministic prior knowledge, we present an optimal time allocation method which is based on the results of non linear programming. finally, in a multitarget context with probabilistic prior knowledge, results in search theory are used to determine an optimal temporal allocation. [J147]

"Chirped Lidar Using Simplified Homodyne Detection"

A simplified homodyne detection scheme for linear FM modulated lidar is presented in which pulse dechirping is performed in the optical domain. This method provides quantum limited detection sensitivity with much less receiver complexity compared to heterodyne detection systems. Another advantage of this approach is the reduced bandwidth requirement for the photodetector. This removes the limit on the chirp bandwidth, and enables the use of more efficient photodiodes with larger detector area. A field trial using a 5-in aperture diameter commercial telescope and a 370-m target range verified the sensitivity estimation and demonstrated the feasibility of this technique. [J148]

"MIMO Radar Waveform Optimization With Prior Information of the Extended Target and Clutter"

The concept of multiple-input multiple-output (MIMO) radar allows each transmitting antenna element to transmit an arbitrary waveform. This provides extra degrees of freedom compared to the traditional transmit beamforming approach. It has been shown in the recent literature that MIMO radar systems have many advantages. In this paper, we consider the joint optimization of waveforms and receiving filters in the MIMO radar for the case of extended target in clutter. A novel iterative algorithm is proposed to optimize the waveforms and receiving filters such that the detection performance can be maximized. The corresponding iterative algorithms are also developed for the case where only the statistics or the uncertainty set of the target impulse response is available. These algorithms guarantee that the SINR performance improves in each iteration step. Numerical results show that the proposed methods have better SINR performance than existing design methods. [J149]

"Chaos UWB Radar for Through-the-Wall Imaging"

In this paper, we propose to apply a novel chaos-based ultra-wide band (UWB) radar for through-the-wall imaging. The proposed chaos modulation offers superior resolution compared to conventional UWB radars when applied for through-the-wall imaging. A noncoherent receiver is designed based on expectation maximization (EM) algorithm. The theoretical detection performance is derived for through-the-wall detection in the presence and absence of room reverberations as a function of dielectric properties of walls, targets, and their geometry illustrating the robustness of the proposed modulation against room reverberations. The resolution of the proposed modulation is analyzed theoretically and verified through simulations for different wall materials. Numerical electromagnetic simulations using finite difference time domain (FDTD) method are performed to confirm the obtained theoretical results. From the theoretical and simulation analysis, we find that the proposed chaos-based pulse amplitude modulated ultra-wide band (CPAM-UWB) radar has better detection performance, penetrating ability and imaging performance compared to other conventional through-the-wall imaging radars. [J150]

"CFAR Detection Strategies for Distributed Targets Under Conic Constraints"

In this paper we deal with the problem of adaptive detection of mismatched mainlobe targets and/or sidelobe interfering signals that are distributed in range. To this end, we investigate the impact of modeling the actual useful signal as a vector belonging to a proper cone with axis the nominal steering vector as a means to improve the robustness of the decision rule in presence of mainlobe targets; similarly, in order to improve the rejection capabilities of the decision rule in presence of sidelobe interferers we study the effects of replacing the usual noise-only hypothesis with a noise-plus-interferers hypothesis where interferers belong to the complement of a cone with axis the nominal steering vector. At the design stage we resort to the two-step GLRT-based design procedure; to this end, we assume that a set of training data is available, namely data free of signal components, but sharing the same Gaussian distribution of the noise in the cells under test. Remarkably, proposed detectors possess the CFAR property under the noise-only hypothesis. The performance assessment, conducted by Monte Carlo simulation, is aimed at assessing the effectiveness of proposed solutions, also in comparison to existing ones. [J151]

"Foundation for mitigating range dependence in radar space-time adaptive processing"

The problem of detecting slow-moving targets using a space-time adaptive processing (STAP) radar is addressed. The determination of the optimum interference-rejection weights at each range is based on snapshots at neighbouring ranges. However, in virtually all bistatic configurations or/and when using conformal antenna arrays (CAA), snapshot statistics are range dependent, which results in poor detection performance. To address this issue, a foundation for range-dependence compensation in STAP in the case of Gaussian interference and noise is proposed. The realistic case where received snapshots are the only source of information for mitigating the range dependence is considered. To illustrate the usefulness of the proposed foundation, this foundation is used to design a method to adaptively compensate for range dependence in a challenging situation, that is, for a radar using a CAA and operating in a bistatic configuration. [J152]

"An Adaptive and Fast CFAR Algorithm Based on Automatic Censoring for Target Detection in High-Resolution SAR Images"

An adaptive and fast constant false alarm rate (CFAR) algorithm based on automatic censoring (AC) is proposed for target detection in high-resolution synthetic aperture radar (SAR) images. First, an adaptive global threshold is selected to obtain an index matrix which labels whether each pixel of the image is a potential target pixel or not. Second, by using the index matrix, the clutter environment can be determined adaptively to prescreen the clutter pixels in the sliding window used for detecting. The G0distribution, which can model multilook SAR images within an extensive range of degree of homogeneity, is adopted as the statistical model of clutter in this paper. With the introduction of AC, the proposed algorithm gains good CFAR detection performance for homogeneous regions, clutter edge, and multitarget situations. Meanwhile, the corresponding fast algorithm greatly reduces the computational load. Finally, target clustering is implemented to obtain more accurate target regions. According to the theoretical performance analysis and the experiment results of typical real SAR images, the proposed algorithm is shown to be of good performance and strong practicability. [J153]

"Improvement of high-frequency surface waves radar performances by use of multiple-input multiple-output configurations"

A multiple-input multiple-output (MIMO) configuration has been studied for communication applications, offering a lot of advantages to mitigate propagation effects because of multipath and fading environments. More recently, MIMO techniques in radar have been proposed. MIMO is discussed in the context of high-frequency surface waves radar (HFSWR). After a short introduction to the MIMO radar technique (a technique which is not new; the RIAS developed by ONERA was probably the first MIMO radar), explores two different applications are explored. The first application aims at improving the resolution and accuracy of a coastal radar, proposed here in a bistatic configuration. Such a radar operates with a wide sparse frequency band and with an equivalent wide aperture, taking advantage of the MIMO configuration. Simulation over a congested area of targets demonstrates the benefit of MIMO over the conventional HFSWR radar, especially in terms of separation of targets. The second application consists in a more practical ship-borne HFWSR configuration compatible with space time adaptive processing (STAP) to improve the detection of slow targets. In this case, a limited number of receiving channels is considered whereas STAP uses the degrees of freedom offered by the transmitting array. The MIMO-STAP is compared with a conventional STAP, showing that theoretical performances should not be affected by the MIMO configuration even if the signals are no longer perfectly orthogonal, because of Doppler shift, once scattered by moving targets. [J154]

"Modified input estimation technique for tracking manoeuvring targets"

A new input estimation (IE) model for problems in tracking manoeuvring targets is proposed. The proposed

model is constructed by combining the two models of uncertainties, Bayesian and Fisher. The conventional model, which describes targets with manoeuvre, is based on the state vector of target position and velocity. The acceleration is treated as an additive input term in the corresponding state equation. The proposed method is a Kalman filter-based tracking scheme with the IE approach. The proposed model is a special augmentation in the state-space model which considers both the state vector and the unknown input vector as a new augmented state vector. In the proposed scheme, the original state and acceleration vectors are estimated simultaneously with a standard Kalman filter. The proposed tracking algorithm operates in both the non-manoeuvring and the manoeuvring modes and the manoeuvre detection procedure is eliminated. The theoretical development is verified by simulation results, which also contain some examples of tracking typical target manoeuvres. The results are compared with a traditional IE method. A comparison based on the Monte-Carlo simulation is also made to evaluate the performances of the proposed method in three scenarios: low, medium and high manoeuvring target. [J155]

"Shape and Motion Reconstruction from 3D-to-1D Orthographically Projected Data via Object-Image Relations"

This paper describes an invariant-based shape- and motion reconstruction algorithm for 3D-to-1D orthographically projected range data taken from unknown viewpoints. The algorithm exploits the object-image relation that arises in echo-based range data and represents a simplification and unification of previous work in the literature. Unlike one proposed approach, this method does not require uniqueness constraints, which makes its algorithmic form independent of the translation removal process (centroid removal, range alignment, etc.). The new algorithm, which simultaneously incorporates every projection and does not use an initialization in the optimization process, requires fewer calculations and is more straightforward than the previous approach. Additionally, the new algorithm is shown to be the natural extension of the approach developed by Tomasi and Kanade for 3D-to-2D orthographically projected data and is applied to a realistic inverse synthetic aperture radar imaging scenario, as well as experiments with varying amounts of aperture diversity and noise. [J156]

"Radiometric Calibration of LIDAR Intensity With Commercially Available Reference Targets"

We present a new approach for radiometric calibration of light detection and ranging (LIDAR) intensity data and demonstrate an application of this method to natural targets. The method is based on 1) using commercially available sand and gravel as reference targets and 2) the calibration of these reference targets in the laboratory conditions to know their backscatter properties. We have investigated the target properties crucial for accurate and consistent reflectance calibration and present a set of ideal targets easily available for calibration purposes. The first results from LIDAR-based brightness measurement of grass and sand show that the gravel-based calibration approach works in practice, is cost effective, and produces statistically meaningful results: Comparison of results from two separate airborne laser scanning campaigns shows that the relative calibration produces repeatable reflectance values. [J157]

"CMP Antenna Array GPR and Signal-to-Clutter Ratio Improvement"

Ground-penetrating radar (GPR) is recognized as a promising sensor for detecting buried landmines. In this case, the GPR antenna(s) must be elevated above the ground. However, this requirement results in heavy surface clutter. It is therefore necessary to overcome the effect. A commonly used procedure of time gating and background averaging cannot suit to small shallow nonmetallic landmine beneath a rough ground surface. In this letter, we proposed techniques to enhance the target signal through common midpoint (CMP) antenna array and data processing techniques, including velocity spectrum and CMP multifold stacking. The method has been tested using experiment data over a rough ground under which small plastic antipersonnel landmines is shallowly buried. The result shows the signal-to-clutter ratio was dramatically improved. [J158]

"Time-Reversal Detection Using Antenna Arrays"

The paper studies detection of a target buried in a rich scattering medium by time reversal. We use a multi-static configuration with receive and transmit arrays of antennas. In time reversal, the backscattered field is recorded, time reversed, and retransmitted (mathematically or physically) into the same scattering medium. We derive two array detectors: the time-reversal channel matched filter when the target channel response is known; and the time-reversal generalized-likelihood ratio test (TR-GLRT) when the target channel response is unknown. The noise added in the initial probing step to the time-reversal signal makes the analysis of the TR-GLRT detector non trivial. The paper derives closed form expressions for the signal-to-noise ratio gain provided by this detector over the corresponding conventional clutter subtraction energy detector in the two extreme conditions of weak and strong (electronic additive) noise and shows that time reversal provides, under weak noise, the optimal waveform shape to probe the environment. We analyze the impact of the array configuration on the detection

performance. Finally, experiments with electromagnetic data collected in a multipath scattering laboratory environment confirm our analytical results. Under the realistic conditions tested, time reversal provides detection gains over conventional detection that range from 2 to 4.7 dB. [J159]

"Optimum Polarizations for Discrimination of a Foliage-Camouflaged Target, Using Genetic Algorithms"

Many realizations of foliage around a hard target are run to obtain the statistical variations of foliage and target responses. This is accomplished by using a hybrid target-foliage model, developed for the investigation of the scattering behavior of metallic targets embedded inside a forest canopy. This model is based on the coherent scattering theory of wave propagation through the foliage and an iterative physical optics approximation of scattering from the target. The model is capable of accounting for the first-order near-field interactions between the hard target and the foliage. Fully polarimetric simulation results of a foliage-camouflaged metallic target having complex geometry are generated at 2 GHz, and a polarization synthesis optimization method for improving signal-to-clutter ratio is carried out by applying genetic algorithms. [J160]

"A New Way to Model Nonstationary Sea Clutter"

Sea clutter refers to the radar backscatter from a patch of ocean surface. To properly characterize radar clutter returns, a lot of effort has been made to fit various distributions to the observed amplitude data of sea clutter. However, the fitting of real sea clutter data using those distributions is not satisfactory. This may be due to the fact that sea clutter data is highly nonstationary. This nonstationarity motivates us to perform distributional analysis on the data obtained by differentiating the amplitude data of sea clutter. By systematically analyzing differentiated data of 280 sea clutter time series measured under various sea and weather conditions, we show that the Tsallis distribution fits sea clutter data much better than commonly used distributions for sea clutter such as the K distribution. We also find that the parameters from the Tsallis distribution are more effective than the ones from the K distribution for detecting low observable targets within sea clutter. [J161]

"Target Detection in SAR Images Based on a Level Set Approach"

This paper introduces a new framework for point target detection in synthetic aperture radar (SAR) images. We focus on the task of locating reflective small regions using a level-set-based algorithm. Unlike most of the approaches in image segmentation, we address an algorithm that incorporates speckle statistics instead of empirical parameters and also discards speckle filtering. The curve evolves according to speckle statistics, initially propagating with a maximum upward velocity in homogeneous areas. Our approach is validated by a series of tests on synthetic and real SAR images and compared with three other segmentation algorithms, demonstrating that it configures a novel and efficient method for target-detection purpose. [J162]

"Pulse-Based Radar Imaging Using a Genetic Optimization Approach for Echo Separation"

This paper describes a novel 3-D ultra-wideband (UWB) imaging technique with the aim of detecting, classifying, and imaging water pipes located inside walls. The target under test was chosen in such a way that the echoes of the front side of the wall and of the water pipes overlap making it impossible to distinguish between them in the raw data. Applying a genetic optimization algorithm for modeling the radar response by a superposition of single echoes it was possible to determine the exact round-trip times of several scatterers. Moreover, the algorithm takes into account the pulse distortion caused by varying angles of incidence at the broad beam antenna. [J163]

"Partially Adaptive STAP using the FRACTA Algorithm"

A partially adaptive space-time adaptive processor (STAP) utilizing the recently developed FRACTA algorithm is presented which significantly reduces the high computational complexity and large sample support requirements of fully adaptive STAP. Multi-window post-Doppler dimensionality reduction techniques are employed to transform the data prior to application of the FRACTA algorithm. The FRACTA algorithm is a reiterative censoring (RC) and detection algorithm which has been shown to provide excellent detection performance in nonhomogeneous interference environments. Two multi-window post-Doppler dimensionality reduction techniques are considered: PRI-staggered and adjacent-bin. The partially adaptive FRACTA algorithm is applied to the KASSPER I (knowledge-aided sensor signal processing & expert reasoning) challenge datacube. The pulse repetition interval (PRI)-staggered approach with D=6 filters per Doppler bin is found to provide the best detection performance, outperforming the fully adaptive case while simultaneously reducing the runtime by a factor of ten. Using this implementation, partially adaptive FRACTA detects 197 out of 268 targets with one false alarm. The clairvoyant processor (the covariance matrix for each range cell is known) detects 198 targets with one false alarm. In addition, the partially adaptive FRACTA algorithm is shown to be resilient to jamming, and performs well for reduced sample support situations. When compared with partially adaptive STAP using

traditional sliding window processing (SWP), the runtime of partially adaptive FRACTA is 14 times faster, and the detection performance is significantly increased (SWP detects 46 out of 268 targets with one false alarm). [J164]

"One- and Two-Stage Tunable Receivers"

In this paper, we propose and assess a CFAR detector that can adjust its ldquodirectivityrdquo through a real scalar parameter. It relies on the usual assumption that a set of homogeneous training data is available and encompasses as special cases the well-known Kelly's GLRT and the recently introduced W-ABORT detector. More important, it can be tuned in order to control the level to which sidelobe signals are rejected. Such functionality is particularly important to contain the number of false alarms in presence of mismatched signals. We also consider a parametric detector which resorts to a diagonally loaded sample covariance matrix commonly adopted to take advantage of the presence of strong interferers. The performance assessment of such detector has shown that it can significantly outperform Kelly's GLRT in terms of prediction probabilities for matched signals and in terms of selectivity, but it is not strictly CFAR. We also propose to use the CFAR parametric detector as second stage of a two-stage tunable detector and show that such a two-stage detector can outperform already proposed tunable receivers in terms of selectivity. The analysis of the detectors is conducted assuming a homogeneous Gaussian environment; with reference to this scenario and to the CFAR detectors we derive analytical expressions for the probability of false alarm and the probability of detection for both matched and mismatched signals. [J165]

"Application of the radon transform to detect small-targets in sea clutter"

The authors present a novel and heuristic approach for the detection of low radar cross-section targets in high-resolution sea clutter. The proposed technique is based on the application of the Radon transform to range-time matrices formed by column-wise storage of consecutive range profiles. The objective of this paper is 2-fold: to analyse the effect of the transform on real high-resolution sea clutter and to describe a detection scheme based on the insight obtained. The proposed technique emulates the behaviour of traditional motion target detection algorithms without the need for reliable Doppler information. It also constitutes a powerful non-coherent integration strategy of the target-s energy along its specific path on the range-time plot. The performance of the detection technique has been tested against real high-resolution sea clutter data, acquired at the south coast of Spain with an in-house developed continuous wave linear frequency modulated millimetre-wave radar system. Monte Carlo simulations show a significant improvement over the conventional cell averaging constant false alarm rate schemes. [J166]

"Target Estimation, Detection, and Tracking"

In this article, we explore the adaptive design of radar polarization waveforms for optimal performance, when the statistical properties of the target and clutter are unknown. We focus on a closed-loop system that sequentially estimates the target and clutter scattering parameters, and then uses these estimates to select the polarization of the subsequent waveforms. We demonstrate that the radar system performance is significantly improved when the polarization of the transmitted signal is optimally and adaptively selected to match the polarimetric aspects of the target and environment. In particular, we provide an overview of our recent results showing that the adaptive design of the radar signal polarization enables achieving optimal performance in several operating modes, including detection, estimation, and tracking. [J167]

"A Short-Range Ship Navigation System Based on Ladar Imaging and Target Tracking for Improved Safety and Efficiency"

A new maritime navigation system based on a laser range-finder scanner for obstacle avoidance and precise maneuvering operations is described in this paper. The main novelty of this work is the adaptation and implementation of known technology for laser range finding and algorithms for target tracking into a system that operates in real time and has been tested in different natural sea and inland navigation scenarios. The principal components of this system, namely, 1) the laser range finder, 2) the scanning unit, and 3) the data processing and displaying unit, are described in detail. Ladar images are dense horizontally and sparse vertically as a compromise between capturing relevant features and quick frame formation. Images are processed for range outlier removal, and significant observable patterns are extracted. This multiple-target tracking problem is tackled using robust Kalman filtering techniques for continuous tracking of each detected observation. We minimize unreliable track initializations and preserve tracks from deletion during temporal misobservations. The evaluation in open-sea and inland waterways gave good results, making the system valid for precise maneuvering, fluent navigation, and accident mitigation. Objects of interest, from boats to ships, are detected and robustly tracked; pier and lock chamber sketches are reliable; bridge height estimation is precise; and narrow waterways (river banks and bridge columns) are correctly detected. The prototype developed can be considered to be a very

valuable complementary device to traditional radar-based techniques that are not totally valid for accurate short-range exploration, improving efficiency and safety in ship operations. [J168]

"Orthogonal frequency-division multiplexing radar signal design with optimised ambiguity function and low peak-to-average power ratio"

Considering the important role of the ambiguity function (AF) of a signal regarding the performance of a matched filter bank for the detection of targets and the estimation of their ranges and velocities, the thumbtack shape is assumed to be the desirable shape of the AF and the method of least squares for the synthesis of the AF is introduced. Then, an iterative method for the allocation of a proper phase to the desired AF is proposed to obtain better results. This method is then applied to select the proper codes for the synthesis of pulsed orthogonal frequency-division multiplexing signals. It is also shown how this method can reduce sidelobes, almost uniformly, throughout the entire ambiguity plane. Finally, an efficient algorithm is presented, which modifies the produced codes in order to reach a lower peak-to-average power ratio suitable for transmission. [J169]

"Ionospheric clutter mitigation using one-dimensional or two-dimensional wavelet processing"

Ionospheric clutter mitigation is an important issue for high-frequency surface wave radar (HFSWR) signal processing. Clutter results from a sky wave propagation mode, which is backscattered by ionospheric ionisation irregularities. The random behaviour and the high strength of clutter signals can strongly limit the HFSWR detection capabilities. Here, an ionospheric clutter mitigation processing using wavelets is described. This new approach is founded on the ability of wavelets to separate signals having different variation scales or different directions of variations. The results obtained on real clutter signals with simulated targets are reported. Using the proposed method, one can expect, at mid-latitude, an improvement of the target-to-clutter ratio of 20-30-dB. [J170]

"Effects of Non-Uniform Motion in Through-the-Wall SAR Imaging"

Synthetic aperture radar (SAR) provides high resolution images that are well suited for through-the-wall target detection and recognition. As targets behind-the-wall undergo non-uniform motions, such as vibration, rotation and acceleration, their patterns can be recognized. To understand these signatures in through-the-wall SAR, we model and analyze the non-uniform motion-induced Doppler effect as well as the focused target SAR image. In particular, the wall effects on the focused SAR image and the micro-Doppler are formulated and analyzed. These analyses facilitate improving the target recognition performance by quantitatively estimating the parameters of the micro-Doppler signatures as well as the SAR imaging. We further analyze the detection performance of the non-uniform motion-induced target based on the generalized likelihood ratio test (GLRT) technique. The relationship between motion parameters and the detection performance allows us to evaluate the performance bound and the minimum detectable parameters. [J171]

"Analysis and extraction of stepped frequency radar signature for micro-motion structure"

Radar signature produced by micro-motion structures contains movement and structure information which is useful for radar target recognition. For stepped frequency (SF) radar, the Doppler modulation is coupled with the stepped carrier frequency. It shifts and smears the high-resolution range profile and makes it difficult to analyse and extract the micro-motion information from the range profile directly. The authors propose to comprehend the SF radar as a special pulse Doppler radar, and the range profile as a Doppler profile for the convenience of motion analysis. The signature of moving targets for SF radar is analysed from this point of view and the equivalent instantaneous Doppler frequency (EIDF) is introduced. Then, a typical micro-motion, rotation, is taken as an example. The sinusoidal vibration of the peaks in the range profile sequence is explained in detail, especially the relationship between the sinusoid parameters and the rotation parameters. An approach to extract the rotation parameters from the range profile or EIDF spectrum sequence is proposed based on the Hough transform. Simulated and experimental results validate the theoretical analysis and the feature extraction method. [J172]

"Azimuth-invariant bistatic multichannel synthetic aperture radar for moving target detection and location"

Ground moving target indication (GMTI) is one of the most important applications of the bistatic synthetic aperture radar (SAR) system as well as the monostatic system. An algorithm for moving target detection and location is presented with an azimuth-invariant bistatic multichannel SAR, which consists of one transmitter (channel) and multireceivers (multichannel). The algorithm is based on the discussion of the particularities of the

bistatic SAR configuration including coherence improvement and clutter characteristics. Then, the corresponding compensating methods including two-dimensional range-azimuth prefiltering and bistatic differential range correction are proposed to solve these particularities. It is shown that using the compensating methods, the stationary clutter can be suppressed and the moving parameters of ground targets can be estimated accurately. Finally, simulation results demonstrate the effectiveness of the proposed algorithm. [J173]

"Direction-of-arrival estimation in radar systems: moving window against approximate maximum likelihood estimator"

In this study, we compare two radar target direction-of-arrival (DOA) estimation algorithms: the classical moving window (MW) estimator, implemented in many real radar systems and the approximate maximum likelihood (AML) estimator. The first technique exploits multiple detections in the same time-on-target and the second one exploits the fact that the radar antenna mechanical scanning impresses an amplitude modulation on the signals backscattered by the target. Performances of the two estimators are numerically investigated through Monte Carlo simulation and compared in terms of root-mean-square-error (RMSE), probability of detection and probability of target splitting, the latter being defined as the probability of detecting more than one target when instead only one is present in the cell under test. Numerical results show that the AML estimator generally outperforms the classical MW estimator, also in terms of robustness to target splitting. [J174]

"Adaptive detectors with diagonal loading for airborne multi-input multi-output radar"

The problem of adaptive target detection for airborne multi-input multi-output (MIMO) radars with space-time receivers in the presence of Gaussian interference (including clutter and noise) is studied. Previous work has assumed the interference covariance matrix to be known. The case with unknown covariance matrix is investigated here. By exploiting the low rank property of clutter subspace, generalised likelihood ratio test detector and adaptive matched filter detector with diagonal loading are suggested to improve the detection performance of MIMO radars in limited secondary data case. The closed-form detection probabilities and false alarm probabilities of the two proposed detectors are derived and numerically evaluated. Theoretical analysis and numerical results show the advantages of the proposed detectors. [J175]

"ISAR imaging of manoeuvring targets with the range instantaneous chirp rate technique"

The conventional range instantaneous Doppler (RID) algorithm is a well accepted inverse synthetic aperture radar (ISAR) imaging method for manoeuvring targets. In the RID imaging, the cross-range resolution depends on the instantaneous Doppler of scatterers at the imaging instant. For a high manoeuvring target, the instantaneous Doppler of scatterers may be small at some imaging instants and the satisfactory RID images may not be obtained. On the other hand, a large instantaneous chirp rate is often present for the same scatterer at the same instant for RID imaging. In order to obtain some additional information of a manoeuvring target, a novel ISAR imaging approach, referred to as the range instantaneous chirp (RIC), is proposed based on instantaneous chirp rate of scatterer to provide cross-range resolution. Using the proposed imaging algorithm, with the same received data of RID, a RIC image is generated at the same instant with a different `view`. Therefore the RIC image may provide some additional information that is not shown in the RID image. With both the RIC and RID images, a better target recognition and identification can be achieved for high-manoeuvring targets. The proposed RIC algorithm is verified by raw radar data. [J176]

"Waveform Design for Multistatic Radar Detection"

We derive the optimal Neyman-Pearson (NP) detector and its performance, and then present a methodology for the design of the transmit signal for a multistatic radar receiver. The detector assumes a Swerling I extended target model as well as signal-dependent noise, i.e., clutter. It is shown that the NP detection performance does not immediately lead to an obvious signal design criterion so that as an alternative, a divergence criterion is proposed for signal design. A simple method for maximizing the divergence, termed the maximum marginal allocation algorithm, is presented and is guaranteed to find the global maximum. The overall approach is a generalization of previous work that determined the optimal detector and transmit signal for a monostatic radar. [J177]

"A Model for Generating Synthetic VHF SAR Forest Clutter Images"

We propose a model for generating low-frequency synthetic aperture radar (SAR) clutter that relates model parameters to physical characteristics of the scene. The model includes both distributed scattering and large-amplitude discrete clutter responses. The model also incorporates the SAR imaging process, which introduces correlation among image pixels. The model may be used to generate synthetic clutter for a range of environmental operating conditions for use in target detection performance evaluation of the radar and automatic

target detection/recognition algorithms. We derive a statistical representation of the proposed clutter model's pixel amplitudes and compare with measured data from the CARABAS-II SAR. Simulated clutter images capture the structure and amplitude responses seen in the measured data. A statistical analysis shows an order of magnitude improvement in model fit error compared with standard maximum-likelihood (ML) density fitting methods. [J178]

"Sensing an intersection using a network of laser scanners and video cameras"

In this research, a novel system for monitoring an intersection using a network of single-row laser range scanners (subsequently abbreviated as "laser scanner") and video cameras is proposed. Laser scanners are set on the road side to profile an intersection horizontally from different viewpoints. The contour points of moving objects are captured at a certain horizontal plane with a high scanning rate (e.g., 37 Hz). A laser-based processing algorithm is developed, thus the moving objects entered the intersection are detected and tracked to estimate their state parameters, such as: location, speed, and direction at each time instance. In addition, laser data and processing results are forwarded to an associated video camera, so that a visualization as well as fusion-based processing can be achieved. An experiment in central Beijing is presented, demonstrating that a large quantity of physical dimension and detailed traffic data can be obtained through such a system. [J179]

"Tracking of Divers using a Probabilistic Data Association Filter with a Bubble Model"

Detection and tracking of divers have become an important factor in port protection against underwater intruders. A problem arises from divers with open breathing systems because detections of the air bubbles they produce can mislead the tracking filter and sometimes result in a lost track. In this paper a probabilistic model is developed which reflects the probability that a false measurement originates from the bubbles. The novel contribution of this paper is the integration of this model in the probabilistic data association filter (PDAF) to improve the track continuity. The bubble detections may also cause confusion in the track initiation. To prevent this problem, a clustering method is proposed based on morphological operators which allows tracks to be initialized based on two-point differencing of the cluster centroids from succeeding scans. This morphological clustering method is included in a cell averaging constant false alarm rate (CA-CFAR) detector in such a way that both the point detections and their corresponding clusters can be fed to the tracking filter. These techniques are implemented and applied to real data of two divers, one with an open breathing system and the other with a closed breathing system, operating simultaneously in a coastal area. The real data were recorded from an active 90 kHz narrowband multibeam imaging sonar. [J180]

"Co-channel interference suppression by time and range adaptive processing in bistatic high-frequency surface wave synthesis impulse and aperture radar"

Intense co-channel interference (CCI) severely depresses the target detection in high-frequency surface wave radar (HFSWR). In this study, the CCI cancellation algorithm by time and range adaptive processing is proposed for a novel HFSWR-bistatic HF surface wave synthesis impulse and aperture radar. With the real data, the interference is firstly modelled and then its features are investigated. The analyses show that the same interference prevails over a few but different bins through different channels, whereas the echoes are relatively weak and exist in all bins; in range domain, however, the interference takes over all the bins including positive and negative bins and will spread over the same and considerable Doppler area through different channels, whereas the echoes appear only in partially positive bins. On the basis of the features, the interference covariance matrix can be obtained by selecting the samples whose average power is much higher than that of the others in time domain and in range domain; the samples from either or both of beyond the detectable bins and negative bins can be selected for training. The interference can be cancelled by projecting the polluted data into the orthogonal subspace, constructing the projecting matrix with the eigenvectors associated with large eigenvalues of the covariance matrix. Finally, the segment handling and samples requirement are also discussed for reducing the computation burden. The experimental results are provided to demonstrate the performance of the method. [J181]

"Signal-to-noise ratio threshold effect in track before detect"

Track before detect (TBD) refers to simultaneous detection and tracking using unthresholded sensor responses over time. The motivation for TBD is its capacity to deal with low signal-to-noise ratio (SNR) targets. Previously, the achievable error for TBD has been established using Crameacuteracute-Rao analysis. Although computationally simple the Crameacuteracute-Rao bound is not useful at low SNR as it does not predict the threshold effect. A more accurate notion of the achievable performance at low SNRs is provided by the computationally more complicated Barankin bound. The computational complexity of the Barankin bound arises from the need to optimise over a number of test points, with the tightness of bound increasing with the number

of test points. An approximation to the Barankin bound is proposed which permits the use of multiple test points with reasonable computational expense. The improvements in threshold SNR prediction offered by the proposed bound are demonstrated in numerical examples. [J182]

"The probabilistic data association filter"

The measurement selection for updating the state estimate of a target's track, known as data association, is essential for good performance in the presence of spurious measurements or clutter. A classification of tracking and data association approaches has been presented, as a pure MMSE approach, which amounts to a soft decision, and single best-hypothesis approach, which amounts to a hard decision. It has been shown that the optimal state estimator in the presence of data association uncertainty consists of the computation of the conditional pdf of the state x(k) given all information available at time k, namely, the prior information about the initial state, the intervening known inputs, and the sets of measurements through time k. It has also been pointed out that if the exact conditional pdf, which is a mixture, is available, then its recursion requires only the probabilities of the most recent association events. The conditions under which this result holds, namely whiteness of the noise, detection, and clutter processes, were presented. The PDAF and JPDAF algorithms, which carry out data association and state estimation in clutter, have been described. A simple example was given to illustrate how the clutter and occasional missed detections can lead to track loss for a standard tracking filter, and how PDAF can keep the target in track under such circumstances. By using the Monte Carlo in a simulated based surveillance as an exampled shown. The numerous applications of the PDAF/JPDAF illustrated in "Real-World Applications of PDAF and JPDAF" show the potential pitfalls of using sophisticated algorithms for tracking in difficult environments as well as how to overcome them. The effect of finite sensor resolution can be a more severe problem than the data association and deserves special attention. [J183]

"Microwave Radar-Based Breast Cancer Detection: Imaging in Inhomogeneous Breast Phantoms"

This letter presents, for the first time, experimental work on microwave breast cancer imaging using inhomogeneous breast phantoms. A recently designed 31-antenna array is used in imaging experiments. The imaging system operates in the full ultrawideband frequency range, between 3 and 10 GHz. To verify imaging performance of our system, new breast phantoms with inhomogeneous interior were developed. For three different breast phantoms presented in this work, the contrast between spherical phantom tumors and surrounding materials ranges from 5:1 to 1.6:1. Our results show that the biggest challenge in radar microwave imaging is the inhomogeneity of the volume being sensed, and not the contrast itself. In addition to experimental results, we also present the new image formation algorithm, which is a modified version of the delay-and-sum (DAS) algorithm. The new algorithm makes use of a new weighting factor, the coherence factor. The new algorithm is effective in reducing clutter, providing better images. For the most demanding imaging example presented herein, the new algorithm improves the peak clutter-to-target energy ratio by 3.1 dB. [J184]

"Effect of antenna dimensions on the antenna footprint in ground penetrating radar applications"

Ground penetrating radar (GPR) surveys show that antenna characteristic is strongly influenced by soil conditions. The footprint of the antenna is an important parameter for a good detection result. Various conditions of soil in which a target is buried may change the footprint of the antenna. An antenna with capability to control its footprint is needed in GPR applications. In this study, the authors investigate several ultra-wideband (UWB) antennas with different dimensions to study the effect of antenna dimension on their footprint. Simulation and experiments show that large (small) antenna dimensions result in a large (small) antenna footprint when the observation is located in the near-field region. When the observation is located in the far-field, the footprint of the antenna becomes large (small) if the dimensions of the antenna are small (large). Thus, the size of the antenna footprint can be adjusted by varying the antenna dimension. It is applied in this work to develop a new method for controlling the antenna footprint to deal with varying soil condition. Measurements have been carried out to validate this concept. [J185]

"Formation of Ambiguity Functions with Frequency-Separated Golay Coded Pulses"

Returns from radar transmitters are filtered to concentrate target power and improve signal-to-noise ratio (SNR) prior to detection. An ideal "thumbtack" filter response in delay and Doppler is impossible to achieve. In practice target power is distributed over the delay-Doppler plane either in a broad mainlobe or in sidelobes with inherent limitations given by Moyal's identity. Many authors have considered the use of pairs or sets of complementary codes as the basis of radar waveforms. The set of filter outputs when combined reduces output to a thumbtack shape, at least on part of the delay-Doppler domain. This paper shows firstly that a pair of complementary codes cannot be multiplexed in frequency because of a phase difference which depends on the unknown range to any targets, thereby preventing the individual filter outputs from being combined coherently. It is shown that the

phase term can be removed by multiplexing the second code twice, at offsets equally spaced above and below carrier, enabling the recovery of the sum of squared ambiguity functions. A proposed modification to the Golay pair results in codes whose squared ambiguities cancel upon addition. This enables complementary behaviour to be achieved by codes which are separated in frequency at the expense of introducing cross-terms when multiple closely separated returns are present. The modified Golay codes are shown to successfully reveal low power returns which are hidden in sidelobes when other waveforms are used. [J186]

"Multisensor Track Management for Targets with Fluctuating SNR"

In active sonar tracking applications, targets frequently undergo fading in which the target's detection probability can shift suddenly between high and low values. This characteristic is a function of the undersea environment. Using a multisensor active sonar problem, we examine the performance of track management (confirmation and termination) routines where target detections are based on an underlying hidden Markov model (HMM) with high and low detection states. Rule-based track confirmation tests are compared including M/N rules and rules that differentiate the measurements by receiver source (M/N from at least C sensors), each of which is suboptimal compared with a fixed-length likelihood ratio test. We show that significant performance improvements (to near-optimal) can be obtained using a composite track confirmation test that combines two or three such rules in a logical OR operation. Track termination tests are next compared, and it is shown that a Bayesian sequential test (the Shiryaev test) yields dramatic performance improvements over a K/N track termination rule and the Page test. The model-based results are validated using simulations of a multisensor tracking scenario. The results of this paper are informed by a multisensor sonar application. However, targets may fade in and out of view in other modalities as well, due to aspect-dependent radar cross-section or occlusion. As such, our suggestions for improved HMM-modulated SNR track initiation and termination apply to multisensor radar target tracking as well. [J187]

"Idealized Radar GMTI Detection with Space-Time Processing"

A new and somewhat different approach is utilized here for determining an upper-bound on ground moving target indication (GMTI) radar performance with two-dimensional space-time processing. An idealized clutter model and other simplifying assumptions are employed. It is shown that the elements of the clutter covariance matrix can be obtained from cross-correlations of the convolution of transmit and receive aperture functions at different times and locations. This feature could provide improved physical insight on how the aperture illumination functions influence performance. Results can be expressed in terms of dimensionless parameters which do not explicitly require the specification of antenna length, radar frequency, platform speed or even target range. Some representative simulation results for idealized and conventional processing are presented and compared. [J188]

"Dual-Frequency Radars for Target Localization in Urban Setting"

A simple radar system, based on trilateration and range estimation from three independent dual-frequency radar units, is proposed for moving target localization in urban sensing applications. The proposed scheme utilizes the bounds imposed by the nature of indoor sensing on both target location and motion. [J189]

"A Generalized Approach to Multiresolution Complex SAR Signal Processing"

Multiresolution synthetic aperture radar (SAR) image formation has been proven to be beneficial in a variety of applications such as improved imaging and target detection as well as speckle reduction. SAR signal processing traditionally carried out in the Fourier domain has inherent limitations in the context of image formation at hierarchical scales. We present a generalized approach to the formation of multiresolution SAR images using biorthogonal shift-invariant discrete wavelet transform (SIDWT) in both range and azimuth directions. Particularly in azimuth, the inherent subband decomposition property of wavelet packet transform is introduced to produce multiscale complex matched filtering without involving any approximations. This generalized approach also includes the formulation of multilook processing within the discrete wavelet transform (DWT) paradigm. The efficiency of the algorithm in parallel form of execution to generate hierarchical scale SAR images is shown. Analytical results and sample imagery of diffuse backscatter are presented to validate the method. [J190]

"Spatial Filtering for Wall-Clutter Mitigation in Through-the-Wall Radar Imaging"

Radio-frequency imaging of targets behind walls is of value in several civilian and defense applications. Wall reflections are often stronger than target reflections, and they tend to persist over a long duration of time. Therefore, weak and close by targets behind walls become obscured and invisible in the image. In this paper, we apply spatial filters across the antenna array to remove, or at least significantly mitigate, the spatial zero-frequency and low-frequency components which correspond to wall reflections. Unmasking the behind-the-wall

targets via the application of spatial filters recognizes the fact that the wall electromagnetic (EM) responses do not significantly differ when viewed by the different antennas along the axis of a real or synthesized array aperture which is parallel to the wall. The proposed approach is tested with experimental data using solid wall, multilayered wall, and cinder block wall. It is shown that the wall reflections can be effectively reduced by spatial preprocessing prior to beamforming, producing similar imaging results to those achieved when a background scene without the target is available. [J191]

"A Multistage Processing Algorithm for Disturbance Removal and Target Detection in Passive Bistatic Radar"

The paper examines the problem of cancellation of direct signal, multipath and clutter echoes in passive bistatic radar (PBR). This problem is exacerbated as the transmitted waveform is not under control of the radar designer and the sidelobes of the ambiguity function can mask targets including those displaced in either (or both) range and Doppler from the disturbance. A novel multistage approach is developed for disturbance cancellation and target detection based on projections of the received signal in a subspace orthogonal to both the disturbance and previously detected targets. The resulting algorithm is shown to be effective against typical simulated scenarios with a limited number of stages, and a version with computational savings is also introduced. Finally its effectiveness is demonstrated with the application to real data acquired with an experimental VHF PBR system. [J192]

"Airborne along-track interferometry for GMTI"

Synthetic Aperture Radar (SAR) Along-Track Interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (-10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. Herein, we describe preliminary results from an ATI GMTI experiment. The SAR data described were collected by the dual-frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pick-up truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J193]

"Flower classification by bats: Radar comparisons"

In recent years, with the development of high-range resolution radars, the desire to identify targets under all weather and clutter conditions has become of great importance. This is an activity carried out with great success by echo-locating mammals such as nectar feeding bats that are able to detect and select flowers of bat-pollinated plants, even in a dense clutter environment. Herein, data consisting of acoustically-generated high-range resolution profiles of four bat-pollinated flower heads are analysed. Multi-perspective classification performance is assessed and compared with the radar case. There are close parallels that suggest lessons can be learnt from nature. [J194]

"Doppler Compensation & Single Pulse Imaging using Adaptive Pulse Compression"

The effects of target Doppler are addressed in relation to adaptive receive processing for radar pulse compression. To correct for Doppler-induced filter mismatch over a single pulse, the Doppler-compensated adaptive pulse compression (DC-APC) algorithm is presented whereby the respective Doppler shifts for large target returns are jointly estimated with the illuminated range profile and subsequently incorporated into the original APC adaptive receive filter formulation. As a result, the Doppler-mismatch-induced range sidelobes can be suppressed thereby regaining a significant portion of the sensitivity improvement that is possible when applying adaptive pulse compression (APC) without the existence of significant Doppler mismatch. In contrast, instead of compensating for Doppler mismatch, the single pulse imaging (SPI) algorithm generalizes the APC formulation for a bank of Doppler-shifted matched filters thereby producing a sidelobe-suppressed range-Doppler image from the return signal of a single radar pulse which is applicable for targets with substantial variation in Doppler. Both techniques are based on the recently proposed APC algorithm and its generalization, the multistatic adaptive pulse compression (MAPC) algorithm, which have been shown to be effective for the suppression of pulse compression range sidelobes thus dramatically increasing the sensitivity of pulse

compression radar. [J195]

"Adaptive Radar Detection in Doubly Nonstationary Autoregressive Doppler Spread Clutter"

The problem of adaptive radar detection in clutter which is nonstationary both in slow and fast time is addressed. Nonstationarity within a coherent processing interval (CPI) often precludes target detection because of the masking induced by Doppler spreading of the clutter. Across range bins (i.e., fast time), nonstationarity severely limits the amount of training data available to estimate the noise covariance matrix required for adaptive detection. Such difficult clutter conditions are not uncommon in complex multipath propagation conditions where path lengths can change abruptly in dynamic scenarios. To mitigate nonstationary Doppler spread clutter, an approximation to the generalized likelihood ratio test (GLRT) detector is presented wherein the CPI from the hypothesized target range is used for both clutter estimation and target detection. To overcome the lack of training data, a modified time-varying autoregressive (TVAR) model is assumed for the clutter return. In particular, maximum likelihood (ML) estimates of the TVAR parameters, computed from a single snapshot of data, are used in a GLRT for detecting stationary targets in possibly abruptly nonstationary clutter. The GLRT is compared with three alternative methods including a conceptually simpler ad hoc approach based on extrapolation of quasi-stationary data segments. Detection performance is assessed using simulated targets in both synthetically-generated and real radar clutter. Results suggest the proposed GLRT with TVAR clutter modeling can provide between 5-8 dB improvement in signal-to-clutter plus noise ratio (SCNR) when compared with the conventional methods. [J196]

"Detection and Localization of Multiple Unresolved Extended Targets via Monopulse Radar Signal Processing"

When the size of targets is comparable to the range resolution of monopulse radars, these targets should be considered as extended rather than point targets. If several closely-spaced targets fall within the same radar beam and between adjacent matched filter samples in range, the full monopulse information from all of these samples can and should be used to resolve these targets, i.e., estimate the number of targets and their respective angles-of-arrival and ranges. To detect and localize multiple unresolved extended targets, we establish a model for monopulse radar returns from extended objects, and present a maximum likelihood estimator (MLE) to localize the targets. Rissanen's minimum description length (MDL) criterion will be used to decide the number of existing extended objects. We also derive the upper limit on the number of targets and their scattering centers that can be resolved, and we provide necessary conditions for these targets to be uniquely identified. We compare the new extended target monopulse processing scheme with previously developed point-target monopulse techniques in the simulations. [J197]

"A Note on Bounds for Target Tracking with p d >1"

Recently several new results for Cramer-Rao lower bounds (CRLBs) in dynamical systems have been developed. Several different approaches and approximations have been presented. For the general case of target tracking with a detection probability smaller than one and possibly in the presence of false measurements, two main approaches have been presented. The first approach is the information reduction factor (IRF) approach. The second approach is the enumeration (ENUM) approach, also referred to as the conditioning approach. It has been found that the ENUM approach leads to a strictly larger covariance matrix than the IRF approach, however, still providing a lower bound on the attainable error covariance. Thus, the ENUM approach provides a strictly tighter bound on the attainable performance. It has been conjectured that these bounds converge to one another in the limit or equivalently after an initial transition stage. We demonstrate, using some recent results from the modified Riccati equation (MRE) and by means of counter examples, that this conjecture does not hold true in general. We also demonstrate that the conjecture does hold true in the special case of deterministic target motion, or equivalently in the absence of process noise. Furthermore, we show that the detection probability has an influence on the limiting behaviors of the bounds. Moreover, we show that the MRE approximation provides a very good and computationally efficient approximation of the ENUM bound. The various results are illustrated by means of representative examples. [J198]

"Multi-Target/Multi-Sensor Tracking using Only Range and Doppler Measurements"

A new approach is described for combining range and Doppler data from multiple radar platforms to perform multi-target detection and tracking. In particular, azimuthal measurements are assumed to be either coarse or unavailable, so that multiple sensors are required to triangulate target tracks using range and Doppler measurements only. Increasing the number of sensors can cause data association by conventional means to become impractical due to combinatorial complexity, i.e., an exponential increase in the number of mappings between signatures and target models. When the azimuthal resolution is coarse, this problem will be

exacerbated by the resulting overlap between signatures from multiple targets and clutter. In the new approach, the data association is performed probabilistically, using a variation of expectation-maximization (EM). Combinatorial complexity is avoided by performing an efficient optimization in the space of all target tracks and mappings between tracks and data. The full, multi-sensor, version of the algorithm is tested on simulated data. The results demonstrate that accurate tracks can be estimated by exploiting spatial diversity in the sensor locations. Also, as a proof-of-concept, a simplified, single-sensor range-only version of the algorithm is tested on experimental radar data acquired with a stretch radar receiver. These results are promising, and demonstrate robustness in the presence of nonhomogeneous clutter. [J199]

"High-Resolution 3-D Imaging Algorithm With an Envelope of Modified Spheres for UWB Through-the-Wall Radars"

Through-the-wall imaging techniques with ultrawideband (UWB) radars are promising candidates for non-destructive testing and reliable human detection, especially in disaster areas, where victims are buried under collapsed walls. These applications require high-resolution target imaging to identify the object shape, such as a human body. We have already proposed a high-quality 3-dimensional (3-D) imaging algorithm in the form of envelope that is aimed at near field sensing for non-contact measurement or target identification for robots. Envelope achieves real-time accurate 3-D imaging with group mapping from multiple observed ranges to target points, and offers a reliable image even in noisy situations. However, this method does not maintain its quality for through-the-wall imaging because an observed range shift due to wall penetration causes a serious distortion in the image. This paper presents a high-resolution 3-D imaging algorithm by modifying the original envelope, and which gives a more accurate object shape behind a wall. Furthermore, to enhance the resolution of the estimated images, this method is combined with a direct waveform compensation method, known as spectrum offset correction. Numerical simulations and an experiment verify that our proposed method achieves high-resolution 3-D imaging for through-the-wall radar applications. [J200]

"Automatic Target Recognition by Means of Polarimetric ISAR Images and Neural Networks"

Inverse synthetic aperture radar (ISAR) images are often used for classifying and recognizing targets. Moreover, the use of fully polarimetric ISAR (Pol-ISAR) images enhances classification capabilities. In this paper, the authors propose a novel automatic target recognition (ATR) technique based on the use of fully Pol-ISAR images and neural networks (NNs). In order to reduce the amount of data processed by the classifier, the brightest scattering centers are first extracted by means of the Pol-CLEAN technique, and then, their scattering matrices are decomposed using Cameron's decomposition. A classifier based on the use of multilayer perceptron NN that makes use of the features extracted from the Pol-ISAR images is then implemented. A proof-of-concept test is performed on real data acquired during a controlled experiment in an anechoic chamber. [J201]

"Maritime border control multisensor system"

This focuses on the classification task performed into a multi-sensor system for the coastal surveillance. The system is composed of two platforms of sensors: a land-based platform equipped with a land based radar, an Automatic Identification System (AIS) and an infrared camera (IR); an airborne platform carrying an airborne radar that can operate in a spotlight Synthetic Aperture Radar (SAR) mode, a video camera, and a second IR camera. The tasks performed by the system are the detection, tracking, identification, and classification of multiple targets, the evaluation of their threat level, and the selection of an intervention on them. The classification algorithm implemented inside the system exploits an analytical approach based on the confusion matrix (CM) of the imaging sensors that belong to the system. Some measures of effectiveness (MoE) of the system are evaluated, considering both cases where an ideal error-free classification process and a non-ideal classification process are performed. [J202]

"Hypothesis Testing and Decision Making: Constant-False-Alarm-Rate Detection"

Detection is the first task in establishing a communication link, or tracking a target with a radar system. This is a decision-making problem, and it is performed through a hypothesis-testing procedure. Hypothesis testing is nothing but constant-false-alarm-rate (CFAR) detection. These issues are reviewed, and simple MATLABtrade codes are presented. [J203]

"Adaptive beamforming for high-frequency over-the-horizon passive radar"

Target detection and tracking systems using emitters of opportunity have received significant interest recently, especially those which exploit VHF and UHF broadcasts as signal sources in so-called passive radar systems. Here, the authors discuss an experimental system in the high-frequency (HF) band, where due to long-distance ionospheric propagation of radio waves in the 3-30-MHz spectrum, the illuminator may be located well beyond

the line-of-sight. In this study, live data was recorded by a high dynamic range multi-channel digital receiver connected to a two-dimensional (L-shaped) antenna array, and signals from an uncooperative HF over-the-horizon (OTH) radar transmitter have been captured and analysed. As a preliminary step towards the development of a general HF-OTH passive radar system, the scope of this work is to compare the performance of conventional and adaptive spatial processing techniques in terms of their ability to cancel direct-wave interference and protect useful signal echoes to detect a small cooperative aircraft target. In particular, an alternative adaptive beamforming method specifically tailored to this application is proposed, and its practical performance is compared with classical and standard adaptive beamforming approaches. GPS data measured on-board the cooperative aircraft provided accurate ground truth of the flight path, enabling target profiles in bi-static range, Doppler frequency and direction-of-arrival (azimuth/elevation) to be calculated as a function of time. This information permitted the different processing schemes to be evaluated with a high degree of confidence. The experimental system and live data analysed are exclusively from the HF Radar program of the Defence Science and Technology Organisation (DSTO), Australia. [J204]

"Position Correction Using Echoes From a Navigation Fix for Synthetic Aperture Sonar Imaging"

In synthetic aperture sonar (SAS), the platform position must be known sufficiently accurately for signals to be added coherently along the synthetic aperture. Often, the onboard navigation system is insufficiently accurate by itself, so corrections are needed. A well-known method is the displaced phase center antenna (DPCA) procedure for correcting platform position using seabed echoes. DPCA methods have the advantage of insensitivity to changing interference patterns, moving specular reflection, and changing occlusion, with aspect. However, when seabed echoes are unusable, either because they are too weak, or because they are corrupted by multipath, the seabed DCPA method may fail. Therefore, we present an alternative DPCA method using sonar echoes from a suitable navigation fix, based on an object detected after standard beamforming. In our proposed system, look angle is obtained by tracking the centroid of the rectified image of the fix object. When the standard DPCA correction equations are modified for a fixed reflector, it turns out that they provide incremental range and look-angle errors, precisely the values required when the target itself is used as the navigation fix. Moreover, the values obtained are then self-compensating for errors in estimating seabed depth or forward motion of the platform. The navigation fix is selected by bracketing in range, and beamforming overlapping subsets of the receiver array. In this paper, we present experimental results at transmitter frequencies of 25 and 100 kHz where our method enabled well-focused SAS images to be generated with little recourse to other navigation information. Hence, SAS can be carried out, even when a sophisticated inertial navigation system (INS) is not available. [J205]

"One- and Two-Stage Tunable Receivers*"

We propose and assess a CFAR detector that can adjust its ldquodirectivityrdquo through a real scalar parameter. It relies on the usual assumption that a set of homogeneous training data is available and encompasses as special cases the well-known Kelly's GLRT and the recently introduced W-ABORT detector. More important, it can be tuned in order to control the level to which sidelobe signals are rejected. Such functionality is particularly important to contain the number of false alarms in presence of mismatched signals. We also consider a parametric detector which resorts to a diagonally loaded sample covariance matrix commonly adopted to take advantage of the presence of strong interferers. The performance assessment of such detector has shown that it can significantly outperform Kelly's GLRT in terms of prediction probabilities for matched signals and in terms of selectivity, but it is not strictly CFAR. We also propose to use the CFAR parametric detector as second stage of a two-stage tunable detector and show that such a two-stage detector can outperform already proposed tunable receivers in terms of selectivity. The analysis of the detectors is conducted assuming a homogeneous Gaussian environment; with reference to this scenario and to the CFAR detectors we derive analytical expressions for the probability of false alarm and the probability of detection for both matched and mismatched signals. [J206]

"Subsurface Target Recognition Based on Transient Electromagnetic Scattering"

The E-pulse technique which typically uses transient scattering data from radar targets in free space is one of the most well known resonance based radar target recognition schemes on which target recognition is based. In this communication, the possibility of subsurface target recognition based on the E-pulse technique is investigated using numerical examples of a metallic hip prosthesis embedded in models of realistic human tissue. [J207]

"Range-Spread Target Detection Based on Cross Time-Frequency Distribution Features of Two Adjacent Received Signals"

High resolution radars (HRRs) transmit a wideband signal to achieve a high range resolution. A target is considered as composed of multiple scatterers, which occupy or spread in multiple radar range cells with several scatterers in each cell. Therefore, the reflection of a target spreads in multiple range cells in the received signal, which contains more information of target than that obtained from low resolution radars. The target in high resolution radar systems is a range-spread target. The range-spreading or echo features of target are utilized for target detection and identification. The echoes of target are convolutions of transmitted signals with target range-scattering functions dependent on the gesture of target to the line of radar sight. A single echo is used in the conventional detection. It is difficult for target detection and identification in low signal-to-noise ratio (SNR) condition. In this paper, we propose a new range-spread target detection scheme exploiting the image features of cross time-frequency distribution (TFD) of a pair of adjacent received signals. After dechirping, the received signal reflected from target consists of multiple sinusoidal components due to its multiple scatterers when a linear frequency modulated (LFM) signal is transmitted from radar. Some regular image patterns or features of target appear in the cross TFD of two adjacent received signals, while the cross TFD of two independent Gaussian noises does not show such patterns. The cross TFD features are exploited in the proposed scheme. Three steps are composed in the proposed scheme. Firstly, a cross smoothed-pseudo Wigner-Ville distribution (CSPWVD) is made for two adjacent received signals to generate a two-dimensional (2-D) TF image. Then, some regular geometric patterns are detected and extracted from the image. At last, two features of the extracted geometric patterns are jointly utilized to detect target. The proposed algorithm is verified by using raw radar data.--It outperforms the conventional detection methods. [J208]

"A Coherent Model of Forest Propagation- Application to Detection and Localization of Targets Using the DORT Method"

We study the propagation of electromagnetic fields in forest media in a frequency band between 100 and 300 MHz. We develop an exact coherent model in order to compute the electromagnetic field of a received wave after multiple scattering from the elements of the medium, in and outside the forest. We propose simplifications for the model of the forest and approximations for the electromagnetic method to reduce the computing time. We use and simulate a DORT based method to detect and locate a hidden target in the medium. We develop this method to adapt it to a real configuration and we apply it to measurements in anechoic chamber. [J209]

"The Doppler wheel revisited"

Millimeter-wave radar returns from cylindrical targets, such as artillery shells or helicopter rotor shafts, can be experimentally evaluated with the classic Doppler wheel. This also is a simple autonomous calibration tool for radar development and field testing. However, the less-apparent wheel-return characteristics found in practice must be taken into account. Doppler spectra for speeds up to 3000 rpm measured with a Ka-band radar against a 100 mm-diameter flat cylinder are presented, showing a frequency range from 200 to 4200 Hz. Meaningful signal amplitudes were measured up to the rim-speed Doppler. Frequency components beyond the range defined by the local radial velocity of the illuminated portion were observed up to 2500 Hz. Miniature surface deformations increased the amplitude of the highest frequencies by 5-10 dB. Simulated spectra agreed with measurement results at the higher Doppler frequencies, but a model based on Physical and Geometrical Optics failed to explain the low-frequency components. [J210]

"Constant false-alarm rate algorithm based on test cell information"

A new constant false-alarm rate (CFAR) detection algorithm, designated as switching CFAR (S-CFAR), is proposed and analysed. The S-CFAR algorithm selects CFAR reference samples using the magnitude of the sample in the cell under test, which is an information that has not been exploited in any other existing CFAR detectors. S-CFAR closed-form analysis is presented, and comparisons with other representative CFAR algorithms are given. An S-CFAR detector can be tuned such that it has a small CFAR loss when operating on a homogeneous background while achieving improved robustness in the presence of interfering targets and clutter power transition. The S-CFAR detector is also simple to design and implement since no sample ordering is required. [J211]

"Estimating building dimensions from synthetic aperture radar image sequences"

The problem of automatically extracting building dimensions from synthetic aperture radar (SAR) image sequences of urban scenes is considered. An algorithm based on the delineation of shadows using active contours constrained by a simple wire-frame building model has been developed and demonstrated using SAR imagery of a village on Salisbury plain. The core of the algorithm is a novel technique for target delineation involving multiple active contours evolving simultaneously. In particular, a technique referred to as multiple hypothesis delineation, in which contours can be in several states simultaneously, is developed and shown to

lead to considerable improvement in convergence time and delineation accuracy when used to delineate multiple targets in close proximity. The technique is applied to the automatic estimation of building dimensions by delineation of shadows in a sequence of SAR images of an urban scene. The estimation of building dimensions is automatic; user interaction is limited identifying a building of interest and a region of background clutter close to the building. Results are presented for six different buildings, in each case two SAR images were used in the estimation process separated in illumination angle by either 28deg or 90deg. The estimates of building dimensions are compared with the actual building dimensions obtained from architectural drawings. The algorithm was found to perform robustly and provide reasonably accurate estimates of the building dimensions, typically within ~10% of the true values. [J212]

"Radar Detection and Classification of Jamming Signals Belonging to a Cone Class"

This paper considers the problem of detecting and classifying a radar target signal and a jamming signal produced by a deception electronic counter measure (ECM) system based on a digital radio frequency memory (DRFM) device. The disturbance is modeled as a complex correlated Gaussian process. The jamming is modeled as a signal belonging to a cone whose axis is the true target signal. Two different approaches are analyzed, based on the adaptive coherent estimator (ACE) and on the generalized likelihood ratio test (GLRT), yielding both to a two-block device. The performance of the two detection/classification algorithms are evaluated, analytically, when possible, and by Monte Carlo simulation. [J213]

"Theoretical Performance Analysis of the W-ABORT Detector"

In a recent paper we introduced a modification of the adaptive beaniformer orthogonal rejection test (ABORT) for adaptive detection of signals in unknown noise, by supposing under the null hypothesis the presence of signals orthogonal to the nominal steering vector in the whitened observation space. We will refer to this new receiver as the whitened adaptive beamformer orthogonal rejection test (W-ABORT). Through Monte Carlo simulations this new detector was shown to provide better rejection capabilities of mismatched (e.g., sidelobe) signals than existing ones, like ABORT or the adaptive coherence estimator (ACE), but at the price of a certain loss in terms of detection of matched (i.e., mainlobe) signals. The aim of this paper is to provide a theoretical validation of this fact. We consider both the case of distributed targets and point-like targets. We provide a statistical characterization of the W-ABORT test statistic, under the null hypothesis, and for matched and mismatched signals under the alternative hypothesis. For distributed targets, the probability of false alarm and the probability of detection can only be expressed in terms of multi-dimensional integrals, and are thus very complicated to obtain; in contrast, for point-like targets, such probabilities can be easily calculated by numerical integration techniques. The theoretical expressions derived herein corroborate the simulation results obtained previously. [J214]

"Data-Level Fusion of Multilook Inverse Synthetic Aperture Radar Images"

Although techniques for resolution enhancement in single-aspect radar imaging have made rapid progress in recent years, it does not necessarily imply that such enhanced images will improve target identification or recognition. However, when multiple looks of the same target from different aspects are obtained, the available knowledge increases, allowing more useful target information to be extracted. Physics-based image fusion techniques can be developed by processing the raw data collected from multiple inverse synthetic aperture radar sensors, even if these individual images are at different resolutions. We derive an appropriate data fusion rule to generate a composite image containing enhanced target shape characteristics for improved target recognition. The rule maps multiple data sets collected by multiple radars with different system parameters on to the same spatial-frequency space. The composite image can be reconstructed using the inverse 2-D Fourier transform over the separated multiple integration areas. An algorithm called the Matrix Fourier Transform is proposed to realize such a complicated integral. This algorithm can be regarded as an exact interpolation such that there is no information loss caused by data fusion. The rotation centers need to be carefully selected to properly register the multiple images before performing the fusion. A comparison of the image attribute rating curve between the fused image and the spatially averaged images quantifies the improvement in the detected target features. The technique shows considerable improvement over a simple spatial averaging algorithm and thereby enhances target recognition. [J215]

"An Investigation of Using the Spectral Characteristics From Ground Penetrating Radar for Landmine/Clutter Discrimination"

Ground penetrating radar (GPR)-based discrimination of landmines from clutter is known to be challenging due to the wide variability of possible clutter (e.g., rocks, roots, and general soil heterogeneity). This paper discusses the use of GPR frequency-domain spectral features to improve the detection of weak-scattering plastic mines

and to reduce the number of false alarms resulting from clutter. The motivation for this approach comes from the fact that landmine targets and clutter objects often have different shapes and/or composition, yielding different energy density spectrum (EDS) that may be exploited for their discrimination (this information is also present in time-domain data, but in the frequency domain we can remove a phase if desired and can reveal better spatial characteristics and therefore often achieve greater robustness). This paper first applies the finite-difference time-domain (FDTD) modeling technique to establish the theoretical foundation. The method to generate EDS from GPR measurements is then described. The consistency of the frequency-domain features is examined through two different GPRs that have different spatial sampling rates and frequency bandwidths. Experimental results from several test sites, based on GPR data collected over buried mines and emplaced buried clutter objects, corroborate the theoretical development and the effectiveness of the proposed spectral feature to increase the accuracy of landmine detection and discrimination. [J216]

"Update on radar detection probabilities and their calculation"

In the 1995 paper entitled radardetectionprobabilitiesandtheircalculation, chi-square density functions, normalized with respect to the clutter variance, were used for the clutter density. While mathematically correct, it makes better physical sense to use clutter constant false-alarm rate (CFAR) density functions both there and in the 1999 paper, GeneralizedRadarClutterModel, that are normalized with respect to the receiver noise, as is done with the target models. We update the results of these papers by redoing the relevant equations with these more appropriate clutter density functions. [J217]

"Detection performance loss due to jitter in naval IRST systems"

Infrared search and track (IRST) systems based on 3-D velocity filters are quite sensitive to the random motion that remains after egomotion compensation has occurred (jitter). These systems are designed to detect small targets at long range and they often employ track-before-detect (TBD) strategies to integrate the target signal along consecutive frames. Jitter causes frame misalignment and leads to a reduction of the detection performance. We analyze the effects of jitter on the false alarm and detection probabilities and on the detection range. The analytical expressions here derived are a valuable tool both in the analysis and synthesis of IRST systems based on 3-D velocity filters. [J218]

"Scanning Laser Radar-Based Target Position Designation for Parking Aid System"

Recently, customers have shown a growing interest in parking aid products. A parking aid system consists of target position designation, path planning, and parking guidance by user interface or path tracking by active steering. For target position designation, various sensors and signal processing technologies have been tried. In the case of parallel parking, an ultrasonic sensor-based method plays a dominant role. In the case of perpendicular parking, a graphical user interface (GUI)-based method and a parking slot marking-based method have been commercialized. However, methods developed for the recognition of free parking space between vehicles have their respective drawbacks. This paper proposes a method for the recognition of free parking space between vehicles using scanning laser radar. This proposed method consists of range data preprocessing, corner detection, and target parking position designation. The authors developed a novel corner-detection method consisting of rectangular corner detection and round corner detection. The newly developed corner detection is unaffected by cluster orientation and the range data interval and is robust to noise. Experimental results showed that even in situations where other methods failed, the proposed scanning laser radar-based method could designate target parking position to viable free parking space. The recognition rate was 98.21%, and the average processing time was about 600 ms. Finally, it is argued that the proposed method will eventually be a practical solution because of the decreasing price of scanning laser radar and multiple-function integration strategies. [J219]

"PRISM: An In-Vehicle CPU-Oriented Novel Azimuth Estimation Technique for Electronic-Scan 76-GHz Adaptive-Cruise-Control Radar System"

In this paper, we have developed a novel azimuth- estimation technique for 76-GHz adaptive-cruise-control radar systems. To resolve the rank deficiency of the signal covariance matrix and to decrease the influence of dominant noise components, we used an improved SS technique. To balance computational cost with azimuth resolution for in-vehicle implementation, we introduced a projection matrix kernel, which formally is similar to that of beamforming (BF) and semantically similar to that of the propagator method. Our technique is called the PRopagator method based on an improved spatial-smoothing matrix (PRISM). Incorrectly estimating the number of targets causes the conventional BF, subspace-based (SB), or maximum- likelihood methods to produce many false spectrum peaks on the relative azimuth-to-distance plane. We omitted the process of estimating the number of targets, which requires high computational power, because our projection matrix kernel strongly

suppresses these false peaks. We conducted numerical experiments using an electronic-scan radar system to examine the performance of PRISM. Compared to conventional SB methods, PRISM requires SNRs that are 2-3 dB higher but has competitive azimuth resolution at a centesimal fraction of the computational cost. [J220]

"Quantifying Bird Migration by a High-Resolution Weather Radar"

We propose a bird detection and count algorithm designed to work with radar maps of plan-position-indicator type. The spatial arrangement of birds is modeled according to the Poisson distribution. It is possible to handle a nonuniform target distribution both on the vertical and horizontal planes. The method is applied to measurements carried out by an S-band Doppler weather radar located on the south side of the Alps. Quantitative estimates are given for the distribution of bird volume density with height, the cumulative density (integrated over height), and, finally, the daily migration traffic rate of nocturnal migrants over an area of about 2000 km2. [J221]

"Sequential Along-Track Integration for Early Detection of Moving Targets"

This paper concerns the joint multiframe sequential target detection and track estimation in early-warning radar surveillance systems. The rationale for applying sequential procedures in such a scenario is that they promise a sensitivity increase of the sensor or, alternatively, a reduction in the time needed to take a decision. Unlike previous works on sequential radar detection, the attention is not restricted to stationary targets, namely position changes during the illumination period are allowed. Starting from previous sequential rules, different truncated sequential strategies are proposed and assessed: they are aimed at orienting the sensor resources towards either the detection or the track estimation or the position estimation. Bounds on the performances of the proposed procedures in terms of the system parameters are derived and computational complexity is examined. Also, numerical experiments are provided to elicit the interplay between sensor-target parameters and system performances, and to quantify the gain with respect to other fixed-sample-size procedures. [J222]

"Atomic decomposition for radar applications"

In this paper, we explore the promising capabilities of atomic decomposition (AD) for radar-related applications from a practical point of view. Some enhancements and new approaches are proposed herein, and their implementations are fully detailed. We apply the AD algorithms in two different environments, for signal detection where high sensitivity is the main requirement, and for inverse synthetic aperture radar (ISAR) imaging where focused images, target feature extraction, and computational burden are the fundamental concerns. [J223]

"Modified difference change detector for small targets in SAR imagery"

One of the most straightforward techniques for detecting changes in an image involves forming the difference between a test image and a reference image. Unfortunately, such a technique can give rise to a large number of false alarms due to the statistical variability of the underlying pixel values, as has been well established within the radar community over the years. One method for dealing with this large number of false alarms involves forming the ratio, rather than the difference, of two synthetic aperture radar (SAR) images. We introduce a modified version of the standard differencing technique to overcome problems associated with pixel value variability. The new (modified) differencing approach utilizes assumptions about the statistics of the image background and the object being sought (target) to reduce the number of false alarms due to highly variable background (clutter) regions, and it includes the standard ratio test as a special case. In fact, we find that the modified difference approach can also be viewed as a modified version of the ratio test with a threshold that varies as a function of the background clutter radar cross section (RCS). We also present an abridged, albeit suboptimal, version of this approach that eliminates assumptions regarding the target's probability distribution, and we analyze both of the approaches. We then compare these results with those obtained with a standard ratio test, and illustrate how the modified difference test reduces to the ratio test under certain operating conditions. The abridged version of the modified approach is applied to high resolution synthetic aperture radar imagery and compared with results obtained with the classical differencing technique, and following this, the modified difference technique is compared with the standard ratio test. Results suggest that under appropriate conditions the abridged, modified technique can successfully detect changes without the need for any image segmentation. [J224]

"MIMO Radar with Widely Separated Antennas"

MIMO (multiple-input multiple-output) radar refers to an architecture that employs multiple, spatially distributed transmitters and receivers. While, in a general sense, MIMO radar can be viewed as a type of multistatic radar, the separate nomenclature suggests unique features that set MIMO radar apart from the multistatic radar literature and that have a close relation to MIMO communications. This article reviews some recent work on MIMO radar with widely separated antennas. Widely separated transmit/receive antennas capture the spatial

diversity of the target's radar cross section (RCS). Unique features of MIMO radar are explained and illustrated by examples. It is shown that with noncoherent processing, a target's RCS spatial variations can be exploited to obtain a diversity gain for target detection and for estimation of various parameters, such as angle of arrival and Doppler. For target location, it is shown that coherent processing can provide a resolution far exceeding that supported by the radar's waveform. [J225]

"Time Reversal Imaging by Adaptive Interference Canceling"

We develop the time reversal adaptive interference canceler (TRAIC) time reversal beamformer (TRBF), a new algorithm to detect and locate targets in rich scattering environments. It utilizes time reversal in two stages: (1) Anti-focusing: TRAIC time reverses and then reshapes the clutter backscatter to mitigate the clutter response; (2) Focusing: TRBF time reverses the residual backscatter to focus the radar image on the target. Laboratory experiments with electromagnetic radar data in a highly cluttered environment confirm the superiority of TRAIC-TRBF over conventional direct subtraction (DS) beamform imaging. [J226]

"Predicted Detection Performance of MIMO Radar"

It has been shown that multiple-input multiple-output (MIMO) radar systems can improve target detection performance significantly by exploiting the spatial diversity gain. We introduce the system model in which the radar target is composed of a finite number of small scatterers and derive the formula to evaluate the theoretical probability of detection for the system having an arbitrary array-target configuration. The results can be used to predict the detection performance of the actual MIMO radar without time-consuming simulations. [J227]

"A High-Resolution Imaging Radar at 580 GHz"

We have developed a high-resolution imaging radar at 580 GHz. Coherent illumination in the 576-589 GHz range and phase-sensitive detection are implemented in an all-solid-state design based on Schottky diode sensors and sources. By employing the frequency-modulated continuous wave (FMCW) radar technique, we achieve centimeter-scale range resolution while utilizing fractional bandwidths of less than 3%. Our high operating frequencies also permit centimeter-scale cross-range resolution at several-meter standoff distances without large apertures. Scanning of a single-pixel transceiver enables targets to be rapidly mapped in three dimensions, and here we apply this technology to the detection of concealed objects on persons. [J228]

"Breast Tumor Characterization Based on Ultrawideband Microwave Backscatter"

Characterization of architectural tissue features such as the shape, margin, and size of a suspicious lesion is commonly performed in conjunction with medical imaging to provide clues about the nature of an abnormality. In this paper, we numerically investigate the feasibility of using multichannel microwave backscatter in the 1-11 GHz band to classify the salient features of a dielectric target. We consider targets with three shape characteristics: smooth, microlobulated, and spiculated; and four size categories ranging from 0.5 to 2 cm in diameter. The numerical target constructs are based on Gaussian random spheres allowing for moderate shape irregularities. We perform shape and size classification for a range of signal-to-noise ratios (SNRs) to demonstrate the potential for tumor characterization based on ultrawideband (UWB) microwave backscatter. We approach classification with two basis selection methods from the literature: local discriminant bases and principal component analysis. Using these methods, we construct linear classifiers where a subset of the bases expansion vectors are the input features and we evaluate the average rate of correct classification as a performance measure. We demonstrate that for 10 dB SNR, the target size is very reliably classified with over 97% accuracy averaged over 360 targets; target shape is classified with over 70% accuracy. The relationship between the SNR of the test data and classifier performance is also explored. The results of this study are very encouraging and suggest that both shape and size characteristics of a dielectric target can be classified directly from its UWB backscatter. Hence, characterization can easily be performed in conjunction with UWB radar-based breast cancer detection without requiring any special hardware or additional data collection. [J229]

"Multitarget Detection and Estimation Based on Passive Multilateral TDOAs of Transient Signals"

A modified deterministic annealing expectation maximization (MDAEM) algorithm has been proposed [D. Carevic, ldquoAutomatic estimation of multiple target positions and velocities using passive TDOA measurements of transients,rdquo IEEE Transactions on Signal Processing, vol. 55, no. 2, pp. 424-436, 2007] for the estimation of the motion parameters of multiple targets moving in cluttered three-dimensional (3D) underwater environments. In many situations, the number of targets in the measurements batch is not known, and the MDAEM algorithm is run for an inexact (guessed) number of the motion models, where, usually, the guessed number of models is larger than the true number of targets. This correspondence describes a detection procedure that determines which of the motion models estimated by the algorithm are related to the true targets in the measurements

batch. [J230]

"Using the Phase Change of a Reflected Microwave to Detect a Human Subject Behind a Barrier"

In a pulsed radar system, the amplitude and sign of the echo from a particular target will depend on the phase of the echo signal relative to that of the local oscillator signal. If the wavelength of the radar signal is very short, the phase of the echo can change greatly if the target moves even slightly. Based on this physical behavior, the pulsed radar system can serve as a life-detection system to detect a human subject's movements, which include breathing and heartbeat. In this paper, a pulsed microwave life-detection system was developed from a pulsed training radar system to successfully detect the presence of human subjects behind a simulated earthquake rubble wall. The sampled echo signals from the background noise, a dummy, and a female human subject are presented directly in the time domain without being transferred into the frequency domain, differentiating this work from recent works by other authors. Furthermore, we also demonstrate several superiorities of a pulsed system over and above the original continuous-wave approach with the experimental results. [J231]

"Improving Coherence of Complex Image Pairs Obtained by Along-Track Bistatic SARs Using Range-Azimuth Prefiltering"

An along-track interferometric synthetic aperture radar (SAR) can be used for ground moving target indication (GMTI) by comparing two SAR images obtained at different observation times. Different geometries of the two observations bring the decorrelation noise, which will degrade the detection performance. For bistatic SARs, the decorrelation theory is quite different from that for monostatic ones. This paper deals with the coherence between two complex SAR images formed by two along-track bistatic SARs with different baseline lengths. Using the single scattering model, the coherence between the two echoes collected by the two receivers is investigated, and the full-coherence conditions are derived. Then, a new method based on range-azimuth prefiltering is proposed to improve the coherence of complex image pairs. As the precise prefiltering is complicated, its three approximate implementations are given. The effects of prefiltering on SAR images are also analyzed. Finally, simulation results validate the effectiveness of the proposed method. [J232]

"Temporal coherent adaptive target detection for multi-input multi-output radars in clutter"

The superiority of multiple-input multiple-output (MIMO) radars over conventional phased-array radars has been recently shown in many aspects. The MIMO radars have better detection performance and can extract target information more precisely than phased-array radars. The problem of adaptive target detection using temporal coherent pulse train in the presence of nonhomogeneous clutter (different clutter statistics in receivers) is considered for MIMO radars. This problem has been formulated as a hypothesis test. For clutter with unknown statistics three adaptive decision rules have been developed using the generalised likelihood ratio test. The results show the superiority of the MIMO radars with temporal coherent processing over conventional phased arrays in the presence of clutter. [J233]

"Receiver Operating Characteristic Curve Confidence Intervals and Regions"

Many researchers have presented results showing the empirical performance of target detection algorithms using hyperspectral or synthetic aperture radar imagery. In nearly all cases, these probabilities of detection and false alarm are presented as precise values as opposed to their true nature as estimates of random values. In this letter, we provide analytical tools and examples of computing confidence intervals and regions around these estimates commonly presented as points on receiver operating characteristic (ROC) curves. It is suggested that these tools be adopted by researchers when presenting their results to provide their audience with a quantitative metric for proper interpretation of empirically estimated ROC curves. [J234]

"Application of Bispectrum Estimation for Time-Frequency Analysis of Ground Surveillance Doppler Radar Echo Signals"

A microwave coherent homodyne and polarimetric ground surveillance Doppler radar is employed for collecting the radar returns from moving objects. Nonstationary nonlinearly frequency-modulated and multicomponent backscattered signals are analyzed and described as a sum of Doppler frequency-shifted polynomial chirp-like components. Instantaneous frequencies corresponding to the radiation backscattered by the different parts of a moving spatially distributed object are extracted from the time-varying bimagnitude estimates of transient sample sequences separated from the total received signal by a sliding window and projected into the time-frequency (TF) domain. Experimental investigations demonstrate a clean recovery of evolutionary phase-coupled harmonics for such targets as a swinging metallic sphere or a walking human. The computed TF distributions can be used in radar automatic target recognition systems to retrieve new data for the classification and recognition of ground

moving objects. [J235]

"Adaptive fusion framework based on augmented reality training"

A framework for the fusion of computer-aided detection and classification algorithms for side-scan imagery is presented. The framework is based on the Dempster-Shafer theory of evidence, which permits fusion of heterogeneous outputs of target detectors and classifiers. The utilisation of augmented reality for the training and evaluation of the algorithms used over a large test set permits the optimisation of their performance. In addition, this framework is adaptive regarding two aspects. First, it allows for the addition of contextual information to the decision process, giving more importance to the outputs of those algorithms that perform better in particular mission conditions. Secondly, the fusion parameters are optimised on-line to correct for mistakes, which occur while deployed. [J236]

"Quickest Detection and Tracking of Spawning Targets Using Monopulse Radar Channel Signals"

Recent advances have been reported in detecting and estimating the location of more than one target within a single monopulse radar beam. Successful tracking of those targets has been achieved with the aid of nonlinear filters that approximate the targets' states' conditional pdf, bypassing the measurement extraction stage, and operating directly on the monopulse sum/difference data, i.e., without measurement extraction. The problem of detecting a target spawn will be tackled in this paper. Particle filters will be employed as nonlinear tracking filters to approximate the posterior probability densities of the targets' states under different hypotheses of the number of targets, which in turn can be used to evaluate the likelihood ratio between two different hypotheses at subsequent time steps. Ultimately, a quickest detection procedure based on sequential processing of the likelihood ratios will be used to decide on a change in the underlying target model as an indication of a newly spawning target. Radar signal processing, data association, and target tracking are handled simultaneously. [J237]

"Recursive parametric tests for multichannel adaptive signal detection"

The problem of detecting a multichannel signal in spatially and temporally coloured disturbances is considered. The parametric Rao and parametric generalised likelihood ratio test detectors, recently developed by modelling the disturbance as a multichannel autoregressive (AR) process, have been shown to perform well with limited or even no range training data. These parametric detectors, however, assume that the model order of the multichannel AR process is known a priori to the detector. In practice, the model order has to be estimated by some model order selection technique. Meanwhile, a standard non-recursive implementation of the parametric detectors is computationally intensive since the unknown parameters have to be estimated for all possible model orders before the best one is identified. To address these issues, herein the joint model order selection, parameter estimation and target detection are considered. We present recursive versions of the aforementioned parametric detectors by integrating the multichannel Levinson algorithm, which is employed for recursive and computationally efficient parameter estimation, with a generalised Akaike Information Criterion for model order selection. Numerical results show that the proposed recursive parametric detectors, assuming no knowledge of the model order, yield a detection performance nearly identical to that of their non-recursive counterparts at significantly reduced complexity. [J238]

"Post-adaptive processing time-delay beamforming for clutter suppression in airborne radar"

A novel beamforming architecture is presented in which time delay steering is applied after the application of space-time adaptive processing (STAP) in a phased array for airborne radar. Improved clutter suppression and slow moving target detection performance can be achieved over that associated with STAP and conventional time delay steering in wideband sideways looking applications. The architecture also provides a computationally efficient means of applying time-delay beamforming in conjunction with STAP in applications where multiple receive beams are required. [J239]

"Polarimetric Detection of Targets in Heavy Inhomogeneous Clutter"

Polarization diversity has proved to be a useful tool for radar detection, especially when discrimination by Doppler effect is not possible. In this paper, we address the problem of improving the performance of polarimetric detectors for targets in heavy inhomogeneous clutter. First, we introduce a new polarimetric radar model that includes the realistic dependence of the clutter reflections on the transmitted signal. Then, we develop a polarimetric detection test that is robust to inhomogeneous clutter. We run this polarimetric test against synthetic and real data to assess its performance in comparison with existing polarimetric detectors. Finally, we propose a polarimetric waveform-design algorithm to further improve the target-detection performance. A numerical analysis is presented to demonstrate the potential performance improvement that can be achieved

with this algorithm. [J240]

"Multi-target tracking in clutter without measurement assignment"

When tracking targets using radars and sonars, the number of targets and the origin of data is uncertain. Data may be false measurements or clutter, or they may be detections from an unknown number of targets whose possible trajectories and detection processes can only be described in a statistical manner. Optimal all-neighbor multi-target tracking (MTT) in clutter enumerates all possible joint measurement-to-track assignments and calculates the a posteriori probabilities of each of these joint assignments. The numerical complexity of this process is combinatorial in the number of tracks and the number of measurements. One of the key differences between most MTT algorithms is the manner in which they reduce the computational complexity of the joint measurement-to-track assignment process. We propose an alternative approach, using a form of soft assignment, that enables us to bypass this step entirely. Specifically, our approach treats possible detections of targets followed by other tracks as additional clutter measurements. It starts by approximating the a~priori probabilities of measurement origin. These probabilities are then used to modify the clutter spatial density at the location of the measurements. A suitable single target tracking (STT) filter then uses the modified clutter intensity for updating the track state. In effect, the STT filter is transformed into an MTT filter with a numerical complexity that is linear in the number of tracks and the number of measurements. Simulations show the effectiveness of this approach in a number of different multi-target scenarios. [J241]

"Fast Chirplet Transform With FPGA-Based Implementation"

This letter presents a fast chirplet transform (FCT) algorithm, a computationally efficient method, for decomposing highly convoluted signals into a linear expansion of chirplets. The FCT algorithm successively estimates the chirplet parameters in order to represent a broad range of chirplet shapes, including the broadband, narrowband, symmetric, skewed, nondispersive, or dispersive. These parameters have significant physical interpretations for radar, sonar, seismic, and ultrasonic applications. For the real-time application and embedded implementation of the FCT algorithm, an FPGA-based hardware/software co-design is developed on Xilinx Virtex-II Pro FPGA development platform. Based on the balance among the system constraints, cost, and the efficiency of estimations, the performance of different algorithm implementation schemes have been explored. The developed system-on-chip successfully exhibits robustness in the chirplet transform of experimental signals. The FCT algorithm addresses a broad range of applications including velocity measurement, target detection, deconvolution, object classification, data compression, and pattern recognition. [J242]

"Track-before-detect procedures in a multi-target environment"

This paper addresses the problem of early detection of K ges 1 multiple moving targets in radar systems through the use of track-before-detect (TBD) techniques. At first, assuming prior knowledge of K, a binary generalized likelihood ratio test (GLRT) is derived, which shows that the multi-target TBD problem can be regarded as a K-path trellis search. Since optimal implementation of the GLRT has a nonlinear complexity either in the number of targets or in the number of integrated frames, suboptimum algorithms are investigated which allow to trade better estimation and tracking accuracy for a much lower implementation complexity. Next, the TBD problem with K unknown is discussed and a novel multi-hypothesis test strategy is derived as the solution to a constrained optimization problem, which subsumes the conventional binary GLRT as the special case of known K. Finally, numerical examples are provided to assess and compare the performances of the proposed TBD procedures. [J243]

"Target detection and parameter estimation for MIMO radar systems"

We investigate several target detection and parameter estimation techniques for a multiple-input multiple-output (MIMO) radar system. By transmitting independent waveforms via different antennas, the echoes due to targets at different locations are linearly independent of each other, which allows the direct application of many data-dependent beamforming techniques to achieve high resolution and excellent interference rejection capability. In the absence of array steering vector errors, we discuss the application of several existing data-dependent beamforming algorithms including Capon, APES (amplitude and phase estimation) and CAPES (combined Capon and APES), and then propose an alternative estimation procedure, referred to as the combined Capon and approximate maximum likelihood (CAML) method. Via several numerical examples, we show that the proposed CAML method can provide excellent estimation accuracy of both target locations and target amplitudes. In the presence of array steering vector errors, we apply the robust Capon beamformer (RCB) and doubly constrained robust Capon beamformer (DCRCB) approaches to the MIMO radar system to achieve accurate parameter estimation and superior interference and jamming suppression performance. [J244]

"Detection of a manoeuvring air target in strong sea clutter via joint time-frequency representation"

Two new approaches for detecting a manoeuvring air target in strong sea clutter are proposed. Whereas one is based on the adaptive chirplet decomposition, the other is inspired by spectral subtraction. Unlike the other time-frequency transform-based methods, the approaches presented can both be used to compute a signal's time waveform with suppressed sea clutter. Experiments with real-world data samples show that both methods can effectively enhance the Doppler radar signals associated with a manoeuvring air target by more than 15-dB. [J245]

"Recent developments in detection, imaging and classification for airborne maritime surveillance"

The role of maritime patrol missions is to monitor large oceanic areas. The authors focus on a complete signal-processing sequence from the primary detection of the targets to their classification or recognition from an airborne radar. Contrary to the classical approach in which detection, tracking, imaging and classification are considered separately, here the authors propose an integrated strategy based on a close cooperation among all of them. Recent developments in high range resolution target detection are presented and their integration in the complete system is discussed to limit false alarms. High-resolution ISAR imaging of ships is then tackled and associated with a feature extraction process and a support vector machine classifier. A set of real data is used to illustrate the imaging and classification results. [J246]

"Wide-Area Traffic Monitoring With the SAR/GMTI System PAMIR"

This paper presents a wide area traffic monitoring experiment under real conditions, using the scan-MTI mode of the airborne radar sensor PAMIR. This flexible GMTI (Ground Moving Target Indication) mode was designed in order to rapidly monitor wide areas for moving targets. The scan operation enables the detection of targets from different aspect angles with a high revisit rate. The parameters (e.g., radial velocity, signal-to-noise ratio, and positioning accuracy) of the detected vehicles are investigated and compared to the expected theoretical GMTI performance. It will be shown that the scan-MTI mode is particularly adapted to perform an efficient wide-area traffic monitoring. [J247]

"Software-Defined Six-Port Radar Technique for Precision Range Measurements"

A software-defined radar measurement system on the basis of a six-port receiver technique is proposed and described in this paper. The system makes use of a hybrid scheme of two performance-complementary operating modes, namely, frequency-modulated continuous-wave (FMCW) and two-tone continuous-wave signals. Generally, the FMCW-based measurement technique is deployed to give an approximate range value of target while the two-tone continuous-wave (CW)-based measurement technique can accurately determine the range that may, however, be ambiguous. The six-port circuit is used for the receiver as a precision phase detector in two-tone CW function and at the same time as a mixer in FMCW function. Various waveforms are generated in direct digital synthesizers and processed by different algorithms in a digital signal processor. The switching between the frequency-modulated CW and two-tone CW functions is controlled by software to improve the resolution and ensure a reliable operation. A system prototype is designed and made for a C-band demonstration. The Schottky diodes used as power detectors in the six-port are calibrated so that they can be used beyond the square-law region, thus allowing a higher power level and a better dynamic range. Measured results validate the proposed software-defined platform and accurate range results are confirmed. [J248]

"Improved Space-Based Moving Target Indication via Alternate Transmission and Receiver Switching"

Ground moving target indication (GMTI) by space-based radar systems requires special antenna and data acquisition concepts to overcome the problem of discriminating target signals from clutter returns. Owing to the high satellite speed, the clutter contains a broad mixture of radial velocities within the antenna beam, leading to a large Doppler spread. Effective clutter suppression can solely be achieved by multiple aperture or phase center antennas. For space-based systems, however, the number of receiver channels connected to subapertures is very limited due to their weight, volume, and high data rates (current systems such as TerraSAR-X and RADARSAT-2 possess only two). This classical along-track interferometry architecture, in which the antenna is split into two halves, achieves only suboptimum GMTI performance. This paper presents and statistically analyzes an innovative approach to create additional independent phase centers to improve the GMTI performance considerably. The extra degrees of freedom are created by cyclical phase and amplitude switchings of the transmit/receive modules for transmitter and receiver between pulses, hence trading Doppler bandwidth for extra spatial diversity. In the first part of this paper, different strategies of spatial-temporal diversity are introduced and analyzed for realistic system parameters with respect to ambiguities and detection performance. The second part is concerned with the elaborate theoretical analysis of the relocation improvement for the spatial

diversity approach. [J249]

"Time-Frequency Analysis for the Localization of Multiple Moving Targets Using Dual-Frequency Radars"

A dual-frequency radar, which estimates the range of a target based on the phase difference between two closely spaced frequencies, has been shown to be a cost-effective approach to accomplish both range-to-motion estimation and tracking. This approach, however, suffers from two drawbacks: it cannot deal with multiple moving targets, and it has poor performance in noisy environments. In this letter, we propose the use of time-frequency signal representations to overcome these drawbacks. The phase, and subsequently the range information, is obtained based on the moving target instantaneous Doppler frequency law, which is provided through time-frequency signal representations. The case of multiple moving targets is handled by separating the different Doppler signatures prior to phase estimation. [J250]

"Maritime border control computer simulation"

This work describes a computer simulator for an integrated command and control (C2) multi-sensor system acting in a maritime border control scenario. The analyzed system is composed of two platforms of multiple sensors: a land-based platform, equipped with a Vessel Traffic System (VTS) radar, an Infrared camera (IR), and an Automatic Identification System (AIS); an airborne platform, carrying an Airborne Early Warning Radar (AEWR) and an IR camera. The mission of the system is the detection, tracking, and identification of multiple naval targets inside a sea region, their threat level evaluation, and the selection of an intervention against possible threat targets, in order to inspect their nature. The Measures of Effectiveness (MoE) of the integrated system are evaluated, i.e., the system performance during the detection, the threat evaluation process, and the intervention. [J251]

"Parametric Velocity Synthetic Aperture Radar: Multilook Processing and Its Applications"

Based on a parametric model and some optimum methods, it has been previously proved that parametric velocity synthetic aperture radar (VSAR) may improve the performances of moving target detection and parameter estimation simultaneously. In this paper, multilook processing is studied for parametric VSAR. At first, statistical signal models are established for azimuth multilook processing (AMLP) and range multilook processing (RMLP), respectively. By combining the multiple AMLP sublook pixel vectors, it is shown that the clutter parameter estimation accuracy can be further improved via the maximum-likelihood estimation methods. Meanwhile, based on the adaptive implementation for the optimum processing of VSAR, RMLP can be used to improve slowly moving target detection performance via the noncoherent integration of multiple range sublooks. Furthermore, it is shown that the Doppler frequencies of moving targets vary linearly with different range sublooks due to the different carrier frequencies of sublooks. Therefore, based on a proposed novel two-step multilook diversity (TS-MLD) estimator for RMLP, the "azimuth location ambiguity" of VSAR can be well resolved via least squares linear regression, without configuration change of the conventional VSAR. Also, the estimation accuracy of target's unambiguous Doppler frequency, as well as target's azimuth location, is derived for the proposed TS-MLD method. Finally, numerical experiments and scene simulations are provided to demonstrate the effectiveness of the proposed multilook-based methods. [J252]

"Modified Hough Transform for Searching Radar Detection"

In this letter, we propose a modified Hough transform (HT) algorithm for radar detection by shifting the parameter space cells as well as exploiting the phase information of signal. The proposed modified HT brings (1) significant improvement of radar target detection at low signal-to-noise ratios and (2) complexity reduction of HT implementation in radar detection applications compared to the conventional HT-based methods. Simulation results are presented showing the performance gain obtained by the proposed modified HT over the conventional methods. [J253]

"Multi-target tracking using multiple passive bearings-only asynchronous sensors"

Passive tracking relies on detection of energy emitted by zero or more targets in surveillance space. When detection occurs, the angle of arrival, or the angle between the sensor and the possible target is measured, with a measurement error. Both targets and sensors can be moving, thus additional source of error is the sensor position uncertainty. If the targets emit beams of energy randomly, then each sensor will detect each target at random times, which are independent from sensor to sensor. False detections or clutter measurements also occur at random times for each sensor. Existence, number, and position of targets are unknown in the surveillance region. The origin of each measurement is unknown, as the measurement may be a detection from any target being tracked, or a clutter detection, or a detection from a new target. The recursive algorithm

presented integrates information from measurements received by an arbitrary number of sensors, to determine the existence, number, and position of targets in a stochastic manner, given assumptions listed above. Simulations show the effectiveness of this approach in a multi-target scenario. [J254]

"Cramer-Rao bounds for target parameters in space-based radar applications"

The Cramer-Rao (CR) bounds for target Doppler and power are presented when detecting targets using a space-based radar (SBR) platform. The target in noise-only case is considered first and the results are compared with those obtained for a centro-symmetric uniform linear pulse array. When clutter is also present, the effect of the Earth's rotation and range foldover becomes significant; and they must be taken into consideration. The CR bounds are computed for target Doppler and power, and compared with their variance estimates obtained from simulation results corresponding to various airborne and SBR situations. From the simulation results, the Earth's rotation together with range foldover significantly increase the CR bounds for both target Doppler and power. This is in agreement with other results that show the Earth's rotation and range foldover together degrade the clutter suppression performance of adaptive processing algorithms. It is shown that when both the Earth's rotation effect and range foldover effect are present in the data, target detection is difficult, and it is necessary to introduce waveform diversity into the transmit design to minimize the effect of clutter and other interference. In this context, using waveform diversity on transmit, it is possible to compensate the degradation in terms of the CR bounds and achieve performance close to the ideal case. [J255]

"Joint detection and tracking of unresolved targets with monopulse radar"

Detection and estimation of multiple unresolved targets with a monopulse radar is a challenging problem. For ideal single bin processing, it was shown in the literature that at most two unresolved targets can be extracted from the complex matched filter output signal. A new algorithm is developed to jointly detect and track more than two unresolved targets from a single detection with the help of tracking information. That is, the method involves the use of tracking information in the detection process. For this purpose, target states are transformed into detection parameter space, which involves high nonlinearities. In order to handle the nonlinearities, the particle filter, which has proven to be effective in nonlinear non-Gaussian estimation problems, is used as the basis of the closed loop system for tracking multiple unresolved targets. In addition to the standard particle filtering steps, the detection parameters corresponding to the predicted particles are evaluated using the nonlinear monopulse radar beam model. This in turn enables the evaluation of the likelihood of the monopulse signal given tracking data. Bayesian model selection is then used to find the correct detection event. The corresponding particle set is taken as the correct representation of the target posterior. A simulated amplitude comparison monopulse radar is used to generate the data and validate the joint detection and tracking of more than two unresolved targets. [J256]

"Wavelet Contribution to Remote Sensing of the Sea and Target Detection for a High-Frequency Surface Wave Radar"

High-frequency waves (3-30 MHz) interact with the sea surface. Thus, a high-frequency surface wave radar (HFSWR) is well suited to perform remote sensing of the sea. The HFSWR coverage range is not limited by the radio horizon: it is possible to keep watch over the sea up to a few hundred kilometers from the coastline. Oceanographic parameters (i.e., wave height, surface current velocity, wind direction, and wind velocity) are derived from the so-called sea spectrum. Moreover, the HFSWR can be used for maritime surveillance of the Exclusive Economic Zone. In that case, the sea spectrum is an unwanted signal because it can mask targets. Sea spectrum extraction is an important issue for HFSWR signal processing since it is a key point for the remote sensing accuracy and the target detection features. In this letter, we show how wavelets may be applied to improve the remote sensing of oceanographic parameters and the target detection using wavelet-based sea clutter extraction. The results obtained using real data with opportune targets validate our approach. [J257]

"GLRT subspace detection for range and Doppler distributed targets"

A generalized likelihood ratio test (GLRT) is derived for adaptive detection of range and Doppler-distributed targets. The clutter is modeled as a spherically invariant random process (SIRP) and its texture component is range dependent (heterogeneous clutter). We suppose here that the speckle component covariance matrix is known or estimated thanks to a secondary data set. Thus, unknown parameters to be estimated are local texture values, the complex amplitudes and Doppler frequencies of all scattering centers. To do so, we use superresolution methods. The proposed detector assumes a priori knowledge on the spatial distribution of the target and has the precious property of having a constant false alarm rate (CFAR) with the assumption of a known speckle covariance matrix or by the use of frequency agility. [J258]

"Sikkim's Teesta River fog, mist and dust particle monitoring using monostatic LiDAR"

Fog, mist, and atmospheric dust particles, having the dimension of one micrometer or less, play an important role in the deterioration of visibility, as well as in causing local warming in the atmosphere. With an attempt to reduce the deterioration, a scientific approach has to be taken to determine their origins. A monostatic LIDAR may be one of the best instruments for such work. The authors are tempted to develop such a LIDAR for fog, mist, and dust particle monitoring over River Teesta at Sikkim. LIDAR is an acronym for Light Detection And Ranging. What can we do with LIDAR? Measure distance, measure speed, measure rotation, measure chemical composition and concentration, and measure cross-sections of the targets. The digital technique is always utilized for its development which results in better security, lower power consumption, higher power efficiency, higher reliability, lower transmitter power, lower multipath effect, higher interference suppression as compared to an analog system. The commercial systems like disdometer, rain radar, mobile robot, etc., utilizing LIDAR principles are operational in different parts of the world. The authors are highly motivated for such LIDAR development and their development effort follows. [J259]

"A Refined GTD Ray System for an Embedded Object and Its Polarimetric Behavior"

A refined ray system based on the geometrical theory of diffraction (GTD) for an object embedded in soil for a monostatic transmitter-receiver alignment is presented. Apart from the investigation of the ldquoclassicalrdquo reflections from the target, creeping waves are also taken into account, and their formalism is presented. The objective of such a ray set is to better understand the different scattering mechanisms, which are presented in the complex scattering framework. In electromagnetic modeling based on GTD, the complex shape of a target is replaced by simpler canonical objects, e.g., facets, cones, wedges, spheres, or cylinders. Here, a cylinder is located in parallel and closely to the plane interface of two dielectric half-spaces. The example of air-soil is taken into account. The numerical results obtained for various directions of incidence are employed to describe the polarimetric characteristics of the diffracted field from grazing to perpendicular incidence to the surface. By representing the diffracted GTD field on the Poincare sphere, the location on the sphere has a one-to-one relationship to the dielectric properties of the soil. The relation can be employed to extract information as the soil moisture. [J260]

"Rao-Blackwellised particle filter based trackbefore- detect algorithm"

A track-before-detect (TBD) algorithm based on the Rao-Blackwellised particle filter (RBPF) is proposed for over-the-horizon radar (OTHR) target detection and tracking. Since the unthresholded measurements are integrated over time in the TBD algorithm, it can potentially detect and track targets with a much lower signal-to-noise ratio than conventional methods. In order to take advantage of the TBD algorithm, both system dynamic and measurement models are defined for the application under consideration. Furthermore, by exploiting the linear sub-structure available in the models, an RBPF based TBD algorithm is derived in detail. The proposed algorithm can provide reduced variance for the estimates with linear sub-structure and a lower computational complexity than the standard particle filter. Simulation results show that the proposed algorithm is capable of detecting and tracking dim targets for OTHR efficiently. [J261]

"High-Resolution Through-the-Wall Radar Imaging Using Beamspace MUSIC"

The MUSIC algorithm is a high-resolution direction finding technique which has been successfully applied to enhance radar imaging in inverse synthetic aperture radar (ISAR). Although this signal subspace-based method has proven effective when dealing with point targets and high signal-to-noise ratio (SNR), it may fail to work when directly applied to extended targets or target returns of low SNR. The Beamspace MUSIC (BS-MUSIC), in which the MUSIC algorithm is applied to multiple beams, is capable of locating spatially extended targets in low SNR environments. In this paper, we consider BS-MUSIC as an image formation method for indoor radar imaging problems and sensing through-the-wall applications. We compare BS-MUSIC performance to conventional beamforming and element-space MUSIC. Imaging results, using both synthesized and real data, demonstrate the advantages of the proposed algorithm in depicting targets behind walls. [J262]

"Monopulse-radar tracking of swerling III-IV targets using multiple observations"

This paper proposes a novel statistical prediction of monopulse errors (Levanon, 1988) for a radar Swerling III-IV target embedded in noise or noise jamming where multiple observations are available. First, the study of the maximum likelihood estimator (MLE) of the complex monopulse ratio for a Swerling III-IV target embedded in spatially white noise allows us to extend the use of the MLE practical approximate form introduced by Mosca (1969) for Swerling 0-I-II cases. Afterward, we derive analytical formulas for both the mean and variance of the MLE in approximate form conditioned by the usual detection step performed on the sum channel of a monopulse

antenna. Last, we provide a comparison of target direction of arrival (DOA) estimation performance based on monopulse ratio estimation as a function of the Swerling model in the context of a multifunction radar. [J263]

"Along-track interferometry for ground moving target indication"

Synthetic aperture radar (SAR) along-track interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (~10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. Herein, we describe preliminary results from an ATI GMTI experiment. The SAR data described were collected by the dual-frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pickup truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J264]

"Design of frequency-coded waveforms for target detection"

The authors propose a novel approach to the design of frequency-coded waveforms using modified pushing sequences. The resulting waveforms show that there is considerable enhancement in delay-Doppler resolution in the ambiguity function. [J265]

"Sequential Detection of Markov Targets With Trajectory Estimation"

The problem of detection and possible estimation of a signal generated by a dynamic system when a variable number of noisy measurements can be taken is here considered. Assuming a Markov evolution of the system (in particular, the pair signal-observation forms a hidden Markov model (HMM)), a sequential procedure is proposed, wherein the detection part is a sequential probability ratio test (SPRT) and the estimation part relies upon a maximum aposterioriprobability (MAP) criterion, gated by the detection stage (the parameter to be estimated is the trajectory of the state evolution of the system itself). A thorough analysis of the asymptotic behavior of the test in this new scenario is given, and sufficient conditions for its asymptotic optimality are stated, i.e., for almost sure minimization of the stopping time and for (first-order) minimization of any moment of its distribution. An application to radar surveillance problems is also examined. [J266]

"Editorial: Signal processing techniques for ISAR and feature extraction"

Inverse synthetic aperture radar (ISAR) is a non-cooperative target recognition technique that has been investigated for target identification by the combat identification (ID) community for the past decade. Recently, ISAR imaging of moving targets has been an area of vigorous research. ISAR imaging is an effective way to acquire high resolution images of targets of interest at long range and as such is an irreplaceable tool in the task of non-cooperative target recognition. Its applications include detection, imaging, and classification of ships and aircraft with airborne, maritime, and land-based radar systems. Being radar-based, this imaging technique can be employed in all weather and day/night conditions. [J267]

"Radar detection based on Bayesian estimation of target amplitude"

A new approach to detect a target with an unknown amplitude in clutter is proposed. The received signal models under two hypotheses, H0and H1, are assumed to be the same, except that the target amplitude is zero under H0. Using the Bayesian approach, it is shown that the likelihood ratio can be calculated as the ratio of the prior to posterior probabilities of the target amplitude. Based on this relation, a new method for target detection in Gaussian clutter is presented. This method is applied to cases with both known and unknown clutter statistics and in each case, white and coloured clutters are considered. Simulation results show that the proposed detector has a much better performance compared with conventional generalised likelihood ratio test detectors. [J268]

"Optimal Two-Stage Search for Sparse Targets Using Convex Criteria"

We consider the problem of estimating and detecting sparse signals over a large area of an image or other medium. We introduce a novel cost function that captures the tradeoff between allocating energy to signal regions, called regions of interest (ROI), versus exploration of other regions. We show that minimizing our cost

guarantees reduction of both the error probability over the unknown ROI and the mean square error (MSE) in estimating the ROI content. Two solutions to the resource allocation problem, subject to a total resource constraint, are derived. Asymptotic analysis shows that the estimated ROI converges to the true ROI. We show that our adaptive sampling method outperforms exhaustive search and are nearly optimal in terms of MSE performance. An illustrative example of our method in radar imaging is given. [J269]

"Novel radar target detection [Jsame as "Radar target novel characteristic detection method", vol. 21, n.1, 06]"

Herein, a novel method of radar target detection based on 2-dimensional (2-D) fractal dimension is proposed. The proposed approach exploits both range information and azimuth information to estimate fractal dimension. Moreover, the approach can increase the number of data points. The above two merits result in the fractal dimension estimated by this method are more accurate and robust than the previous method. The detection performance is also better than the previous, which only makes use of 1-dimensional (1-D) information to estimate fractal dimension. Theoretical analysis and experimental results show that the proposed method performs well in a strong clutter background. The proposed method is also validated by real-life radar data, and the better result has been achieved. [J270]

"Stretch processing for masking effect removal in noise radar"

A method of removing the masking effect caused by strong target echoes in a noise radar is presented. Signal processing in noise radar is based on the calculation of the correlation between transmitted and received signals. Strong echoes of nearby targets produce relatively high sidelobes in the correlation function, thus masking weak echoes of far targets. The classical method of masking effect removal, taking into consideration only the Doppler shift of target echoes, does not remove the strong target echo completely when targets migrate between range resolution cells in the integration time. The method proposed, based on signal stretch processing and a point target model, shows an improvement over existing methods and allows for the detection of weak targets also in the presence of the fast and strong ones. [J271]

"Parametric Velocity Synthetic Aperture Radar:Signal Modeling and Optimal Methods"

Velocity synthetic aperture radar (VSAR) is equipped with a linear array to receive the echoes from a radar illuminating area via multiple channels, each of which can reconstruct a reflectivity image for the same stationary scene. Based on analysis of pixel vector sampled among multi-images, VSAR may effectively suppress the strong ground clutter and improve moving target detection and location. In this paper, different Doppler-distributed properties are derived for the moving target and clutter, respectively. Then, we propose a novel parametric statistical model for VSAR by dividing the pixel vector into three components, namely, target, clutter, and noise. Furthermore, a method of adaptive implementation of optimal processing (AIOP-VSAR) is presented for moving target detection. It is shown that the optimum detection performance may be obtained via AIOP-VSAR, particularly for the slowly moving target in an inhomogeneous clutter environment. Also, the Cramer-Rao bounds (CRBs) are derived for the estimation of unknown model parameters, as well as the azimuth locations of moving targets, and the maximum-likelihood methods are proposed to reach these CRBs. Based on the proposed target detection and parameter estimation methods, we present a complete parametric flowchart for VSAR. It is demonstrated that the proposed flowchart may effectively mitigate the "azimuth location ambiguity" of VSAR and has the super-resolution ability to resolve "velocity layover" for multiple targets. Finally, some detailed numerical experiments and scene simulations are provided to show the effectiveness of the proposed methods. [J272]

"An Interacting Multiple-Model-Based Abrupt Change Detector for Ground-Penetrating Radar"

In this letter, we propose an interacting multiple-model (IMM)-based abrupt change detector for ground-penetrating radar (GPR) applications. Ground clutter varies with surface roughness, soil nature, as well as depth of the soil layer, necessitating a multiple-model approach. The IMM is first trained for a chosen number of models and then used to characterize the GPR data. The IMM predictor segments the entire GPR data into regions of identical models and then identifies targets by detecting abrupt changes in model parameters. The number of models is determined using the minimum prediction error criterion. The prediction performance of the IMM predictor is theoretically analyzed, and its detection performance is also evaluated through an receiver operating characteristics analysis to illustrate the improved performance of the proposed detector. [J273]

"A Multiple-Hypothesis Approach for Multiobject Visual Tracking"

In multiple-object tracking applications, it is essential to address the problem of associating targets and observation data. For visual tracking of multiple targets which involves objects that split and merge, a target may

be associated with multiple measurements and many targets may be associated with a single measurement. The space of such data association is exponential in the number of targets and exhaustive enumeration is impractical. We pose the association problem as a bipartite graph edge covering problem given the targets and the object detection information. We propose an efficient method of maintaining multiple association hypotheses with the highest probabilities over all possible histories of associations. Our approach handles objects entering and exiting the field of view, merging and splitting objects, as well as objects that are detected as fragmented parts. Experimental results are given for tracking multiple players in a soccer game and for tracking people with complex interaction in a surveillance setting. It is shown through quantitative evaluation that our method tracks through varying degrees of interactions among the targets with high success rate. [J274]

"Rigid data association for shallow water surveys"

An automatic procedure for target data association is presented here. The procedure is particularly appropriate for shallow water applications, where navigation errors are limited and where sufficient overlap is present between successively surveyed areas. The proposed method includes a performance check that can be used to confirm that solutions are meaningful and also to produce a time-bounded implementation suitable for real-time operation. Main applications for the procedure include change detection and navigation enhancements (for example, by concurrent mapping and localisation/simultaneous localisation and mapping procedures). Results are presented for different survey platforms. [J275]

"Statistical prediction of monopulse angle measurement"

The statistical prediction of monopulse angle measurement where the amplitude fluctuation law of the signal source is unknown and multiple observations are available is presented. The mean and the variance of the monopulse ratio have been derived for the general case where the signal source is embedded in spatially coloured Gaussian noise and the receiver sum-channel is possibly completed by a detection step. This result completes the statistical prediction of a Swerling target and provides a powerful method to compute the mean and variance of the monopulse ratio conditioned by the detection test, whatever the amplitude fluctuation law of the signal source. [J276]

"High-bandwidth 220 GHz experimental radar"

An experimental radar at 220 GHz has been developed which is capable of delivering an instantaneous bandwidth of 8000 MHz. The solid-state radar uses an FM-CW waveform. The development is based on experience with a 94 GHz broadband measurement radar. The data undergo an ISAR imaging process to derive high-resolution scattering centre distributions for targets measured in tower/turntable configuration. High-resolution processing algorithms have been developed which result in scattering centre distributions with a resolution better than 2 cm at ranges of and exceeding 200 m. The radar will be used for investigations on target signatures of small objects for stand-off detection of concealed weapons and other threat material. [J277]

"Sea-Ice Deformation State From Synthetic Aperture Radar Imagery-Part I: Comparison of C- and L-Band and Different Polarization"

In this paper, we present a quantitative comparison of L- and C-band airborne synthetic aperture radar imagery acquired at like- and cross-polarizations over deformed sea ice under winter conditions. The parameters characterizing the deformation state of the ice are determined at both radar bands and at different polarizations. The separation of deformed and level ice is based on a target detection technique. The threshold is set such that image pixels with intensities equal to or larger than the highest 2% of the level-ice intensity distribution are classified as deformed ice, independent of the radar configuration and ice conditions. Optical imagery of sufficient quality for comparison is available only in a very few cases. To characterize the deformation state, the areal fraction of deformation features and the average distance between these features are evaluated. The values obtained for both parameters are very sensitive to the radar frequency. Aeral fractions are larger, and average distances are smaller at L-band than at C-band because of the much higher intensity contrast between the deformed and level ice at L-band. The differences between polarizations at one radar band are smaller but not always negligible. In comparison to optical images, it was observed that deformed-ice areas can be distinguished from level ice over their whole length and extension at L-band, whereas at C-band, often, only prominent parts are visible. [J278]

"Target Detection and Texture Segmentation in Polarimetric SAR Images Using a Wavelet Frame: Theoretical Aspects"

Theoretical aspects of a technique for target detection and texture segmentation in synthetic aperture radar

(SAR) imagery using a wavelet frame are presented. Texture measures consist of multiscale local estimates of the following: 1) normalized second moment of the backscattered intensity and 2) variance of the wavelet-frame coefficients. This work is an extension of a method proposed in the image-processing literature. Novel issues, which are considered in the passage to radar imagery, are the influence of speckle on texture measures afforded by the wavelet frame and their dependence on polarization states (polarimetric texture). Regarding speckle, estimators that decouple the influence of speckle over texture are introduced and characterized by their expected value and variance. The response of the wavelet frame to discontinuities, which is an important issue in target detection problems, is addressed in terms of signal-to-speckle-noise ratio. The notion of polarimetric texture is revisited, providing a theoretical model that explains the dependences of texture measures on the polarization states. For one-point statistics, such model calls for a mixture of diverse polarimetric scattering mechanisms within the texture estimator support. For two-point statistics, the difference in spatial correlation properties among the polarimetric channels is called into play. To analyze these effects in polarimetric SAR data, a novel tool is introduced that is called the Wavelet Polarimetric Signature. The tool encapsulates, in graphical form, the dependence on scale and polarization state of the texture measure afforded by the wavelet frame. The theory exposed here underpins a method that has been proven successful and computationally attractive in a selected number of SAR thematic applications. It also sets the stage for the exploitation of novel target detection and textural segmentation capabilities based on polarimetric diversity. [J279]

"On Parameter Identifiability of MIMO Radar"

A multi-input multi-output (MIMO) radar system, unlike a standard phased-array radar, can transmit multiple linearly independent probing signals via its antennas. We show herein that this waveform diversity enables the MIMO radar to significantly improve its parameter identifiability. Specifically, we show that the maximum number of targets that can be uniquely identified by the MIMO radar is up to Mttimes that of its phased-array counterpart, where Mtis the number of transmit antennas. [J280]

"A Novel Clutter Suppression Algorithm for Landmine Detection With GPR"

In this paper, we propose a new algorithm for the enhancement of plastic-cased antipersonnel mine detection using a video-impulse ground-penetrating radar (GPR). The algorithm is implemented as a nonlinear signal processor, which searches for the presence of a reference waveform in a 1D GPR echo return. The reference waveform represents a class of targets within a certain environment. The processor marks the presence of all responses similar to the reference waveform with a sharp mono-cycle. Simultaneously, responses with different waveforms, which presumably correspond to clutter, are suppressed. The reference waveform and other algorithm parameters are determined from training data sets acquired in a controlled environment. After training, the algorithm can be successfully applied at sites where soil, targets, and measurement scenarios are similar but not identical to those of the training site. The processor is integrated into an automated data processing and mine detection scheme as an additional clutter suppression step. The scheme consists of clutter suppression, synthetic aperture radar focusing, construction of a confidence map, and automated detection in it. The suggested algorithm is tested on experimental data, and its performance is compared against schemes where clutter suppression is organized by means of background removal and the cross correlation with a reference wavelet. The performance comparison is done in terms of receiver operating characteristic curves. It has been found that the suggested algorithm reduces the false alarm rate in about two and a half times in comparison to the cross-correlation-based clutter suppression. [J281]

"Selection of Contributing Natural Poles for the Characterization of Perfectly Conducting Targets in Resonance Region"

In the resonance region, the radar scattering response of any target can be modeled by natural poles, with the formalism of the singularity expansion method. The mapping of poles gives useful information for the discrimination of radar targets. In this paper, we show that a reduced number of natural poles is sufficient to characterize such objects. Furthermore, we propose a procedure for selecting the poles that actually contribute to the scattering response. Results are presented for various perfectly conducting (PC) canonical targets and for a PC complex shape target. [J282]

"Robust SVA method for every sampling rate condition"

Linear apodization, or data weighting, is the traditional procedure to improve sidelobe levels in a finite sampled signal at the expense of resolution. New apodization methods, such as spatially variant apodization (SVA), apply nonlinear filtering to the signal in order to completely remove sidelobes without any loss of resolution. However, the results are strongly influenced by signal sampling rate. Some variations which improve results have been previously published, but sidelobe cancellation gets worse since sampling frequency is not settled at Nyquist (or

a multiple). This paper presents a new and efficient technique based on SVA that drastically reduces sidelobe levels for every sampling rate condition. The algorithm is, essentially, a parameter optimization of a variant filter for each pixel of the image. A one-dimensional case and a two-dimensional generalization are presented, as well as some applications to target detection capability in a synthetic aperture radar (SAR) system. [J283]

"Adaptive detection of range spread targets with orthogonal rejection"

In this paper we consider the problem of detecting range spread targets in the presence of Gaussian disturbance with unknown covariance matrix. To this end we resort to the modified generalized likelihood ratio test (MGLRT) and devise a robust detector, the orthogonal rejection MGLRT (OR-MGLRT), capable of deciding whether some observations contain a useful target or if they contain a signal belonging to the orthogonal complement of the useful subspace. Hence we investigate the possibility of exploiting the new algorithm as the second stage of a double threshold receiving structure, obtained cascading the MGLRT and the OR-MGLRT. At the analysis stage, we assess the performance of the new double threshold decision rule, both in the matched and mismatched signal cases, also in comparison with previously proposed receivers. The results show that the new test allows for a wide range of compromises between the detection and the rejection performance. [J284]

"An Alternative Model for Target Position Estimation in Radar Processors"

In this paper, we analyze the target position estimation errors induced by conventional radar signal processors, which assume a point-target model in matched filtering-based detection and tracking. As we demonstrated through simulations, the performance degradation under the point-target assumption can be significant for high-resolution radars, where targets extend across several detection cells. One of the main contributions of this paper is to provide an alternative model for reflections from extended targets and clutter. We model the events of backscatters from illuminated targets and clutter as a nonhomogenous Poisson process. The corresponding maximum likelihood estimator and the Cramer-Rao lower bound have been derived. Typical target detection process has been simulated and the validity of the model has been verified by using the Kullback-Leibler distance. It has been shown that the new method significantly reduces target position estimation errors compared to the peak picking method. [J285]

"Noise-correlating radar based on retrodirective antennas"

A new retrodirective antenna-based search radar system has been introduced. The suggested system uses a noise correlation technique to detect the presence and the direction of the target. Simulation and analytical results show an order of magnitude improvement in acquisition time of the radar when compared with a phased array antenna-based radar system with the same specifications, except transmit power. To the best knowledge of the authors, no radar of a comparable acquisition time has been designed to this date. Power versus acquisition time tradeoff has been compared with a phased array radar for evaluating performance of the system. The radar is self-tracking due to retrodirectivity of the antenna array, and is much easier to implement, as it does not require any phase shifters etc. [J286]

"Closed-form Pd expression for diagonally-loaded GLRT"

The recent paper by Shnidman [1] introduced two new models for radar target fluctuation. One of them is the noncentral gamma-gamma (NCGG) distribution, specified by a density function expressed as an infinite sum. It is shown here that one can actually derive an expression for the density in terms of the confluent hypergeometric function. A general elementary expression is provided for the associated moments. [J287]

"Application of the Deflection Criterion to Classification of Radar SAR Images"

An original application of the weighted deflection is proposed for radar target classification by quadratic filters. An explicit formulation of optimal filters is derived. We analyze the impact of the weighting parameter on real data recognition and show that performances are better when the deflection coincides with the Fisher ratio. [J288]

"Along-Track Focusing of Airborne Radar Sounding Data From West Antarctica for Improving Basal Reflection Analysis and Layer Detection"

This paper presents focused synthetic aperture radar (SAR) processing of airborne radar sounding data acquired with the High-Capability Radar Sounder system at 60 MHz. The motivation is to improve basal reflection analysis for water detection and to improve layer detection and tracking. The processing and reflection analyses are applied to data from Kamb Ice Stream, West Antarctica. The SAR processor correlates the radar data with reference echoes from subsurface point targets. The references are 1-D responses limited by the pulse nadir footprint or 2-D responses that include echo tails. Unfocused SAR and incoherent integration are included for

comparison. Echoes are accurately preserved from along-track slopes up to about 0.5deg for unfocused SAR, 3deg for 1-D correlations, and 10deg for 2-D correlations. The noise/clutter levels increase from unfocused SAR to 1-D and 2-D correlations, but additional gain compensates at the basal interface. The basal echo signal-to-noise ratio improvement is typically about 5 dB, and up to 10 dB for 2-D correlations in rough regions. The increased noise degrades the clarity of internal layers in the 2-D correlations, but detection of layers with slopes greater than 3deg is improved. Reflection coefficients are computed for basal water detection, and the results are compared for the different processing methods. There is a significant increase in the detected water from unfocused SAR to 1-D correlations, indicating that substantial basal water exists on moderately sloped interfaces. Very little additional water is detected from the 2-D correlations. The results from incoherent integration are close to the focused SAR results, but the noise/clutter levels are much greater. [J289]

"Low elevation sea-surface target tracking using IPDA type filters"

When detecting a target using radar in the presence of multipath fading, the signal to noise ratio (SNR) at receiver can be dramatically reduced at certain ranges due to multipath signal cancellation, which leads to a significant drop of the detection probability at those ranges. The detection of a low elevation sea-surface target (LESST) is one example. For target tracking, this special case contrasts to the usual situation where we may often assume a constant probability of detection. Automatic target tracking requires a measure of track quality to discriminate between true and false tracks. This track quality measure should take both the existence of target and the SNR of the sensor into account, and be consistent with tracking performance. This paper investigates automatic target tracking using the integrated probabilistic data association (IPDA) type filters in the presence of multipath fading. Several existing single-scan probabilistic data association (PDA)-based filters, which calculate the probabilistic measure of track quality while estimating the track state, are evaluated in the scenario of tracking a nonmaneuvering LESST in the presence of both multipath fading and clutter. In addition, a variable Markov chain (VMC) IPDA tracker (IPDA-VMC), which has joint merits of both IPDA and the IPDA with a three state Markov chain (IPDA-M2), has been designed and evaluated here. In the derivation of track quality measure of both IPDA-M2 and 1PDA-VMC, the possibility that a target is present but is temporarily unable to be detected has been explicitly considered. A tracker using this track quality measure for false track discrimination has significantly improved LESST tracking performance. A simulation study verifies that both IPDA-M2 and IPDA-VMC have better capability to handle the LESST tracks and have an improved tracking performance over other PDA-based tracking algorithms under consideration. [J290]

"Optimum and decentralized detection for multistatic airborne radar"

The likelihood ratio test (LRT) for multistatic detection detection is derived for the case where each sensor platform is a coherent space-time radar. Due to the geometric separation of the platforms, target statistics are modeled as independent from platform to platform but constant over the local data on a single platform. Clutter statistics are also assumed independent from platform to platform but have a local space-time correlation structure typical of monostatic space-time adaptive processing (STAP). Moreover, the target Doppler hypothesis varies from platform to platform due to multiple viewing perspectives. Previous published work has investigated the detection improvement obtained by multiple input, multiple output (MIMO) radar. This prior work, however, has only considered white noise. When clutter is considered, the diversity benefit of a MIMO or multistatic radar system is strongly dependent on geometry. We investigate the relationship between geometry and diversity gain for multistatic airborne space-time radar and the effects of this relationship on decentralized and centralized detection. [J291]

"Statistical CLEAN Technique for ISAR Imaging"

Inverse synthetic aperture radar (ISAR) images are frequently used in target classification and recognition applications. Some classifiers often require features that can be more easily obtained by extracting scattering centers from ISAR data rather than by reconstructing ISAR images. An available method for scattering center extraction, namely, the CLEAN technique, was proposed in a recent paper by Yang et al. In this paper, an improvement of this CLEAN technique is proposed that introduces a new method for detecting scattering centers. The proposed technique is based on a Gaussianity test, and its effectiveness is first theoretically proven and then tested on real data. Moreover, a comparison with the technique proposed by Yang et al. is shown. [J292]

"Waveform Design for MIMO Radars"

We consider the problem of waveform design for multiple input/multiple output (MIMO) radars, where the transmit waveforms are adjusted based on target and clutter statistics. A model for the radar returns which incorporates the transmit waveforms is developed. The target detection problem is formulated for that model.

Optimal and suboptimal algorithms are derived for designing the transmit waveforms under different assumptions regarding the statistical information available to the detector. The performance of these algorithms is illustrated by computer simulation. [J293]

"Suboptimum CFAR detectors based on singular-value decomposition"

The realisation of a constant false-alarm rate (CFAR) detector is dealt with, based on an estimation of the clutter covariance matrix and its singular-value decomposition for selecting the type of detector structure to be used. Some results show the performance of this hybrid CFAR detector. [J294]

"Framework and Taxonomy for Radar Space-Time Adaptive Processing (STAP) Methods"

The goal of radar space-time adaptive processing (STAP) is to detect slow moving targets from a moving platform, typically airborne or spaceborne. STAP generally requires the estimation and the inversion of an interference-plus-noise (I+N) covariance matrix. To reduce both the number of samples involved in the estimation and the computational cost inherent to the matrix inversion, many suboptimum STAP methods have been proposed. We propose a new canonical framework that encompasses all suboptimum STAP methods we are aware of. The framework allows for both covariance-matrix (CM) estimation and range-dependence compensation (RDC); it also applies to monostatic and bistatic configurations. Finally, we discuss a taxonomy for classifying the methods described by the framework. [J295]

"Location and Imaging of Moving Targets using Nonuniform Linear Antenna Array SAR"

By using a linear antenna array, velocity synthetic aperture radar (VSAR) can detect, focus, and locate slowly moving targets well. However, it may mis-locate fast moving targets in the azimuth (cross-range) direction. In this correspondence, we propose a synthetic aperture radar (SAR) with a nonuniform linear antenna array and give a design of the antenna arrangement. It is shown that our proposed nonuniform linear antenna array SAR (NULA-SAR) can locate both slowly and fast moving targets correctly. An integrated NULA-SAR algorithm for moving target imaging is also presented, and it is verified by some simulations. [J296]

"Enhancement of Low-Contrast Curvilinear Features in Imagery"

A new method is described for enhancing low-contrast curvilinear features in imagery that combines directional filtering with Fischler, Tenenbaum and Wolf's F*algorithm for computing minimum cost paths. The method exploits a phenomenon called "the stability of lines over angle." The idea is that when a directionally filtered image contains a line plus noise, minimum cost paths tend to be aligned in the direction of the line with random jumps between parallel paths. When the input image contains noise only, the direction of minimum cost paths resemble random walks with drift. As the direction of the filter changes, minimum cost paths that follow true features persist and are more stable over angle than those that follow noise. Adding them up in an accumulator array over angle produces a larger number of votes along signal paths than along noise paths. This provides a means for enhancing trajectories of low-contrast features. Several examples illustrate the enhancement of forest trails in USGS aerial imagery, linear features on Mars, and roads in synthetic aperture radar imagery [J297]

"Integrated track splitting filter--efficient multi-scan single target tracking in clutter"

A fully automatic tracking algorithm must be able to deal with an unknown number of targets, unknown target initiation and termination times, false measurements and possibly time-varying target trajectory behaviour. An efficient algorithm for tracking in this environment is presented here. This approach makes use of estimates of the probability of target existence, which is an integral part of the algorithm. This allows for the efficient generation and management of possible target hypotheses, yielding an algorithm with performance that matches what can be obtained by multiple hypothesis tracking-based approaches, but at a significantly lower computational cost. This paper considers only the single target case for clarity. The extension to multiple targets is easily incorporated into this framework. Simulation studies are given that show the effectiveness of this approach in the presence of heavy and nonuniform clutter when tracking a target in an environment of low probability of detection and in an environment where the target performs violent manoeuvres. [J298]

"Doppler and direction-of-arrival (DDOA) radar for multiple-mover sensing"

A low-cost two-element receiving array concept is investigated for detecting multiple moving targets in indoor surveillance applications. Conventional direction-of-arrival (DOA) detection requires the use of an antenna array with multiple elements. Here we investigate the use of only two elements in the receiver array. The concept entails resolving the Doppler frequencies of the returned signals from the moving targets, and then measuring the phase difference at each Doppler frequency component to calculate the DOA of the targets. Simulations are

performed to demonstrate the concept and to asses the DOA errors for multiple movers. An experimental system is designed and constructed to test the concept. The system consists of a two-element receiver array operating at 2.4 GHz. Measurement results of human subjects in indoor environments are presented, including through-wall scenarios. [J299]

"Dynamic range improvements and measurements in radar systems"

The extension of the dynamic range performance of existing radar systems is integral to the requirement for current sensors to see deeper into clutter, that is, to detect weak signals (e.g. small targets) in the presence of strong interference (e.g. urban clutter signals). The rationale behind this requirement is that this additional capability greatly enhances the utility of military and commercial systems. Two approaches to improving the dynamic range of modern radar and surveillance receivers are described: (1) linearisation of intermodulation distortion (IMD) using digital post-distortion algorithms and (2) linearisation of IMD using frequency retranslation mixer (FRM). The experimental results presented illustrate that the digital post-distortion and FRM approaches are effective in providing IMD improvements for the hardware and test scenarios measured. The improvements measured ranged from 15 to 35 dB for narrowband signals to 2-6 dB for frequency-modulated continuous wave (FMCW) wideband signals. The digital post-distortion approach provided the greatest performance improvement when the input signals were between the analogue-to-digital converter full range and 20 dB below that level. The improvements measured for the FRM linearisation approach ranged from 20 to 25 dB for the narrowband two-tone tests and 16-18 dB for the wideband FMCW signal chirps. [J300]

"Forward scattering radar power budget analysis for ground targets"

An accurate approach to power budget analysis for forward scattering radar with application to the detection of ground targets is presented. A modification of the range equation is used, and the results of experimental testing for its confirmation are given. [J301]

"Correspondence-Optimum Radar Signal for Detection in Clutter"

It is shown that in order to maximize the detectability of a radar target in clutter whose Doppler is unknown and is uniformly distributed over the Doppler bandwidth a simple CW or narrowband signal is optimal. The optimality criterion is the average deflection coefficient, with the averaging being over target Doppler frequency. Most remarkably the result does not depend on the clutter spectrum but holds for any distribution of clutter energy with frequency. [J302]

"Development of a Tunable Multiband UWB Radar Sensor and Its Applications to Subsurface Sensing"

Development of a new tunable multiband ultra-wideband (UWB) radar sensor is presented. The UWB sensor integrates the transmitter, receiver, and antennas completely in a single package using microwave integrated circuits and operates over multiple pulse durations or frequency bands. The sensor can transmit pulses with duration varying from 450 to 1170 ps and peak power from 200 to 400 mW and can detect signals with a conversion gain of 6.5-9.5 dB and a dynamic range of 50dB over a 5.5-GHz RF bandwidth. It has a range resolution of around 1 in. The sensor performs well through tests of various samples, demonstrating its success for subsurface sensing. The multipulse/multiband feature allows the sensor to achieve both fine-range resolution and long operating range and enhanced target detection and classification [J303]

"A New Application for PolSAR Imagery in the Field of Moving Target Indication/Ship Detection"

Recent analysis of a polarimetric synthetic aperture radar (PolSAR) velocity experiment has shown that azimuth ambiguities can provide useful information for the detection of moving targets with an across-track velocity component in PolSAR images using cross-polarization clutter cancellation. This paper examines this phenomenon using theoretical analysis and simulations and illustrates its application with experimental results. It is shown that, for reciprocal scatterers, the phase difference between HV and VH images is zero, whereas for HV and VH ambiguities, the phase difference is pi. For land applications, clutter cancellation is essential for the detection of moving targets in PolSAR images. For maritime applications, it can be used to distinguish images from ambiguities. However, it is important to note that the underlying physical reasons for the performance of clutter cancellation are entirely different from ground moving target indication along-track interferometric SAR. It is also shown that cross-pol clutter cancellation is related to filtering of a double-rate-sampled single-channel SAR signal. [J304]

"Neural Networks for Improved Tracking"

In this letter, we have developed a neural network (NN) based upon modeling fields for improved object tracking. Models for ground moving target indicator (GMTI) tracks have been developed as well as neural architecture incorporating these models. The neural tracker overcomes combinatorial complexity of tracking in highly cluttered scenarios and results in about 20-dB (two orders of magnitude) improvement in signal-to-clutter ratio. [J305]

"Detection of Antipersonnel Mines by Using the Factorization Method on Multistatic Ground-Penetrating Radar Measurements"

The factorization method (FM) has been applied to measurement data from a multistatic ground-penetrating radar operating in close proximity to the ground, which was used in a measurement campaign on the Joint Research Centre mine test lane in Ispra, Italy. This paper is targeted toward a future hand-held demining system. The according space limits restrict an independent positioning of transmit and receive antennas. Hence, very small multistatic datasets are obtained, representing a difficult case for the reconstruction with the FM [J306]

"Radar Target Tracking via Robust Linear Filtering"

In this letter, we provide a robust version of a linear Kalman filter for target tracking based on a measurement conversion technique on the nonlinear radar measurements. We prove that the state estimation error is bounded in a probabilistic sense. We compare our approach with the current state of the art in converted radar measurement-based linear filtering. [J307]

"Moving Targets Processing in SAR Spatial Domain"

This paper presents a novel technique to estimate the initial coordinates and velocity vector of moving targets, including those with velocities above the Nyquist limit, using a single synthetic aperture radar (SAR) sensor without increasing the pulse repetition frequency (PRF). The basic reasoning is that, although the returned echoes may be undersampled in the azimuth direction, their phase and amplitude are informative with respect to the moving target trajectory parameters. Therefore, the so-called blind angle ambiguity, inherent to systems using a single SAR sensor, is overcome. The proposed method samples the data in the spatial domain, along the signature curve which depends on the moving target trajectory parameters. The resulting algorithm is a highly efficient (from the computational point of view) ID matched filter. The effectiveness of the proposed scheme is illustrated using simulated SAR data and real data from the MSTAR public release data set, corresponding to a static SAR scene and a static BTR-60 with simulated motion. [J308]

"HRR Detector for Slow-Moving Targets in Sea Clutter"

The radar detection of targets in the presence of sea clutter has historically relied upon the radial velocity of targets with respect to the radar platform either by exploiting the relative target Dopplers (for targets with sufficient radial velocity) or by discerning the paths targets traverse from scan to scan. For targets with little to no radial velocity component, though, it can become quite difficult to differentiate targets from the surrounding sea clutter. This paper addresses the detection of slow-moving targets in sea clutter using a high resolution radar (HRR) such that the target has perceptible extent in range. Under the assumption of completely random sea clutter spikes based on an epsiv-contaminated mixture model with the signal and clutter powers known, optimal detection performance results from using the likelihood ratio test (LRT). However, for realistic sea clutter, the clutter spikes tend to be a localized phenomenon. Based upon observations from real radar data measurements, a heuristic approach exploiting a salient aspect of the idealized LRT is developed which is shown to perform well when applied to real measured sea clutter. [J309]

"Refraction and Dispersion Effects Compensation for UWB SAR Subsurface Object Imaging"

It is a trend to use airborne or vehicle-borne ultrawideband synthetic aperture radar (UWB SAR) to quickly detect subsurface objects, i.e., landmines or minefields, over large areas from a safe standoff distance. The traditional image formations without considering the refraction and dispersion of electromagnetic wave will lead to locating error and defocusing for subsurface objects. In this paper, an efficient refraction and dispersion effects compensation method is proposed, which can be integrated with the traditional three-stage automatic target detection framework for detection of subsurface landmines. The compensation method can focus and correctly locate multiple objects buried in different soils with different depths over large areas, which satisfies the operating requirement of an airborne or vehicle-borne UWB SAR system. The proposed method is proved efficient for subsurface object imaging by the field data collected by a UWB SAR system. [J310]

"Detection of Depth Changes of a Metallic Target Buried in a Frequency-Dependent Lossy

Halfspace Using the E-Pulse Technique"

The extinction pulse (E-pulse) technique has been widely applied to the problem of free-space radar target identification. In this paper, the possibility of applying the same E-pulse technique to a subsurface target recognition scheme is investigated. In particular, the detection of depth changes of a metallic target is considered with numerical examples that determine the depth of a hip prosthesis model buried inside representative human tissue. [J311]

"On Probing Signal Design For MIMO Radar"

A multiple-input multiple-output (MIMO) radar system, unlike a standard phased-array radar, can choose freely the probing signals transmitted via its antennas to maximize the power around the locations of the targets of interest, or more generally to approximate a given transmit beampattern, and also to minimize the cross-correlation of the signals reflected back to the radar by the targets of interest. In this paper, we show how the above desirable features can be achieved by designing the covariance matrix of the probing signal vector transmitted by the radar. Moreover, in a numerical study, we show that the proper choice of the probing signals can significantly improve the performance of adaptive MIMO radar techniques. Additionally, we demonstrate the advantages of several MIMO transmit beampattern designs, including a beampattern matching design and a minimum sidelobe beampattern design, over their phased-array counterparts. [J312]

"Angular Dependence of -Distributed Sonar Data"

Backscattered signal statistics are widely used for target detection and seafloor characterization. The K-distribution shows interesting properties for describing experimental backscattered intensity statistics. In addition to the fact that its probability distribution function accurately fits actual sonar data, it advantageously provides a physical interpretation linked to the backscattering phenomenon. Sonar systems usually record backscattered signals from a wide angular range across the ship's track. In this context, previous studies have shown that backscatter statistics strongly depend on the incidence angle. In this paper, we propose an extension of previous works to model the angular evolution of the K-distribution shape parameter. This evolution is made clear and analyzed from experimental data recorded with two sonar systems: a 95-kHz multibeam echosounder and a 110-kHz sidescan sonar. Model fitting with data backscattered from six seafloor configurations shows the improvement provided by our extension as compared to two previous models [J313]

"MIMO radar waveform design based on mutual information and minimum mean-square error estimation"

This paper addresses the problem of radar waveform design for target identification and classification. Both the ordinary radar with a single transmitter and receiver and the recently proposed multiple-input multiple-output (MIMO) radar are considered. A random target impulse response is used to model the scattering characteristics of the extended (nonpoint) target, and two radar waveform design problems with constraints on waveform power have been investigated. The first one is to design waveforms that maximize the conditional mutual information (MI) between the random target impulse response and the reflected waveforms given the knowledge of transmitted waveforms. The second one is to find transmitted waveforms that minimize the mean-square error (MSE) in estimating the target impulse response. Our analysis indicates that under the same total power constraint, these two criteria lead to the same solution for a matrix which specifies the essential part of the optimum waveform design. The solution employs water-filling to allocate the limited power appropriately. We also present an asymptotic formulation which requires less knowledge of the statistical model of the target [J314]

"IMMPDAF Approach for Road-Boundary Tracking"

Robust road-boundary extraction/tracking is one of the main problems in autonomous roadway navigation. Although the road boundary can be defined by various means including lane markings, curbs, and borders of vegetation, this paper focuses on road-boundary tracking using curbs. A vehicle-mounted (downward tilted) 2-D laser-measurement system is utilized to detect the curbs. The tracking problem is difficult because both the vehicle is moving and the target is disappearing, reappearing, and maneuvering in clutter. The interacting-multiple-model probabilistic-data-association filter (IMMPDAF) is proposed to solve the problems after detailed analysis. Track initiation, confirmation, and deletion are performed using the sequential-probability-ratio test. Extensive simulations followed by experiments in a campus environment show that the road-boundary tracking utilizing curbs is possible and robust through IMMPDAF [J315]

"Reduced-Dimensional Processing for Ground Moving Target Detection in Distributed Space-Based Radar"

With multisatellite radar systems, several additional features are achieved: multistatic observation, interferometry, ground moving target indication (GMTI). In this letter, a new reduced-dimensional method based on joint pixels sum-difference (Sigma-Delta) data for clutter rejection and GMTI is proposed. The reduced-dimensional joint pixels Sigma-Delta data are obtained by the orthogonal projection of the joint pixels data of different synthetic aperture radar (SAR) images generated by a multisatellite radar system. In the sense of statistic expectation, the joint pixels Sigma-Delta data contain the common and different information among SAR images. Then, the objective of clutter cancellation and GMTI can be achieved by adaptive processing. Simulation results demonstrate the effectiveness and robustness of the proposed method even with clutter fluctuation and image coregistration errors [J316]

"Moving target location and imaging using dual-speed velocity SAR"

Velocity synthetic aperture radar (VSAR) is an effective tool for slowly moving target detection, location and imaging. However, it may mislocate fast moving targets because of the azimuth location ambiguity. The VSAR is generalised from flying with single speed to flying with dual-speed to resolve the azimuth location ambiguity. This new system is named dual-speed velocity SAR (DS-VSAR). Using DS-VSAR, the locations of both slowly and fast moving targets can be estimated accurately, and in the meantime the clutter can be suppressed. Some numerical examples are given to prove the effectiveness of DS-VSAR [J317]

"Introduction to the issue on adaptive waveform design for agile sensing and communication"

The 18 papers in this issue focus on the following areas: waveform design; adaptive waveform design; surveillance and classification in radar; multiple-input multiple-output (MIMO) radar systems; and wireless communications. [J318]

"Arctangent Demodulation With DC Offset Compensation in Quadrature Doppler Radar Receiver Systems"

Direct-conversion microwave Doppler radar can be used to detect cardiopulmonary activity at a distance. One challenge for such detection in single channel receivers is demodulation sensitivity to target position, which can be overcome by using a quadrature receiver. This paper presents a mathematical analysis and experimental results demonstrating the effectiveness of arctangent demodulation in quadrature receivers. A particular challenge in this technique is the presence of dc offset resulting from receiver imperfections and clutter reflections, in addition to dc information related to target position and associated phase. These dc components can be large compared to the ac motion-related signal, and thus, cannot simply be included in digitization without adversely affecting resolution. Presented here is a method for calibrating the dc offset while preserving the dc information and capturing the motion-related signal with maximum resolution. Experimental results demonstrate that arctangent demodulation with dc offset compensation results in a significant improvement in heart rate measurement accuracy over quadrature channel selection, with a standard deviation of less than 1 beat/min [J319]

"Non-coherent radar CFAR detection based on goodness-of-fit tests"

This paper considers the problem of constant false alarm rate (CFAR) detection of radar targets using multiple observations. In the Gaussian clutter scenario, the structure of the optimum (uniformly most powerful) CFAR detector is rather simple, but when the clutter is heavy-tailed, that is non-Gaussian distributed, the derivation of the optimal detector becomes infeasible. For this latter relevant case, a new CFAR algorithm is porposed based on goodness-of-fit (GoF) tests. The performance of the proposed detector is numerically investigated through Monte Carlo simulations assuming heavy-tailed Weibull and Lognormal distributed clutter. Numerical results shown that, in heavy-tailed clutter and also when several interfering targets exist, the proposed detector outperforms the conventional CFAR detector based on binary integration. Performance is also tested processing real sea clutter data collected by a non-coherent navigation radar [J320]

"Adaptive Radar Detection of Distributed Targets in Homogeneous and Partially Homogeneous Noise Plus Subspace Interference"

This paper addresses adaptive radar detection of distributed targets in noise plus interference assumed to belong to a known or unknown subspace of the observables. At the design stage we resort to either the GLRT or the so-called two-step GLRT-based design procedure and assume that a set of noise-only data is available (the so-called secondary data). Detection algorithms have been derived modeling noise vectors, corresponding to different range cells, as independent, zero-mean, complex normal ones, sharing either the same covariance matrix (homogeneous environment) or the same covariance matrix up to possibly different (mean) power levels

between primary data, i.e., range cells under test, and secondary ones (partially homogeneous environment). The performance assessment has been conducted by Monte Carlo simulation, also in comparison to previously proposed detection algorithms, and confirms the effectiveness of the newly proposed ones [J321]

"SAR Polarimetry to Observe Oil Spills"

A study on sea oil spill observation by means of polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on the use of a polarimetric constant false alarm rate filter to detect dark patches over SAR images. Then, the target decomposition theorem is exploited to distinguish oil spills and look-alikes. Experiments are conducted on polarimetric SAR data acquired during the SIR-C/X-SAR mission on October 1994. The data were processed and calibrated at the Jet Propulsion Laboratory, National Aeronautics and Space Administration. Results show that the new polarimetric approach is able to assist classification [J322]

"Improved Multiple Target Tracking via Global Motion Compensation and Optoelectronic Correlation"

Camera motion estimation in image sequences generally focuses on the recovery of the frames when the camera is mounted on a moving platform. Global motion in video sequences is more complex and involves camera operation, camera motion, and other nontarget motions. Global motion compensation is usually handled by compensating the dominant motion using estimation and segmentation techniques. To enhance tracker performance and accuracy, frame recovery operation plays a crucial role by estimating undesired motion. In this paper, a normalized correlation-based regional template-matching (TM) algorithm has been developed to accurately recover frames before the application of the tracking algorithm. Then, a robust multiple-target-tracking system has been developed using a combination of fringe-adjusted joint transform correlator and TM techniques. Joint transform correlation detects a target optoelectronically, while TM technique is performed digitally. To increase the tracking system speed and decrease the effects of clutter, a subframe segmentation and local deviation-based image-preprocessing algorithm has been proposed. The improved performance of multiple-target-tracking system is tested using real-life forward-looking infrared (IR) imagery video sequences obtained from IR sensors mounted on an airborne platform [J323]

"Investigation of Time–Frequency Features for GPR Landmine Discrimination"

Ground-penetrating radar (GPR) is capable to detect plastic antipersonnel landmines as well as other subsurface targets. In order to reduce false alarms, an option of automatic landmine discrimination from neutral minelike targets would be very useful. This paper presents a possibility for such discrimination and analyzes it experimentally. The authors investigate time-frequency features of an ultrawideband (UWB) target response for the discrimination between buried landmines and other objects. The discrimination method includes the extraction of an early-time target impulse response, its time-frequency transformation, and the extraction of time-frequency features based on a singular value decomposition of the transformed image. In order to take into account the changes in the UWB target signals, the experimental conditions are completely controlled to focus on the behavior of the target's response with respect to its depth and the horizontal position of the GPR above it. The dependence of the features on the GPR bandwidth is analyzed as well. The Mahalanobis distance is used as a criterion for optimal discrimination. The obtained results define the best features and conditions when the landmine discrimination is successful. For comparison, the discriminant power of the proposed features has been tested on a dataset, acquired during a field campaign in Angola [J324]

"Measurement of human heartbeat and respiration signals using phase detection radar"

This article introduces a low-cost phase detection radar aimed at measuring the human heartbeat and respiration signals without any physical connections to the human body. A continuous-wave radar targeting the chest will detect the phase difference, resulted by the time-varying target position of the heartbeat, between the transmitted signal and the reflected signal. We have tested the developed radar to measure the heartbeat and respiration signals at a distance of about 40cmfrom the chest. [J325]

"Supervised target detection and classification by training on augmented reality data"

A proof of concept for a model-less target detection and classification system for side-scan imagery is presented. The system is based on a supervised approach that uses augmented reality (AR) images for training computer added detection and classification (CAD/CAC) algorithms, which are then deployed on real data. The algorithms are able to generalise and detect real targets when trained on AR ones, with performances comparable with the state-of-the-art in CAD/CAC. To illustrate the approach, the focus is on one specific algorithm, which uses Bayesian decision and the novel, purpose-designed central filter feature extractors. Depending on how the training database is partitioned, the algorithm can be used either for detection or

classification. Performance figures for these two modes of operation are presented, both for synthetic and real targets. Typical results show a detection rate of more that 95% and a false alarm rate of less than 5%. The proposed supervised approach can be directly applied to train and evaluate other learning algorithms and data representations. In fact, a most important aspect is that it enables the use of a wealth of legacy pattern recognition algorithms for the sonar CAD/CAC applications of target detection and target classification [J326]

"UWB Perimeter Surveillance"

This program will develop an automated and unmanned ultra-wide band (UWB) perimeter surveillance sensor designed to provide detection and tracking of personnel and vehicles at the perimeter of critical areas such as military installations and other such facilities. This effort describes the work being done for the protection of high value assets using a compact system which incorporates two technologies to enhance the probability of detection in stressing environments [J327]

"Bistatic Linear Antenna Array SAR for Moving Target Detection, Location, and Imaging With Two Passive Airborne Radars"

In this paper, we propose a bistatic linear array synthetic aperture radar (BLA-SAR) system for moving target detection, location, and imaging. In the BLA-SAR system, a geostationary satellite is used as a transmitter, and two airborne linear array radars are used as passive receivers, where the transmitted waveforms from the geostationary satellite may have two different carrier frequencies, two linear array antennas on two different airplanes may be equipped with different spacings, or two airplanes may fly with two different velocities. It is shown that, using the BLA-SAR, not only the stationary clutter can be suppressed but also locations of both slow and fast moving targets can be accurately estimated. Furthermore, an effective BLA-SAR algorithm of moving target imaging is also proposed. Lastly, some numerical experiments are given to demonstrate the effectiveness of the BLA-SAR [J328]

"Mutual Interference of Millimeter-Wave Radar Systems"

This paper examines the probability that any millimeter-wave radar systems will interfere mutually by considering spatial, temporal, and operational frequency-related overlaps. It examines the nature and magnitude of the interference under different conditions and for different sensor types before concluding that in an overlapping frequency band, the probability that interference will occur is high. It goes on to demonstrate that, though there are some forms of interference that can be identified and controlled, there are others which are impossible to isolate, resulting in degraded target detection performance and tracking [J329]

"Signal-to-Noise and Resolution Enhancement in Ion Mobility Spectrometry Using Correlation Gating Techniques: Barker Codes"

Ion mobility spectroscopy (IMS) is a technology that is ideally suited for the detection of very low levels of analyte due to its extreme sensitivity and ability to speciate. Detection of common military and industrial explosives using IMS is an ideal application, since IMS can be tailored to be sensitive to compounds that form negative ions such as nitrate-laden explosives. However, realization of a miniaturized IMS-based detection system for explosives has been hampered by limitations in resolution of miniaturized IMS tubes and by the need to preconcentrate explosive samples and then rapidly desorb them creating a transient chemical concentration. We have demonstrated a new gating and data processing technique that takes advantage of pulse compression approaches developed for modern radar systems for decreasing granularity in target identification. We will show that closely spaced peaks can be isolated by adding discriminating codes to the gating signal. We will then employ matched filtering for the received ion current signal greatly improving instrument performance. This scheme is most advantageous to small geometry IMS drift cells that suffer from lack of resolution due to their small size but would improve sensitivity and peak location uncertainty in any geometry IMS tube. Specifically, we have demonstrated a 13 fold increase in signal-to-noise ratio and have effectively decreased the uncertainty in the location of the signal peak by a factor of 4.4 using a 13-bit Barker coding pattern to operate our IMS gating. [J330]

"Bounding the performance of sidescan sonar automatic target recognition algorithms using information theory"

Modern sidescan sonars provide the ability to image the seafloor with increasingly high resolution. With this comes a corresponding increase in complexity of determining the performance of the sensor, with focus shifting from simple signal detection theory to assess the capability for automatic target recognition (ATR) algorithms to discriminate between different objects based on the shape of the projected acoustic shadows on the seafloor.

This paper uses information theory to place bounds on the performance of ATR algorithms which use features based on an object's shadow as a classification cue. Information is used to compute different bounds on the performance of any classification method. The technique is applied to a simple classification task namely to discriminate between circular and square shapes. The effect of sensor characteristics, such as contrast and resolution, are computed. An example is given where the bounds on performance for a sidescan sonar with given characteristics under some environmental conditions are computed. The performance is then analysed as a function of the shapes being classified by changing the circular shape to a superellipse. Although high-frequency imaging sonar is examined here, the method could be applied to other types of monochromatic imagery that contains multiplicative noise. [J331]

"MCMC methods for tracking two closely spaced targets using monopulse radar channel signals"

Four techniques to successfully track two closely spaced and unresolved targets using monopulse radar measurements have been discussed, the quality of such tracking being a determinant of successful detection of target spawn. The paper explores statistical estimation techniques based on the maximum likelihood criterion and Gibbs sampling, and addresses concerns about the accuracy of the measurements delivered thereby. In particular, the Gibbs approach can deliver joint measurements (and the associated covariances) from both targets, and it is therefore natural to consider a joint filter. The ideas are compared, and among the various strategies discussed, a particle filter that operates directly on the monopulse measurements seems to be the best. [J332]

"REPLY TO COMMENTS-REPLY TO THE COMMENT ON "MULTI-RANGE-RESOLUTION RADAR USING SIDEBAND SPECTRUM""

In this paper proposed a method that translates the high SNR of a target at a closer distance to a better range resolution without sacrificing the maximum detection range. It is a well-known fact that radar range resolution is a constant parameter unrelated to the detection range. This is because range resolution is dependent on the transmitted and received signal. At the same time, the signal-to-noise ratio (SNR) is dependent on the detection range. For example, at a distance of half the maximum detection range, the SNR increases by 12 dB from that of the maximum detection range and at one-fourth the distance, it increases by 24 dB. [J333]

"Walled LTSA Array for Rapid, High Spatial Resolution, and Phase-Sensitive Imaging to Visualize Plastic Landmines"

We propose a walled linearly tapered slot antenna (LTSA) array to visualize plastic landmines. Previously, we reported an adaptive nonlinear visualization system based on a complex-valued self-organizing map (CSOM) that deals with complex amplitude texture in reflection images at multiple frequencies. The system distinguishes landmines from clutter by paying attention to textural features obtained by high spatial resolution and wideband reflection measurement. Because the system employed a mechanical scan of a pair of horn antennas, the measurement required a long time. An array antenna can reduce the time. The antenna element to be used there should therefore be compact and wideband. This paper reports the design and fabrication of a walled LTSA array visualization system. The antenna element has a 14 times 28 mm aperture size, and works at the 8-12 GHz frequency band. Because the structure is a simple combination of glass epoxy substrates and metal plates, we can easily fabricate low-cost and lightweight arrays. Electrical switches realize a high-speed scanning of 12 times 12 = 144 elements in total. We also report the results of a visualization experiment, in which plastic landmines are clearly visualized with the array in combination with the adaptive CSOM processing. Detection of landmines at frequencies of 10 GHz is only likely to be possible for targets buried a few centimeter deep or where the soil attenuation is very low. This might be a severe limitation of applicability of the method, as in field conditions soil attenuations of 10 dB or considerably more are commonly encountered, requiring the radar to operate at frequencies below 2-3 GHz. The best solution may be a multisensor system comprising these complementary high- and low-frequency radars. [J334]

"A Novel Direction-Finding Algorithm for Directional Borehole Radar"

A directional borehole radar system has been developed for the purpose of 3-D imaging of subsurface targets in a single-hole measurement. The radar system is equipped with a uniform circular array consisting of four dipole antennas as a receiver in order to realize azimuth bearing sensitivity. We propose a new direction-finding (DF) algorithm that is suitable for directional borehole radar measurement, and we apply this algorithm to actual field measurement data. This algorithm is based on the Adcock DF antenna principle where the complex time series (analytic signal) expression, the optimization, and the filtering procedure are incorporated to provide more accurate estimation. The algorithm was first verified in a transmission measurement in boreholes with a cross-hole configuration (15 m apart from each other) by estimating a direction of the incident wave from a transmitter

to the receiver. Finally, the algorithm was applied to single-hole measurement data to demonstrate the ability to detect the 3-D location of a subsurface tunnel which was located 5.5 m from the borehole. The result showed fairly good agreement with the actual location of the tunnel, i.e., to an azimuth estimation error of within 10deg. [J335]

"Ultra-Wideband Multifunctional Communications/Radar System"

We have designed, simulated, fabricated, and tested an ultra-wideband (UWB) multifunctional communication and radar system utilizing a single shared transmitting antenna aperture. Two surface acoustic wave bandpass chirp filters were used to modulate the radar and communications pulses, generating linear frequency modulation waveforms with opposite slope factors. The system operates at a center frequency of 750 MHz with 500 MHz of instantaneous bandwidth. The measured range resolution is 63 cm (25 in) using targets with a radar cross section of 2.7 m2. The probability of detection was measured to be 99%, and the probability of false alarm was 7% with the communication and radar systems operating simultaneously. The bit error rate for simultaneous communication at 1 Mb/s, and radar at 150 kHz pulse repetition frequency and 1.5-ns pulsewidth is 2e-3. Our UWB multifunctional system demonstrates the ability to simultaneously interrogate the environment and communicate through a shared transmitting antenna aperture, while realizing a simple system architecture with low output power and not employing time-division multiplexing. [J336]

"Multistatic Ground-Penetrating Radar Experiments"

A multistatic ground-penetrating radar (GPR) system has been developed and used to measure the response of a number of targets to produce data for the investigation of multistatic inversion algorithms. The system consists of a linear array of resistive-vee antennas, microwave switches, a vector network analyzer, and a 3-D positioner, all under computer control. The array has two transmitters and four receivers which provide eight bistatic spacings from 12 to 96 cm in 12-cm increments. Buried targets are scanned with and without surface clutter, which is a layer of rocks whose spacing is empirically chosen to maximize the clutter effect. The measured responses are calibrated so that the direct coupling in the system is removed, and the signal reference point is located at the antenna drive point. Images are formed using a frequency-domain beamforming algorithm that compensates for the phase response of the antennas. Images of targets in air validate the system calibration and the imaging algorithm. Bistatic and multistatic images for the buried targets are very good, and they show the effectiveness of the system and processing. [J337]

"Optimum relative speed discretisation for detection of moving objects in wide band SAR"

Here, ground moving target indication (GMTI) using synthetic aperture radar (SAR) is considered. SAR GMTI requires that relative speed between the target and the SAR platform is included in the detection algorithm. A separation between the true relative speed and the relative speed used in the SAR process will cause unfocused targets, and decrease detectability. Blind hypotheses of relative speeds are used in the detection phase of moving targets in SAR. The step size between the hypotheses (or discretisation step) in relative speed involves a trade off between the number of hypotheses to test and detectability. A large number of tests will increase detectability but will also increase computation load and vice versa. The relevance of relative speed increases as the azimuth integration time gets larger. Long integration time is associated with low signature moving target detection in strong clutter environments, or for SAR GMTI at low frequencies. The optimum discretisation of normalised relative speed for moving target detection has been determined. The optimum discretisation is derived from the moving target impulse response. Use of optimum discretisation reduces the computation burden in SAR GMTI and secures the detectability. [J338]

"Adaptive Waveform Design for Improved Detection of Low-RCS Targets in Heavy Sea Clutter"

The dynamic adaptation of waveforms for transmission by active radar has been facilitated by the availability of waveform-agile sensors. In this paper, we propose a method to employ waveform agility to improve the detection of low radar-cross section (RCS) targets on the ocean surface that present low signal-to-clutter ratios due to high sea states and low grazing angles. Employing the expectation-maximization algorithm to estimate the time-varying parameters for compound-Gaussian sea clutter, we develop a generalized likelihood ratio test (GLRT) detector and identify a range bin of interest. The clutter estimates are then used to dynamically design a phase-modulated waveform that minimizes the out-of-bin clutter contributions to this range bin. A simulation based on parameters derived from real sea clutter data demonstrates that our approach provides around 10 dB improvement in detection performance over a nonadaptive system [J339]

"GLRT-Based Direction Detectors in Homogeneous Noise and Subspace Interference"

In this paper, we derive and assess decision schemes to discriminate, resorting to an array of sensors, between

the H0hypothesis that data under test contain disturbance only (i.e., noise plus interference) and the H1hypothesis that they also contain signal components along a direction which is a priori unknown but constrained to belong to a given subspace of the observables. The disturbance is modeled in terms of complex normal random vectors plus deterministic interference assumed to belong to a known subspace. We assume that a set of noise-only (secondary) data is available, which possess the same statistical characterization of noise in the cells under test. At the design stage, we resort to either the plain generalized-likelihood ratio test (GLRT) or the two-step GLRT-based design procedure. The performance analysis, conducted resorting to simulated data, shows that the one-step GLRT performs better than the detector relying on the two-step design procedure when the number of secondary data is comparable to the number of sensors; moreover, it outperforms a one-step GLRT-based subspace detector when the dimension of the signal subspace is sufficiently high [J340]

"Cramйr–Rao Bound Analysis on Multiple Scattering in Multistatic Point-Scatterer Estimation"

The resolution improvements of time reversal methods through exploiting nonhomogeneous media have attracted much interest recently with broad applications, including underwater acoustics, radar, detection of defects in metals, communications, and destruction of kidney stones. In this paper, we analyze the effect of inhomogeneity generated by multiple scattering among point scatterers under a multistatic sensing setup. We derive the Crameacuter-Rao bounds (CRBs) on parameters of the scatterers and compare the CRBs for multiple scattering using the Foldy-Lax model with the reference case without multiple scattering using the Born approximation. We find that multiple scattering could significantly improve the estimation performance of the system and higher order scattering components actually contain much richer information about the scatterers. For the case where multiple scattering is not possible, e.g., where only a single target scatterer exists in the illuminated scenario, we propose the use of artificial scatterers, which could effectively improve the estimation performance of the target despite a decrease in the degrees of freedom of the estimation problem due to the introduced unknown parameters of the artificial scatterers. Numerical examples demonstrate the advantages of the artificial scatterers [J341]

"Optimal Signal Design for Detection of Gaussian Point Targets in Stationary Gaussian Clutter/Reverberation"

In this paper, we address the design of an optimal transmit signal and its corresponding optimal detector for a radar or active sonar system. The focus is on the temporal aspects of the waveform with the spatial aspects to be described in a future paper. The assumptions involved in modeling the clutter/reverberation return are crucial to the development of the optimal detector and its consequent optimal signal design. In particular, the target is assumed to be a Gaussian point target and the clutter/reverberation a stationary Gaussian random process. In practice, therefore, the modeling will need to be assessed and possibly extended, and additionally a means of measuring the "in-situ" clutter/reverberation spectrum will be required. The advantages of our approach are that a simple analytical result is obtained which is guaranteed to be optimal, and also the extension to spatial-temporal signal design is immediate using ideas of frequency-wavenumber representations. Some examples are given to illustrate the signal design procedure as well as the calculation of the increase in processing gain. Finally, the results are shown to be an extension of the usual procedure which places the signal energy in the noise band having minimum power [J342]

"Adaptive Waveform Design and Sequential Hypothesis Testing for Target Recognition With Active Sensors"

Cognitive radar is a recently proposed approach in which a radar system may adaptively and intelligently interrogate a propagation channel using all available knowledge including previous measurements, task priorities, and external databases. A distinguishing characteristic of cognitive radar is that it operates in a closed loop, which enables constant optimization in response to its changing understanding of the channel. In this paper, we compare two different waveform design techniques for use with active sensors operating in a target recognition application. We also propose the integration of waveform design with a sequential-hypothesis-testing framework that controls when hard decisions may be made with adequate confidence. The result is a system that updates multiple target hypotheses/classes based on measured data, customizes waveforms as the class probabilities change, and draws conclusions when sufficient understanding of the propagation channel is achieved [J343]

"Information Theoretic Adaptive Radar Waveform Design for Multiple Extended Targets"

In this paper, we use an information theoretic approach to design radar waveforms suitable for simultaneously estimating and tracking parameters of multiple extended targets. Our approach generalizes the information theoretic water-filling approach of Bell to allow optimization for multiple targets simultaneously. Our paper has three main contributions. First, we present a new information theoretic design criterion for a single transmit

waveform using a weighted linear sum of the mutual informations between target radar signatures and the corresponding received beams (given the transmitted waveforms). We provide a family of design criteria that weight the various targets according to priorities. Then, we generalize the information theoretic design criterion for designing multiple waveforms under a joint power constraint when beamforming is used both at the transmitter and the receiver. Finally, we provide a highly efficient algorithm for optimizing the transmitted waveforms in the cases of single waveform and multiple waveforms. We also provide simulated experiments of both algorithms based on real targets and comment on the generalization of the proposed technique for other design criteria, e.g., the linearly weighted noncausal MMSE design criterion [J344]

"Iterative Generalized-Likelihood Ratio Test for MIMO Radar"

We consider a multiple-input multiple-output (MIMO) radar system where both the transmitter and receiver have multiple well-separated subarrays with each subarray containing closely spaced antennas. Because of this general antenna configuration, both the coherent processing gain and the spatial diversity gain can be simultaneously achieved. We compare several spatial spectral estimators, including Capon and APES, for target detection and parameter estimation. We introduce a generalized-likelihood ratio test (GLRT) and a conditional generalized-likelihood ratio test (cGLRT) for the general antenna configuration. Based on GLRT and cGLRT, we then propose an iterative GLRT (iGLRT) procedure for target detection and parameter estimation. Via several numerical examples, we show that iGLRT can provide excellent detection and estimation performance at a low computational cost [J345]

"Reverberations-The SCR-270 Radar"

The paper discusses the development of SCR-270 radar and the evolution of radar technique. [J346]

"Image feature-based space-time processing for ground moving target detection"

An image feature-based space time processing (IFSTP) algorithm is introduced to effectively detect ground moving targets in clutter and jamming via airborne radar. This new approach exploits the distinct image features of targets and interference signals in the angle-Doppler domain. An image segmentation algorithm, referred to as region growing, extracts targets and interference features in the angle-Doppler domain, and an innovative block-size detection algorithm discriminates between moving targets and interference based on the extracted image features. The proposed IFSTP algorithm is particularly suitable for detecting ground moving targets in highly nonhomogeneous clutter environments, without any requirement for clutter covariance estimation. [J347]

"Geometric symmetry in the quadratic fisher discriminant operating on image pixels"

This correspondence examines the design of Quadratic Fisher Discriminants (QFDs) that operate directly on image pixels, when image ensembles are taken to comprise all rotated and reflected versions of distinct sample images. A procedure based on group theory is devised to identify and discard QFD coefficients made redundant by symmetry, for arbitrary sampling lattices. This procedure introduces the concept of a degeneracy matrix. Tensor representations are established for the square lattice point group (8-fold symmetry) and hexagonal lattice point group (12-fold symmetry). The analysis is largely applicable to the symmetrization of any quadratic filter, and generalizes to higher order polynomial (Volterra) filters. Experiments on square lattice sampled synthetic aperture radar (SAR) imagery verify that symmetrization of QFDs can improve their generalization and discrimination ability [J348]

"Incoherent SAR polarimetric analysis over point targets"

In this letter, we show that the polarimetric behavior of point targets is preserved even in the case of multipolarization incoherent acquisitions. Point targets are defined as targets embedded in one image pixel and presenting a very stable backscatter during the integration time. We discuss in particular how the polarimetric response restoration can be helpful for point target detection and analysis from such acquisitions (e.g., ASAR Alternate Polarization mode of ENVISAT), but also for permanent scatterers interferometry applications. [J349]

"Demining sensor modeling and feature-level fusion by Bayesian networks"

A method for obtaining the Bayesian network (BN) representation of a sensor's measurement process is developed so that the problems of sensor fusion and management can be approached from a unified point of view. Uncertainty, reliability, and causal information embedded in the sensor data are used to build the BN model of a sensor. The method is applied to model ground-penetrating radar, electromagnetic induction, and infrared sensors for humanitarian demining. Structural and parameter learning algorithms are employed to encode relationships among mine features, sensor measurements, and environmental conditions in the BN

model. Inference is used to estimate target features in the presence of heterogeneous soil and varying environmental conditions. A multisensor fusion technique operating on BN models is developed to exploit the complementarity of the sensor measurements. Through the same approach, a BN classifier is obtained to estimate the target typology. The BN models and classifier also compute so-called confidence levels that quantify the uncertainty associated with the feature estimates and the classification decisions. The effectiveness of the approach is demonstrated by implementing these BN tools for the detection and classification of metal and plastic landmines that are characterized by different shape, size, depth, and metal content. Through BN fusion, the accuracy of the feature estimates is improved by up to 64% with respect to single-sensor measurements, and the number of objects that are both detected and classified is increased by up to 62%. [J350]

"Detecting and characterising returns in a pulsed ladar system"

A new multi-spectral laser radar (ladar) system based on the time-correlated single photon counting, time-of-flight technique has been designed to detect and characterise distributed targets at ranges of several kilometres. The system uses six separated laser channels in the visible and near infrared part of the electromagnetic spectrum. The authors present a method to detect the numbers, positions, heights and shape parameters of returns from this system, used for range profiling and target classification. The algorithm has two principal stages: non-parametric bump hunting based on an analysis of the smoothed derivatives of the photon count histogram in scale space, and maximum likelihood estimation using Poisson statistics. The approach is demonstrated on simulated and real data from a multi-spectral ladar system, showing that the return parameters can be estimated to a high degree of accuracy. [J351]

"CFAR detection of extended and multiple point-like targets without assignment of secondary data"

We design and assess adaptive schemes to detect extended and multiple point-like targets embedded in correlated Gaussian noise. Proposed algorithms rely on either the generalized likelihood ratio test (GLRT) or ad hoc procedures. Such detectors make it possible to get rid of distinct secondary data and guarantee the constant false alarm rate (CFAR) property with respect to the covariance matrix of the disturbance. A preliminary performance assessment, conducted by resorting to simulated data, also in comparison to the so-called modified GLRT (MGLRT) proposed in, has shown that newly introduced CFAR detectors may represent a viable means to deal with uncertain scenarios. [J352]

"Prediction of inverse covariance matrix (PICM) sequences for STAP"

In this letter, we study issues associated with applying least-squares estimation to predict the inverse covariance matrix in bistatic airborne radar systems. For the bistatic ground moving target indication radar, the clutter Doppler frequency depends on the range for all array geometries. This range dependency leads to problems in clutter suppression through space-time adaptive processing (STAP) techniques. This paper proposes a new method of obtaining an estimate of the inverse covariance matrix using linear prediction techniques. Simulation results show a significant improvement in processor performance as compared to conventional STAP methods. [J353]

"A coherent model of forest scattering and SAR imaging in the VHF and UHF-band"

We present a coherent scattering model to determine the forest response to an illuminating plane wave in the frequency band 20-300 MHz. In this frequency band, at low frequencies, it is well-known that the waves penetrate the canopy and allow the detection of a hidden target. We have developed a model based on a domain integral representation of the electric field. A decoupling hypothesis is stated and validated, allowing to significantly reduce the numerical complexity of the problem inherent to integral representations. The simulated scattered field is used in a standard synthetic aperture radar (SAR) imaging algorithm to build horizontal and vertical SAR images of a set of trunks and a concealed target. [J354]

"A hardware signal processing platform for sensor systems"

A field programmable gate array-based computing platform for high-speed sensors such as short-range radars is presented. The circuit performs necessary A/D conversions, raw data stream compression and target detection, and constructs a message structure suitable for external displays. In the prototype, USB is the connecting path to a laptop computer. An elementary pulse radar is utilized as an application example. An application interest would be in collision avoidance systems. Observed data transfer rates with real radar input signals were 36 Mbytes/s when typical target detection algorithms were applied. [J355]

"Two-dimensional and three-dimensional NUFFT migration method for landmine detection using

ground-penetrating Radar"

Ground-penetrating radar (GPR) has been widely used for landmine detection due to its high signal-to-noise ratio (SNR) and superior ability to image nonmetallic landmines. Processing GPR data to obtain better target images and to assist further object detection has been an active research area. Phase-shift migration is a widely used method; however, its wavenumber space is nonuniformly sampled because of the nonlinear relationship between the uniform frequency samples and the wavenumbers. Conventional methods use linear interpolation to obtain uniform wavenumber samples and compute the fast Fourier transform (FFT). This paper develops two- and three-dimensional migration methods that process GPR data to obtain images close to the actual target geometries using a nonuniform fast Fourier transform (NUFFT) algorithm. The proposed method is first compared to the conventional migration approaches on simulated data and then applied to landmine field data sets. Results suggest that the NUFFT migration method is useful in focusing images, estimating landmine structure, and retaining relatively high signal-to-noise ratio in the migrated data. The processed data sets are then fed to the normalized energy and least-mean-square-based anomaly detectors. Receiver operating characteristic curves of data sets processed by different migration methods are compared. The NUFFT migration shows potential improvements on both classifiers with a reduced false alarm rate at most probabilities of detection. [J356]

"Uniform versus nonuniform sampling when tracking in clutter"

Many target tracking subsystems have the ability to schedule their own data rates; essentially they can "order" new information whenever they need it, and the cost is in terms of the sensor resource. But among the unmanaged schemes, uniform sampling, in which a new measurement is requested periodically and regularly, is the most commonly-used sampling scheme; deliberately nonuniform schemes are seldom given serious consideration. In this paper, however, we show that such schemes may have been discarded prematurely: a nonuniform sampling can have its benefits. Specifically, the nonuniform and uniform sampling schemes are compared for two kind of trackers: the probabilistic data association filter (PDAF), which updates its track based on a single scan of information at a time; and N-D assignment (an optimization-based implementation of the multi-hypothesis tracker (MHT)), in which the sliding window involves many scans of observations. We find that given the ground rule of maintenance of the same overall scan rate (i.e., the same sensor effort) uniform sampling is always optimal for the single-scan tracker in the sense of track life. However, nonuniform sampling can outperform uniform sampling if a more sophisticated multi-scan tracker is used, particularly when 1) the target has a high process noise, and/or 2) the false alarm density is high, and/or 3) the probability of detection is high. [J357]

"Performance analysis of a novel matched filter detector with reduced out-of-band response for narrowband signals"

Reduced spectral response in adjacent spectral bins is very desirable for detectors since it provides the capability to detect narrowband signals in the presence of unknown interference and colored noise. Recently, a new method of detecting narrowband signals which uses a close approximation to the matched filter is proposed by Raja Kumar. The impulse response of this filter turns out to be longer than that of the matched filter. In order to support this extra length of filter response, it is proposed that the signal be extrapolated by prediction before the filtering operation. In this paper, the characteristics of this detector are mathematically analyzed and the performance of the detector in the presence of additive white Gaussian noise (AWGN) is studied. The detection method uses predicted signals that are obtained typically from short time data. Hence, in this paper, a method of analyzing the statistics of predicted signals from short time data is presented, and it is applied for the performance analysis of the present detector. The accuracy of the present detection analysis is demonstrated through theoretical and simulation studies. Also the analysis and performance study is extended to fluctuating targets, and it is shown that the proposed method yields near-optimum performance for Swerling's Case-1 and Case-3 targets while giving the excellent advantage of low out-of-bin response [J358]

"Performance of an adaptive feature-based processor for a wideband ground penetrating radar system"

A two-stage algorithm for landmine detection with a ground penetrating radar (GPR) system is described. First, 3-D data sets are processed using a computationally inexpensive pre-screening algorithm which flags potential locations of interest. These flagged locations are then passed to a feature-based processor which further discriminates target-like anomalies from naturally occurring clutter. Current field trial (over 6500 square meters) and blind test results (over 39000 square meters) are presented and these show at least an order of magnitude improvement over other radar system-based detection algorithms on the same test lanes. [J359]

"Performance analysis of multistatic configurations for spaceborne GMTI based on the auxiliary beam approach"

In addition to powerful earth imaging and remote sensing, a multistatic spaceborne synthetic aperture radar (SAR) configuration offers the possibility of detecting efficiently the presence of slowly moving targets and surfaces as a result of the large baselines. Such a configuration can be achieved by a constellation of coherent passive satellites receiving the echoes of pulses transmitted by a separate SAR satellite and reflected from the earth. It also enables resolution of the design difficulty of space-based ground moving target indication (GMTI) systems caused by the severe spatial conditions. Owing to the additional degrees of freedom available in a multisatellite constellation compared with a monostatic system, the problem of blindness against certain directions of target motion can be overcome and the sensitivity can be extended to almost any direction of motion, depending on the configuration. For this purpose, non-classical algorithms have to be developed. Because of the high system complexity and the huge amount of data to be processed, only suboptimum methods can be implemented. A suboptimum method is proposed for multistatic spaceborne moving target detection based on the auxiliary beam approach. The main feature of this processing is estimation of both velocity and direction of target motion. According to this method, an analysis of multistatic SAR satellite configurations for their GMTI capability is carried out and the choice of the constellation baselines inferring directly on the expected GMTI sensitivity is discussed. [J360]

"GMTI along-track interferometry experiment"

Synthetic aperture radar (SAR) along track interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. In this paper we describe preliminary results from an ATI GMTI experiment. The SAR data described herein were collected by the dual-frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pickup truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J361]

"Monitoring and surveillance potentialities obtained by splitting the antenna of the COSMO-SkyMed SAR into multiple sub-apertures"

The authors discuss the potentialities obtained by splitting the antenna of the COSMO-SkyMed synthetic aperture radar (SAR), developed by Alenia Spazio under contract to the Italian Space Agency and Italian Ministry of Defence, into multiple sub-apertures. The modified sensor has the capability to detect slowly moving ground targets that compete with the clutter Doppler spectrum. Special attention is devoted to a preliminary analysis of the signal processing techniques to be used. Moreover their capabilities for surveillance purposes are characterised based on theoretical and simulated results. Moreover the modified sensor is shown to allow sea current/wave monitoring by along-track SAR interferometry, relocation of moving targets in high resolution SAR images, and fully polarimetric imaging. Some practical implementation issues related to the possible modification are also briefly discussed. [J362]

"Derivation and comparison of SAR and frequency-wavenumber migration within a common inverse scalar wave problem formulation"

Two common Fourier imaging algorithms used in ground penetrating radar (GPR), synthetic aperture radar (SAR), and frequency-wavenumber (F-K) migration, are reviewed and compared from a theoretical perspective. The two algorithms, while arising from seemingly different physical models: a point-scatterer model for SAR and the exploding source model for F-K migration, result in similar imaging equations. Both algorithms are derived from an integral equation formulation of the inverse scalar wave problem, which allows a clear understanding of the approximations being made in each algorithm and allows a direct comparison. This derivation brings out the similarities of the two techniques which are hidden by the traditional formulations based on physical scattering models. The comparison shows that the approximations required to derive each technique from the integral equation formulation of the inverse problem are nearly identical, and hence the two imaging algorithms and physical models are making similar assumptions about the solution to the inverse problem, thus clarifying why

the imaging equations are so similar. Sample images of landmine-like targets buried in sand are obtained from experimental GPR data using both algorithms. [J363]

"X-band experimental airborne radar-Phase II: synthetic aperture radar and ground moving target indication"

Defence Research and Development Canada, Ottawa, has completed Phase II of a multifunction X-band wideband experimental airborne radar. The system consists of a high average power transmitter, a digital waveform generator, two wideband 8-bit channels for synthetic aperture radar (SAR)/inverse synthetic aperture radar and two narrowband 14-bit channels for ground moving target indication (GMTI). The reflector antenna uses a novel multimode feedhorn to derive two phase centres displaced in azimuth. The radar was designed to support research into SAR imaging of fixed and moving targets (ocean and land), time-frequency analysis of moving targets, clutter suppression for GMTI radar and ocean surveillance for small and large target detection. Highlights of the data collection capabilities, include a swath width 16 K points wide in the single-channel SAR modes, 8 K points wide in the two-channel integrated SAR-GMTI modes and 4 K points wide in the GMTI surveillance modes. The architecture of the radar, its modes of operation with respect to the SAR and GMTI data collection capabilities, the MATLAB-based GMTI processor, and the real-time kernel developed for the SAR processor are discussed; and results from its high resolution stripmap, landspot, seaspot and GMTI modes are presented from trials in July 2003. [J364]

"Cognitive radar: a way of the future"

This article discusses a new idea called cognitive radar. Three ingredients are basic to the constitution of cognitive radar: 1) intelligent signal processing, which builds on learning through interactions of the radar with the surrounding environment; 2) feedback from the receiver to the transmitter, which is a facilitator of intelligence; and 3) preservation of the information content of radar returns, which is realized by the Bayesian approach to target detection through tracking. All three of these ingredients feature in the echo-location system of a bat, which may be viewed as a physical realization (albeit in neurobiological terms) of cognitive radar. Radar is a remote-sensing system that is widely used for surveillance, tracking, and imaging applications, for both civilian and military needs. In this article, we focus on future possibilities of radar with particular emphasis on the issue of cognition. As an illustrative case study along the way, we consider the problem of radar surveillance applied to an ocean environment. [J365]

"Knowledge-based radar signal and data processing: a tutorial review"

Radar systems are an important component in military operations. In response to increasingly severe threats from military targets with reduced radar cross sections (RCSs), slow-moving and low-flying aircraft hidden in foliage, and in environments with large numbers of targets, knowledge-based (KB) signal and data processing techniques offer the promise of significantly improved performance of all radar systems. Radars under KB control can be deployed to utilize valuable resources such as airspace or runways more effectively and to aid human operators in carrying out their missions. As battlefield scenarios become more complex with increasing numbers of sensors and weapon systems, the challenge will be to use already available information effectively to enhance radar performance, including positioning, waveform selection, and modes of operation. KB processing fills this need and helps meet the challenge. [J366]

"Spatial diversity in radars-models and detection performance"

Inspired by recent advances in multiple-input multiple-output (MIMO) communications, this proposal introduces the statistical MIMO radar concept. To the authors' knowledge, this is the first time that the statistical MIMO is being proposed for radar. The fundamental difference between statistical MIMO and other radar array systems is that the latter seek to maximize the coherent processing gain, while statistical MIMO radar capitalizes on the diversity of target scattering to improve radar performance. Coherent processing is made possible by highly correlated signals at the receiver array, whereas in statistical MIMO radar, the signals received by the array elements are uncorrelated. Radar targets generally consist of many small elemental scatterers that are fused by the radar waveform and the processing at the receiver, to result in echoes with fluctuating amplitude and phase. It is well known that in conventional radar, slow fluctuations of the target radar cross section (RCS) result in target fades that degrade radar performance. By spacing the antenna elements at the transmitter and at the receiver such that the target angular spread is manifested, the MIMO radar can exploit the spatial diversity of target scatterers opening the way to a variety of new techniques that can improve radar performance. This paper focuses on the application of the target spatial diversity to improve detection performance. The optimal detector in the Neyman-Pearson sense is developed and analyzed for the statistical MIMO radar. It is shown that the optimal detector consists of noncoherent processing of the receiver sensors' outputs and that for cases of

practical interest, detection performance is superior to that obtained through coherent processing. An optimal detector invariant to the signal and noise levels is also developed and analyzed. In this case as well, statistical MIMO radar provides great improvements over other types of array radars. [J367]

"Impact-time-control guidance law for anti-ship missiles"

In this paper, a new guidance problem with the impact time constraint is investigated, which can be applied to salvo attack of anti-ship missiles. The closed form solution based on the linear formulation is derived, suggesting an additional loop for adjusting the impact time in addition to the traditional optimal guidance loop. This solution is a combination of the well-known PNG law and the feedback of the impact time error, which is the difference between the impact time by PNG and the prescribed impact time. The new guidance law called ITCG (Impact-Time-Control Guidance) can be used to guide multiple missiles to hit a stationary target simultaneously at a desirable impact time. Nonlinear simulation of several engagement situations demonstrates the performance and feasibility of ITCG. In addition, the similarity of the closed form solution and APNG is investigated and the switching rule for practical implementation is discussed. [J368]

"Main beam cochannel interference suppression by range adaptive processing for HFSWR"

The performance of high-frequency (HF) surface wave radar degrades significantly due to cochannel interferences (CCIs) in the user-congested HF band (3-30 MHz). Most of the conventional techniques generally follow a simple spatial adaptive processing (SAP) only in the presence of spatially structured interference, but sometimes, we cannot rely on SAP to cancel interference received through the main beam. In this letter, the correlation function of CCI applied in range domain is analyzed, and a new range adaptive processing technique is utilized to suppress the CCI. Real and simulated data results are presented that the general and robust algorithm can achieve effective CCI suppression without comprising the target detection. [J369]

"Refined estimation of time-varying baseline errors in airborne SAR interferometry"

The processing of airborne synthetic aperture radar (SAR) data requires a precise compensation of the deviations of the platform movement from a straight line. This is usually carried out by recording the trajectory with a high-precision navigation system and correcting them during SAR focusing. However, due to the lack of accuracy in current navigation systems, residual motion errors persist in the images. Such residual motion errors are mainly noticeable in repeat-pass systems, where they are causing time-varying baseline errors, visible as artefacts in the derived phase maps. In this letter, a refined method for the estimation of time-varying baseline errors is presented. An improved multisquint processing approach is used for obtaining robust estimates of higher order baseline errors over the entire scene, even if parts of the scene are heavily decorrelated. In a subsequent step, the proposed method incorporates an external digital elevation model for detection of linear and constant components of the baseline error along azimuth. Calibration targets in the scene are not necessary. [J370]

"Radar target novel characteristic detection method"

In this paper, a method of radar target detection based on 2-dimensional (2D) fractal dimension is proposed. The proposed approach exploits both range information and azimuth information to estimate fractal dimension. Moreover, the approach can increase the number of the data points. The above two merits result in the fractal dimension estimated by this method is more accurate and robust than the previous method. The detection performance is also better than the previous one, which only makes use of 1-dimensional (1-D) information to estimate fractal dimension. Theoretical analysis and experimental result show that the proposed method performs well in strong clutter background. The proposed method is also validated by real-life radar data, and the better result has been achieved. [J371]

"Signal subspace change detection in averaged multilook SAR imagery"

This paper addresses change detection in averaged multilook synthetic aperture radar (SAR) imagery. Averaged multilook SAR images are preferable to full-aperture SAR reconstructions when the imaging algorithm is approximation-based (e.g., polar format processing) or when motion data are not accurate over a long full aperture. We examine the application of a SAR change-detection method, known as signal subspace processing, which is based on the principles of two-dimensional adaptive filtering, and we use it to recognize the addition of surface landmines to a particular area under surveillance. We describe the change-detection problem as a trinary hypothesis testing problem, and define a change signal and its normalized version to determine whether: 1) there is no change in the imaged scene; 2) a target has entered the imaged scene; or 3) a target has exited the imaged scene. A statistical analysis of the error signal is provided to show its properties and merits. Results are presented for averaged noncoherent multilook and coherent single-look X-band SAR imagery. [J372]

"Detection of low observable targets within sea clutter by structure function based multifractal analysis"

Sea clutter is the backscattered returns from a patch of the sea surface illuminated by a radar pulse. Robust detection of targets within sea clutter may strengthen coastal security, improve navigation safety, and help environmental monitoring. However, no simple and reliable methods for detecting targets within sea clutter have been proposed. We introduce the structure function based multifractal theory to analyze 392 sea clutter datasets measured under various sea and weather conditions. It is found that sea clutter data exhibit multifractal behaviors in the time scale range of about 0.01 s to a few seconds, especially for data with targets. The fractal and multifractal features of sea clutter enable us to develop a simple and effective method to detect targets within sea clutter. It is shown that the method achieves very high detection accuracy. It is further shown that in the time scale range of 0.01 s to a few seconds, sea clutter data is weakly nonstationary. The nonstationarity may explain why modeling using distributions such as Weibull, log-normal, K, and compound-Gaussian only offers limited understanding of the physics of sea clutter and is not very effective in detecting targets within sea clutter. [J373]

"GMM-based target classification for ground surveillance Doppler radar"

An automatic target recognition (ATR) algorithm, based on greedy learning of Gaussian mixture model (GMM) is developed. The GMMs were obtained for a wide range of ground surveillance radar targets such as walking person(s), tracked or wheeled vehicles, animals, and clutter. Maximum-likelihood (ML) and majority-voting decision schemes were applied to these models for target classification. The corresponding classifiers were trained and tested using distinct databases of target echoes, recorded by ground surveillance radar. ML and majority-voting classifiers obtained classification rates of 88% and 96%, correspondingly. Both classifiers outperform trained human operators. [J374]

"Preventing Damage by Hidden Objects in Vegetation"

The paper presents the experimental radar-based sensor to operate in environment with vegetation cover for detection and discrimination there the small-sized invisible dielectric and metallic objects. This sensor constitutes a vehicle-housed emergency system for surveillance of area with vegetation ahead on the path of moving vehicle to prevent its contact with hidden objects. The emergency system functioning in basically implemented by real-time electromagnetic imaging of the scene of interest and its following image processing to enhance the target responses. The developed and tested experimental radar techniques are under consideration. The results of experimental examinations in field are presented and discussed. [J375]

"Results on the modified Riccati equation: target tracking applications"

The modified Riccati equation is studied in this paper. This equation has been associated with tracking a target under measurement origin uncertainty. We consider the case of tracking a target with a detection probability less than one. This case has received attention recently, especially in relationship with Cramer Rao bounds. Results on this equation have been derived. We compare these results and point out their importance for performance assessment for target tracking. [J376]

"Tracker and signal processing for the benchmark problem with unresolved targets"

Radar signal processing is particularly important in tracking closely spaced targets and targets in the presence of sea-surface-induced multipath. Closely spaced targets can produce unresolved measurements when they occupy the same range cell of the radar. These issues are the salient features of the benchmark problem for tracking unresolved targets combined with radar management, for which this paper presents the only complete solution to date. In this paper a modified version of a recently developed maximum likelihood (ML) angle estimator, which can produce two measurements from a single (unresolved) detection, is presented. A modified generalized likelihood ratio test (GLRT) is also described to detect the presence of two unresolved targets. Sea-surface-induced multipath can produce a severe bias in the elevation angle measurement when the conventional monopulse ratio angle extractor method is used. A modified version of a recently developed ML angle extractor, which produces nearly unbiased elevation angle measurements and significantly improves the track accuracy, is presented. Efficient radar resource allocation algorithms for two closely spaced targets and targets flying close to the sea surface are also presented. Finally, the IMMPDAF (interacting multiple model estimator with probabilistic data association filter modules) is used to track these targets. It is found that a two-model IMMPDAF performs better than the three-model version used in the previous benchmark. Also, the IMMPDAF with a coordinated turn model works better than the one using a Wiener process acceleration model. The signal processing and tracking algorithms presented here, operating in a feedback manner, form a comprehensive solution to the most realistic

tracking and radar management problem to date. [J377]

"Performance analysis of ML-CFAR detection for partially correlated chi-square targets in Rayleigh correlated clutter and multiple-target situations"

The problem of adaptive constant false alarm rate detection of a pulse-to-pulse partially correlated target with 2K degrees of freedom in pulse-to-pulse partially Rayleigh correlated clutter and multiple-target situations is addressed. Both the target and the clutter covariance matrices are assumed to be known and are modelled as first-order Markov Gaussian processes. An exact expression for the probability of false alarm (Pfa) for the mean level detector is derived. It is shown that it depends on the degree of pulse-to-pulse correlation of the clutter samples. The probability of detection (Pd) is shown to be sensitive to the degree of correlation of the target returns and the degree of correlation of the clutter returns as well. Swerling's well-known cases I, II, III and IV are handled as extreme limits of the proposed model. [J378]

"Modified Riccati equation and its application to target tracking"

The modified Riccati equation is studied here. This modified Riccati equation has already been associated with tracking a target under measurement uncertainty. The authors consider the special case of tracking a target without clutter but with a probability of detection of less than one. This special case has received some attention recently, especially in relationship with Cramer-Rao bounds. Here, some properties of the modified Riccati equation are derived and proved. Also the relationship of the modified Riccati equation with two special suboptimal filters is shown. Furthermore, the relationship with the Cramer-Rao bound and other bounds is studied. [J379]

"Adaptive MFR parameter control: fixed against variable probabilities of detection"

An efficient adaptive parameter control scheme for multi-function radar is used here. The scheme has been designed in such a way that it meets constraints on specific quantities that are relevant for target tracking while minimising the energy spent on a target or track. It is shown here that this efficient scheme leads to a considerable variation of the realised detection probability, even within a single scenario. The authors also show that constraining or fixing the probability of detection to a certain predefined value leads to a considerable increase in the energy spent on the target. This holds even when one optimises the fixed probability of detection. The bottom line message is that the detection probability is not a design parameter by itself, but merely the product of an optimal schedule. [J380]

"Adaptive polarisation-space-time domain radar target detection in inhomogeneous clutter environments"

The polarisation-space-time processing technique performs significantly better than the space-time processing technique, as it makes use of the polarisation information as well as the angle and Doppler information of radar returns when the secondary data set is large enough to overcome the detection loss. However, considering the degree of freedom of the polarisation-space-time processor, it is rarely possible to obtain such a large set of secondary data vectors, especially in an airborne radar target detection where clutter is inhomogeneous and/or non-stationary. Here, two adaptive polarisation-space-time localised processors, which are of significant use in limited secondary data environments, are developed by efficiently combining the space-time localised processor and the polarisation processor. The authors first analyse the performance potential of the polarisation-space-time processors with different configurations because selecting a processor configuration is a critical issue that should be solved prior to developing adaptive algorithms. The detection performance of the adaptive processors developed by considering the performance potential is then derived analytically in terms of the probabilities of detection and false alarm, and a performance comparison is made for limited secondary data environments. [J381]

"Impact of diverse polarisations on clutter statistics"

The author addresses the impact of diverse polarisations on clutter statistics in the context of waveform diversity for multi-functional operation from a specific platform as well as for multiple sensing from multiple platforms. A key issue in this context is that of clutter mitigation via the use of diverse waveforms. Classical space-time adaptive processing (STAP) methods for radar target detection can be viewed in the context of a whiten and match filter. To this end, efficient waveforms that lend themselves for such processing are sought. The author specifically considers a statistical analysis of experimental data collected at low grazing angles to validate the fact that vertical transmit-vertical receive (VV) polarised data conform to Rayleigh scatter, whereas horizontal transmit-horizontal receive data do not. Consequently, VV data are suitable for whiten and match processing

adopted in conventional radar STAP. [J382]

"Forward-looking radar GMTI benefits using a linear frequency diverse array"

The ability to suppress range ambiguous clutter is difficult for forward-looking arrays in GHTI processing. Use of linear frequency diverse array (FDA) is proposed, whereby each array channel operates at a different frequency and produces a range dependent pattern. The FDA significantly increases output signal-to-interference plus noise ratio (SINR) at the range ambiguous clutter Doppler, suggesting detection improvement. Output SINR is shown to increase by as much as 40 dB when compared to a constant frequency array [J383]

"The moving target detector"

The paper presents a brief biographical note about the moving target detector (MTD) radar, the evolution from multiple antenna surveillance radar up to the designs to overcome the limitations of the existing moving target indicator radar [J384]

"LIDAR Sensing for Vehicle Lateral Guidance: Algorithm and Experimental Study"

This paper describes a new vehicle detection system based on a laser imaging, detection, and ranging (LIDAR) sensor, and conducts an experimental study to investigate the sensor's role in the current California PATH vehicle lateral guidance systems. The LIDAR sensor is installed on a controlled vehicle and it can measure the relative distance of the vehicle from a preceding vehicle, by scanning the horizontal plane with laser beams. Environmental clutter becomes the main challenge in data processing, when LIDAR tries to track the desired target. A probabilistic data association-based algorithm has been developed to solve this problem, which has been verified in real-time experiments using two Buick LaSabre vehicles. The experimental study also reveals the relation between the LIDAR outputs and the magnetic reference system widely used by the current PATH lateral control systems, and the results provide the guidelines on how this new sensor system may be used for vehicle lateral guidance [J385]

"Visual Tracking in Cluttered Environments Using the Visual Probabilistic Data Association Filter"

Visual tracking in cluttered environments is attractive and challenging. This paper establishes a probabilistic framework, called the visual probabilistic data-association filter (VPDAF), to deal with this problem. The algorithm is based on the probabilistic data-association method for estimating a true target from a cluster of measurements. There are two other key concepts which are involved in VPDAF. First, the sensor data are visual, similar to the target in the image space, which is a crucial property that should not be ignored in target estimation. Second, the traditional probabilistic data-association filter for the underlying application is vulnerable to stationary disturbances in image space, mainly due to some annoying background scenes which are rather similar to the target. Intuitively, such persistent noises should be separated out and cleared away from the continuous measurement data for seeking successful target detection. The proposed VPDAF framework, which incorporates template matching, can achieve the goal of reliable realtime visual tracking. To demonstrate the superiority of the system performance, extensive yet challenging experiments have been conducted [J386]

"An approach to knowledge-aided covariance estimation"

This paper introduces a parametric covariance estimation scheme for use with space-time adaptive processing (STAP) methods operating in heterogeneous clutter environments. The approach blends both a priori knowledge and data observations within a parameterized model to capture instantaneous characteristics of the cell under test (CUT) and reduce covariance errors leading to detection performance loss. We justify this method using both measured and synthetic data. Performance potential for the specific operating conditions examined herein include: 1) averaged behavior within roughly 2 dB of the optimal filter, 2) 1 dB improvement in exceedance characteristic relative to the optimal filter, highlighting improved instantaneous capability, and 3) impervious ness to corruptive target-like signals in the secondary data (no additional signal-to-interference-plus-noise ratio (SINK) loss, compared with 10 dB or greater loss for the standard STAP implementation), with corresponding detections comparable to the optimal filter case [J387]

"Knowledge-based system for multi-target tracking in a littoral environment"

The paper addresses how to efficiently exploit the knowledge-base (KB), e.g. environmental maps and characteristics of the targets, in order to gain improved performance in the tracking of multiple targets via measurements provided by a ship-borne radar operating in a littoral environment. In this scenario, the nonhomogeneity of the surveillance region makes the conventional tracking systems (not using the KB) very sensitive to false alarms and/or missed detections. It is demonstrated that an effective use of the KB can be

exploited at various levels of the tracking algorithms so as to significantly reduce the number of false alarms, missed detections, and false tracks and improve true target track life. The KB is exploited at two different levels. First, some key parameters of the tracking system are made dependent upon the track location, e.g., sea, land, coast, meteo zones (i.e., zones affected by meteorological phenomena) etc. Second, modifications are introduced to cope with a priori identified regions nit hi high clutter density (e.g. littoral areas, roads, meteo zones etc.). To evaluate the behavior of the proposed knowledge-based tracking systems, extensive results are presented using both simulated and real radar data [J388]

"Multimode adaptive signal processing: a new approach to GMTI radar"

We show how a single reflector antenna with a multimode feed horn can be used in a ground moving target indication (GMTI) radar. In particular, we demonstrate the simultaneous detection and estimation of angular location of a ground moving target via adaptive cancellation of ground clutter [J389]

"Design and analysis of a knowledge-aided radar detector for doppler processing"

In this paper we discuss the combined use of a priori information and adaptive signal processing techniques for the design and the analysis of a knowledge-aided (KA) radar receiver for Doppler processing. To this end, resorting to the generalized likelihood function (GLF) criterion (both one-step and two-step), we design and assess data-adaptive procedures for the selection of training data. Then we introduce a KA radar detector composed of three elements: a geographic-map-based data selector, which exploits some a priori information concerning the topography of the observed scene, a data-adaptive training selector which removes dynamic outliers from the training data, and an adaptive radar detector which performs the final decision about the target presence. The performance of the KA algorithm is analyzed both on simulated as well as on real radar data collected by the McMaster University IPIX radar. The results show that the new KA system achieves a satisfactory performance level and can outperform some previously proposed adaptive detection schemes [J390]

"Stap using knowledge-aided covariance estimation and the fracta algorithm"

In the airborne space-time adaptive processing (STAP) setting, a priori information via knowledge-aided covariance estimation (KACE) is employed in order to reduce the required sample support for application to heterogeneous clutter scenarios. The enhanced FRACTA (FRACTA.E) algorithm with KACE as well as Doppler-sensitive adaptive coherence estimation (DS-ACE) is applied to the KASSPER I & II data sets where it is shown via simulation that near-clairvoyant detection performance is maintained with as little as 1/3 of the normally required number of training data samples. The KASSPER I & II data sets are simulated high-fidelity heterogeneous clutter scenarios which possess several groups of dense targets. KACE provides a priori information about the clutter covariance matrix by exploiting approximately known operating parameters about the radar platform such as pulse repetition frequency (PRF), crab angle, and platform velocity. In addition, the DS-ACE detector is presented which provides greater robustness for low sample support by mitigating false alarms from undernulled clutter near the clutter ridge while maintaining sufficient sensitivity away from the clutter ridge to enable effective target detection performance [J391]

"Multisensor deployment using PCRLBS, incorporating sensor deployment and motion uncertainties"

Recently, a general framework for sensor resource deployment (Hernandez, et. al. 2004) has been shown to allow efficient and effective utilization of a multisensor system. The basis of this technique is to use the posterior Cramer-Rao lower bound (PCRLB) to quantify and control the optimal achievable accuracy of target state estimation. In the original formulation (Hernandez, et. al. 2004) it was assumed that the sensor locations were known without error. In the current paper, the authors extend this framework by addressing the issues of imperfect sensor placement and uncertain sensor movement (e.g., sensor drift). The crucial consideration is then how these two forms of uncertainty are factored into the sensor management strategy. If unaccounted for, these uncertainties will render the output of the resource manager inaccurate and overoptimistic. The authors adjust the PCRLB to account for sensor location uncertainty, and we also allow for measurement origin uncertainty due to missed detections and false alarms. The work is motivated by the problem of tracking a submarine by adaptively deploying sonobuoys from a helicopter. Simulation results are presented to show the advantages of accounting for sensor location uncertainty within this focal domain of antisubmarine warfare. The authors note that the generic nature of the technique allows it to be utilized within other problem domains, including tracking ground-based targets using unattended ground sensors (UGSs) or unmanned aerial vehicles (UAVs) [J392]

"Road-map assisted ground moving target tracking"

Tracking ground targets with airborne GMTI (ground moving target indicator) sensor measurements proves to be

a challenging task due to high target density, high clutter, and low visibility. The exploitation of nonstandard background information such as road maps and terrain information is therefore highly desirable for the enhancement of track quality and track continuity. The present paper presents a Bayesian approach to incorporate such information consistently. It is particularly suited to deal with winding roads and networks of roads. The target dynamics is modeled in quasi one-dimensional road coordinates and mapped onto ground coordinates using linear road segments taking road map errors into account. The case of several intersecting roads with different characteristics, such as mean curvature, slope, or visibility, is treated within an interacting multiple model (IMM) scheme. Targets can be masked both by the clutter notch of the sensor and by terrain obstacles. Both effects are modeled using a sensor-target state dependent detection probability. The iterative filter equations are formulated within a framework of Gaussian sum approximations on the one hand and a particle filter approach on the other hand. Simulation results for single targets taken from a realistic ground scenario show strongly reduced target location errors compared with the case of neglecting road-map information. By modeling the clutter notch of the GMTI sensor, early detection of stopping targets is demonstrated [J393]

"Preventing Damage by Hidden Objects in Vegetation"

The paper presents the experimental radar-based sensor to operate in environment with vegetation cover for detection and discrimination there the small-sized invisible dielectric and metallic objects. This sensor constitutes a vehicle-housed emergency system for surveillance of area with vegetation ahead on the path of moving vehicle to prevent its contact with hidden objects. The emergency system functioning in basically implemented by real-time electromagnetic imaging of the scene of interest and its following image processing to enhance the target responses. The developed and tested experimental radar techniques are under consideration. The results of experimental examinations in field are presented and discussed [J394]

"Clutter Rejection using Peak Curvature"

A typical tracking algorithm takes its input from a peak detector or plot extractor. This process reduces the sensor image data to point measurements and reduces the volume of data that the tracker must process. However, useful information can be lost. This paper shows how the clutter of a peak can be a useful feature for discriminating false alarms and valid detections. The benefit obtained by using this feature is quantified through false track rate on recorded sensor data. On recorded data with difficult clutter conditions, approximately sixty percent of false tracks are rejected by exploiting peak curvature [J395]

"Time-frequency method for detecting an accelerating target in sea clutter"

The authors design a time-frequency (TF) method for use in high-frequency surface-wave radar (HFSWR) for detecting a small accelerating target in sea clutter. The clutter is modelled by pseudo targets moving with Bragg velocity towards and away from the radar. The design is based on the Wigner distribution (WD) defined by Chan (type-III WD, in our terminology) rather than the WD defined by Claasen and Mecklenbrauker (1980) (2times type-I WD, in our terminology). Like the type-I WD, the type-III WD also concentrates a chirp signal onto a straight line in the TF plane. The type-III WD has the following advantages: 1) Its range of unambiguously measurable frequencies (RUMF) is [-pi,pi] rad/s, whereas for the type-I WD the RUMF is [-pi/2,pi/2] rad/s. 2) It allows a target separated from the clutter by pi rad/s to be detected, whereas the type-I WD coalesces such a target with the clutter and thereby mask it. An ambiguity function (AF) was defined corresponding to the type-III WD and use it to derive a smoothed type-III WD that mitigates the clutter. The smoothed type-III WD method is applied to real radar data and shown to be superior to the conventional Fourier transform method. The advantages of the type-III WD over the type-I WD are also demonstrated. The design principles laid out in the paper can also be used to develop a TF method for use in air traffic control radar (ATCR) for detecting an accelerating target in land clutter [J396]

"Training strategies for joint domain localised-space-time adaptive processing in a bistatic environment"

Optimum space-time adaptive processing (STAP) requires knowledge of the true interference covariance matrix. In practice, this matrix is not known and must be estimated from training data, which must be target free and statistically homogeneous with respect to the range gate under test. These conditions are often not satisfied, which degrades the detection performance. Particularly for bistatic ground moving target indication radar, the clutter Doppler frequency depends on range for all array geometries. This range dependency leads to problems in clutter suppression through STAP techniques. The main aim in this paper is to access the relative merits of several strategies associated with STAP weight training for bistatic airborne radar applications. In particular, the issues associated with applying reduced-dimension conventional STAP and in-the-gate processing are studied.

Simulation results show that, for a bistatic radar environment, in-the-gate processing approach performs better than conventional STAP approaches [J397]

"Range/Doppler ambiguity elimination in high-frequency chirp radars"

Range/Doppler ambiguity is an important problem in chirp radar operations with all the existing schemes for ambiguity elimination relying on multiple waveform switching. Now, a new method for ambiguity elimination is proposed. It is based on a single waveform and only involves a series of software computations associated with the instantaneous amplitudes of the target under consideration at adjacent range bins. Besides the ambiguity factor, the instantaneous range of the target is also estimated. The method can greatly improve the target detection and tracking capability of high-frequency chirp radars. Both simulation and real data processing results are demonstrated to validate of the method [J398]

"Adaptive turn rate estimation using range rate measurements"

The coordinated turn (CT) model is often used to track maneuvering target which performs CT motion. The key point to the successful use of this model is to determine the turn rate parameter. A new method to estimate the turn rate by using radar range-rate measurements is presented. First, four possible turn rates can be achieved with the range-rate measurements. Second, the minimum turn rate and its opposite value are chosen to be the possible turn rates. Finally, an interacting multiple model (IMM) algorithm with one constant velocity (CV) model and two CT models is designed to track the maneuvering target which performs uniform and ct motions. Monte-Carlo simulation results show that this algorithm is not only better than equivalent noise approach in tracking performance, but also better than the conventional IMM algorithm with the adaptive turn rate model. Further simulations show that the algorithm is robust with the accuracy of the range-rate measurements [J399]

"Synthetic aperture radar-moving target indicator processing of multi-channel airborne radar measurement data"

Coherent signal processing methods for combining the data that are collected via a multi-channel airborne radar system for moving target detection and image formation, are examined. Methods that convert multi-channel radar data into dual along-track monopulse synthetic aperture radar (SAR) signals of the radiated scene, are studied. A two-dimensional adaptive filtering method that projects the data in one synthesised SAR channel into the signal subspace of the other, is used for blind calibration of the monopulse SAR signals and generation of the moving target indication statistic. The merits of these algorithms are studied using the data from the multi-channel airborne radar measurement system that has been developed by the Air Force Research Laboratory at Rome, New York [J400]

"Adaptive Detection and Interference Rejection of Multiple Point-Like Radar Targets"

We present an adaptive algorithm aimed at detecting multiple point-like radar targets embedded in correlated Gaussian noise. The proposed detector modifies and improves the adaptive beamformer orthogonal rejection test (ABORT) idea to address detection of multiple targets. More precisely, it relies on the so-called two-step generalized likelihood ratio test (GLRT) design procedure implemented without assignment of a distinct set of secondary data. The newly proposed detector can guarantee the constant false alarm rate (CFAR) property and the performance assessment, conducted resorting to simulated data, has shown that it exhibits better rejection capabilities of mismatched signals than previously proposed detectors, at the price of an acceptable performance loss for matched signals [J401]

"Investigations on the polarimetric behavior of a target near the soil"

The polarimetric behavior of the diffracted field from an object located close to the ground is investigated for a varying incidence angle. Here, the field is described by the geometrical theory of diffraction in accordance to its asymptotic formulas (krarrinfin). As a result, a ray system composed of 13 different rays was implemented for the monostatic case by applying the principle of Fermat. The different spatial and creeping waves give a physical insight in the mechanisms involved in the entire scattering process. By varying the angle from perpendicular to grazing incidence 0deg-90deg, geometrical surface shadow boundaries are present for the backscattered field. At such boundaries, the spatial waves are replaced by their corresponding creeping waves, leading to a strong attenuation. The diffracted field for look angles related to the transition zones has a characteristic polarimetric behavior, which can be represented on the Poincare sphere. The typical locations on the sphere can be exploited to get information about the geometrical parameters of the target and its height above the ground [J402]

"Imaging Through Unknown Walls Using Different Standoff Distances"

In through-the-wall imaging, errors in wall parameters cause targets to be imaged away from their true positions. The displacement in target locations depend on the accuracy of the estimates of the wall parameters as well as the target position relative to the antenna array. A technique using two or more standoff distances of the imaging system from the wall is proposed for application under wall parameter ambiguities. Two different imaging schemes can then be applied to correct for errors in wall characteristics. The first scheme relies on forming target displacement trajectories, each corresponding to a different standoff distance, and assuming different values of wall thickness and dielectric constant. The target position is then determined as the trajectories crossover point. In the second scheme, an image sequence is generated. Each specific image in this sequence is obtained by summing those corresponding to different standoff distances, but with the same assumed wall parameters. An imaging-focusing metric can then be adopted to determine the target position. The paper analyzes the above two schemes and provides extensive simulation examples demonstrating their effectiveness [J403]

"An Efficient Method of Eliminating the Range Ambiguity for a Low-Cost FMCW Radar Using VCO Tuning Characteristics"

This paper describes a simple method of eliminating the range ambiguity and the design approach for low-cost and small-size homodyne frequency-modulated continuous-wave (FMCW) radars. The range measurement accuracy could be efficiently improved by proper time gating of the beat signal without any closed-loop linearity compensation circuitry for typical varactor-tuned voltage-controlled oscillators (VCOs). The presented selectively gated fast Fourier transformation method is immune to the frequency shift of the VCOs. A W-band FMCW radar using a raw varactor-tuned VCO having the percent linearity of 7.16% was implemented, and achieved less than 2% ranging error of the target lying at 200 m. Owing to the simple structure and fast processing speed, this method is applicable to the various low-cost radar sensors for ranging and detection [J404]

"A hybrid time-domain model of electromagnetic induction from conducting, permeable targets"

Electromagnetic induction (EMI) is a popular technique to detect and discriminate buried unexploded ordnance (UXO). However, modeling of the EMI response from many types of UXO is difficult due to the small skin depth of the interior fields. In grid-based numerical methods, meshing the target volume or surface to resolve the skin depth is often highly impractical, yet a failure to do so yields inaccurate results. This paper addresses the problem with a time-domain hybrid technique based on thin-skin approximation (TSA) that is very accurate for small skin depths. The TSA method is applied to axisymmetric problems and is shown to be both fast and accurate when the skin depth is small. The method is compared with analytical results, and excellent agreement is obtained. For magnetic materials (such as steel), the TSA method is accurate for the complete time-domain EMI response. In such cases, the TSA method provides an improved accuracy along with an order-of-magnitude reduction in CPU time compared to a dense-mesh finite-element method (FEM). For nonmagnetic materials, the TSA loses accuracy as time progresses and must be combined with a coarse-mesh FEM. In such cases, the combined method still provides greater accuracy with comparable CPU time [J405]

"Lossless Information Fusion for Active Ranging and Detection Systems"

The authors develop a centralized information fusion architecture from basic principles of information theory and Bayesian statistics. It is well known that any clustering, quantizing, or thresholding of data causes loss of information unless a sufficient statistic is computed in the processing. For the case of wideband active ranging systems, the coherent output of an optimum beamformer and a matched filter is a sufficient statistic that can be transmitted to the fusion center. For unknown target velocity, range, and bearing, the wideband space-time matched filter output can be interpreted as a multidimensional wavelet transform or a delay-scale-bearing map. In this paper, a Bayesian, joint estimation-detection approach is used for computation of sufficient statistics and multisensor information fusion. An approach borrowed from sequential Bayesian processing is used to compute prior densities for joint Bayesian estimation-detection. In this approach, a posteriori densities become priors after a coordinate transformation that transforms the outputs of each sensor to a common reference frame for all sensors. Reproducing prior densities are used to simplify Bayesian computation [J406]

"Spectral signature calculations and target tracking for remote sensing"

Enhanced tornado detection and tracking can prevent loss of life and property damage. The research weather surveillance radar (WSR)-88D locally operated by the National Severe Storms Laboratory (NSSL) in Norman, OK, has the unique capability of collecting massive volumes of time-series data over many hours, which provides a rich environment for evaluating our new postprocessing algorithms. With the advent of more memory and computing power, new state-of-the-art algorithms can be explored. In this paper, an approach of identifying

tornado vortices in Doppler spectra is proposed and investigated through the use of neural networks. Once the coordinate of the tornado has been established, the research question becomes the following: Can we apply target tracking algorithms to a volume of radar data to make estimations about where the tornado is going? In recent years, particle filters have attracted great attention in several research communities. These filters are used in problems where time-varying signals must be processed in real time, and the objective is to estimate various unknowns of the signals and to detect events described by the signals. The standard solutions of such problems in many applications are based on the Kalman or extended Kalman filters. In situations when the models that describe the behavior of the system are highly nonlinear and/or the noise that distorts the signals is non-Gaussian, the Kalman-filter-based algorithms provide solutions that may be far from optimal. Here, the path of the tornado follows a path that may be described by a set of nonlinear equations. To estimate the path, the particle filter will provide the better estimates. In addition to the single WSR-88D sensor designs, data fusion and tracing designs are also given for a four-node remote sensor network in central Oklahoma. By incorporating the data from each of the sensors, improvements in tracking are illustrated. The particle-filtering algorithms are especially effective in a networked system of sensors when they are in a data-fusion setting. [J407]

"Signal Waveform's Optimal-under-Restriction Design for Active Sensing"

We consider Signal Waveform's Optimal-under-Restriction Design (SWORD) for active sensing. In the presence of colored interference and noise with known statistical properties, waveform optimization for active sensors such as radar can significantly increase the signal-to-interference-plus-noise ratio needed for much improved target detection. However, the so-obtained optimal waveforms can result in significant modulus variation, poor range resolution, and/or high peak sidelobe levels. To mitigate these problems, we can constrain the waveform optimization problem by restricting the sought-after waveform to be similar to a desired waveform, which is known to have, for example, constant modulus as well as reasonable range resolution and peak sidelobe level. One example of the desired waveform is the widely used linear frequency modulated waveform or chirp. We will provide a detailed solution to the constrained optimization problem and explain how it is related with the existing waveform optimization methods [J408]

"Target Detection and Localization Using MIMO Radars and Sonars"

In this paper, we propose a new space-time coding configuration for target detection and localization by radar or sonar systems. In common active array systems, the transmitted signal is usually coherent between the different elements of the array. This configuration does not allow array processing in the transmit mode. However, space-time coding of the transmitted signals allows to digitally steer the beam pattern in the transmit in addition to the received signal. The ability to steer the transmitted beam pattern, helps to avoid beam shape loss. We show that the configuration with spatially orthogonal signal transmission is equivalent to additional virtual sensors which extend the array aperture with virtual spatial tapering. These virtual sensors can be used to form narrower beams with lower sidelobes and, therefore, provide higher performance in target detection, angular estimation accuracy, and angular resolution. The generalized likelihood ratio test for target detection and the maximum likelihood and Cramer-Rao bound for target direction estimation are derived for an arbitrary signal coherence matrix. It is shown that the optimal performance is achieved for orthogonal transmitted signals. Target detection and localization performances are evaluated and studied theoretically and via simulations [J409]

"Double-Sided Exponentially Tapered GPR Antenna and Its Transmission Line Feed Structure"

A double-sided broadband antenna for applications including ground-penetrating radar for detecting buried target is described. When compared with traditional coplanar-strip antennas, a better performance is achieved with a more practical design for construction. The steps in the design procedure are demonstrated herein. In addition, using incremental segments of current elements, a distributed dipole array model is derived and presented for determining S11in the time domain and for determining the radiation pattern of this antenna. By comparing measured results and HFSS simulations, our straightforward dipole array model of the more complicated antenna structure is justified by the accuracy of the results obtained. Finally, an experimental example is presented to show that this antenna in a GPR system application is effective in detecting even small plastic targets [J410]

"Parametric Inversion Technique for Location of Cylindrical Structures by Cross-Hole Measurements"

A new parametric inversion technique to locate cylindrical structures has been developed for borehole radar cross-hole measurements. The technique calculates prediction errors, focusing on curve shapes of first-arrival times, and explicitly uses known parameters on a target. Two schemes to compare the measured first-arrival time curves with the calculated ones are proposed. One is by taking the errors between curve gradients of measured and calculated first-arrival times, and the other is by taking the cross correlation between calculated

first-arrival times and measured data. The schemes do not need to select the true first-arrival times, which makes this inversion technique robust and easy to use. This technique is validated with synthetic data sets modeling a metallic pipe in homogeneous and heterogeneous medium models. By both models, the inversion technique is able to retrieve the exact location of the pipe, though it employs a rather simple forward model, which can be solved by only geometrical calculations. The technique is applied to measured data sets, and it successfully estimates a pipe location in good agreement with known information. The inversion is also used for an air-filled subsurface cavity with a very simplified forward model, which considers only Snell's law at the cavity-subsurface media interface. It is also able to locate the cavity at a similar location estimated by other conventional techniques [J411]

"High-Accuracy Urban DEM Using Permanent Scatterers"

The permanent scatterers (PS) technique is a powerful operational tool that exploits a long series of synthetic aperture radar data for monitoring ground deformations with millimeter accuracy on a high spatial density grid of pointwise targets. The technique has been applied successfully to a number of applications, from subsidence and volcano monitoring to slow-landslide detection. This paper aims to analyze and demonstrate the positioning capability of the PS technique applied to the generation of urban elevation maps. The problem of the univocal identification of the PS position (discarding pixel-dependent sidelobes, both far and near) is addressed, and an easy and efficient solution is proposed. The results obtained in the Milan site allow the appreciation of the very high quality of an urban digital elevation model retrieved with the PS technique. The ground level of the city is identified with submeter accuracy, and elevated targets, where present, reveal building profiles. The estimated city street level (ranging plusmn3m in 16times18 km2) is then compared to those obtained with the same technique using a descending parallel track and an ascending one. Furthermore, the estimated PS elevation with respect to the ground has been connected to temperature-dependent elongations of high structures [J412]

"Bistatic Synthetic Aperture Radar Imaging: Theory, Simulations, and Validations"

A three-dimensional "full-polarized" model for arbitrary transmitter, receiver and target motions in bistatic synthetic aperture radar configurations is proposed. Qualitative validation of this model is presented through comparison with existing results and quantitative validation is obtained from proposed general analytical resolution equations. To take into account complex targets, geometric theory of diffraction based models are considered. Some numerical results are proposed in bistatic and monostatic configurations which permit to check the performance of the proposed model and to highlight the interest of the bistatic synthetic aperture radar imaging [J413]

"Design of Ultra-Wideband Monopulse Receiver"

In this paper, we propose a novel amplitude-comparison monopulse receiver architecture for ultra-wideband radars. This monopulse receiver consists of four ridged-horn antennas placed in a square-feed configuration, a comparator circuit that generates the monopulse sum and difference signals, cross-correlation receivers that detect the monopulse signals, and an amplitude-comparison monopulse processor that determines the target's angular position. The derived monopulse sum and difference signals are verified through measurements. The derived sum and difference patterns are compared with measured patterns, and they show good agreements-measured 3-dB beamwidth=6.4deg(derived=6deg), measured unambiguous tracking range=plusmn5deg(derived=plusmn5deg), and measured sum pattern sidelobe level=-6 dB (derived=-8 dB) [J414]

"Over-the-horizon radar target tracking using multi-quasi-parabolic ionospheric modelling"

As over-the-horizon radar (OTHR) uses ionosphere reflection to detect and track targets, they are faced with a possible appearance of multi-paths and difficulties in estimating the target's ground location. The multi-quasi-parabolic (MQP) model is a sophisticated ionosphere model from which the electromagnetic waves' propagation can be deduced, as long as the measurement of the elevation angle is known. As the French OTHR Nostradamus measures this angle, the use of this model is proposed to improve target-tracking. This model is directly taken into account in the tracking algorithm equations. Here, the target's ground location estimation is specifically tackled and a method is proposed to handle MQP parameters even if elevation angle measurement resolution is poor. The proposed algorithm, based on a particle filter, enables the estimated model parameters to be dealt with and is able, in some circumstances, to ameliorate their estimations. This approach, applied to OTHR Nostradamus, is compared to a geometric one with numerical simulations and a real data example [J415]

"On the Characterization of Buried Targets Under a Rough Surface Using the Wigner–Ville Transformation"

This letter considers the problem of detecting and characterizing a target buried beneath a rough surface separating two homogeneous half spaces. The problem of detecting the target is tackled by analyzing the frequency-averaged Wigner-Ville function, the purpose of which is to filter out rough surface scattering. Characterization of the target is performed using the iterative solution derived from the Newton-Kantorovitch algorithm as applied to the Wigner-Ville function instead of the scattered field as is usually done. In addition, the scattering model involved in the inversion scheme assumes a flat interface, and surface roughness is handled as clutter. The efficiency of the approach is illustrated through numerical experiments, and the comparison between inversions from the scattered field and the Wigner-Ville function is reported [J416]

"Signal Decomposition by Using the S-Method With Application to the Analysis of HF Radar Signals in Sea-Clutter"

This paper presents a new approach to the time-frequency signal analysis and synthesis, using the eigenvalue decomposition method. It is based on the S-method, the time-frequency representation that can produce a distribution equal or close to a sum of the Wigner distributions of individual signal components. The new time-frequency signal decomposition method is evaluated on the simulated and experimental high-frequency surface-wave radar (HFSWR) data. Results demonstrate that it provides an effective way for analyzing and detecting maneuvering air targets with significant velocity changes, including target signal separation from the heavy clutter. The analysis shows that this method can provide additional insight into the interpretation and processing of radar signals, with respect to the traditional Fourier transform based methods currently used by the HFSWRs. The proposed method could also be used in other signal processing applications [J417]

"Ultra-wideband synthetic aperture radar time-frequency representation image formation"

In ultra-wideband synthetic aperture radar (UWB SAR) imaging, scatterers often perform the frequency- and aspect angle-dependent reflectivity characteristic, which is usually neglected in traditional imaging processing. A novel UWB SAR time-frequency representation image formation (TFRIF) is proposed to retrieve the frequency- and aspect angle-dependent information, which is valuable in target detection. Based on the TFRIF, two fusion schemes are studied: pixel level fusion (PLF) and decision level fusion (DLF). Based on the analytical expressions, it is concluded that TFRIF can extract the reflectivity pattern information with high precision and little sacrifice of the spatial resolutions. Quantitative analyses of spatial resolutions and detectability improvement of the proposed fusion schemes are tested on airborne UWB SAR data. The real data results validate the proposed TFRIF and its associated PLF and DLF schemes [J418]

"Multi-range-resolution radar using sideband spectrum energy"

A radar range resolution is generally determined by its transmitted pulse width and is thus a constant parameter unrelated to the detection range. However, a method has been proposed for greatly improving a radar range resolution by using signal-processing techniques to reduce the received pulse width at the expense of a high target signal-to-noise ratio. In this method, an autocorrelation output is first obtained from a time-series representation of the received signal, and this autocorrelation output is then processed using a least-squares error-shaping filter. This creates a corresponding increase in the bandwidth of the principal frequency spectrum, thereby improving the range resolution. The relationship between this spectral distribution and the range side-lobes in cases where the transmitted signal is a simple pulse or a plain phase-modulated wave is investigated. The interference cancelling effect achieved when a radar based on the proposed scheme receives interference is also investigated [J419]

"FM radio based bistatic radar"

An experimental bistatic radar system is described that detects and tracks targets to ranges in excess of 150 km from the receiver, using echoes from a non-cooperative FM radio transmitter. The system concept and limitations on performance are described, followed by details of the processing used to implement the system. An adaptive filter algorithm is described that is used to efficiently remove interference and strong clutter signals from the receiver channels. A computationally efficient algorithm for target detection using Doppler-sensitive cross-correlation techniques is described. A simple constant false alarm rate algorithm for target detection is described, together with a description of a Kalman filter based target association algorithm. Representative results from the system are provided and compared to truth data derived from air traffic control data. [J420]

"Passive radar using Global System for Mobile communication signal: theory, implementation and measurements"

Passive radars using illuminators of opportunity have attracted much attention in the international radar

community. One existing radio transmission system that may be utilised for this purpose is the Global System for Mobile communication (GSM). This paper presents a study showing the feasibility of using a GSM signal for passive radar. The analysis of the GSM waveform, and any significance or influence it has with respect to the passive radar design considerations are investigated in detail. The paper describes fully the design and implementation of a low-cost GSM-based passive radar prototype in addition to the associated signal processing scheme. Numerous measurements for various ground-moving targets were investigated extensively. The preliminary processing results demonstrate the feasibility of using GSM signals as a radar waveform and have the potential capability to detect and track different types of ground-moving targets. [J421]

"Passive detection using digital broadcasters (DAB, DVB) with COFDM modulation"

For some years, 'coded orthogonal frequency division multiplexing' (COFDM) has been emerging in many European countries. This waveform is used for digital audio broadcasting (DAB) with 1.5 MHz bandwidth and for terrestrial digital video broadcasting (DVB) with 7.6 MHz bandwidth. The objective of the study is to prove the feasibility of target detection using such COFDM broadcasters. After a description of COFDM modulation, the adaptive filter required for zero-Doppler paths cancellation (clutter contributors and transmitters in a single frequency network, SFN, configuration, where all transmitters are identical) is described and applied to experimental data. [J422]

"Target detection by marine radar"

First Page of the Article [J423]

"A novel approach to complex target recognition using RCS wavelet decomposition"

A novel approach to complex target recognition using wavelet decomposition of the radar cross section is introduced. The analysis technique is presented, and it shown how it can be implemented using MATLAB software. Applications in the radar field are then investigated, both for simple and complex targets. The results obtained show that this technique is very promising and yields recognition levels difficult to achieve with any other available technique. [J424]

"Editorial: Passive radar systems"

This IEE Special Issue on passive radar systems coincides with the seventieth anniversary of the first British radar experiment at Daventry in February 1935. The papers in this Special Issue cover the full spectrum of topics currently being researched in the area of passive radar systems. There are papers addressing the use of a variety of transmitters of opportunity -FM radio, digital audio broadcast (DAB), digital video broadcast (DVB), global navigation satellite systems and cell-phone base-stations-plus one paper that looks at detecting targets by radiometry. Other papers examine specific signal processing issues, including the problem of nearby large targets masking smaller more distant targets, improved computational performance for cross-correlation processing and the use of the probability hypothesis density (PHD) tracker to solve the problem of multistatic passive radars with non-directional antennas. Finally, a number of papers look at the issues of performance and deployment modelling and address the problems of optimally siting the radar receivers for passive radar and bearings-only systems and predicting the performance of passive radar systems. A common feature in all the systems described in this Special Issue is the extensive use of digital hardware and software processing and it seems inevitable that in the future we might see the development of passive radar systems that simultaneously exploit a wide range of different transmissions of opportunity. [J425]

"A joint compression-discrimination neural transformation applied to target detection"

Many image recognition algorithms based on data-learning perform dimensionality reduction before the actual learning and classification because the high dimensionality of raw imagery would require enormous training sets to achieve satisfactory performance. A potential problem with this approach is that most dimensionality reduction techniques, such as principal component analysis (PCA), seek to maximize the representation of data variation into a small number of PCA components, without considering interclass discriminability. This paper presents a neural-network-based transformation that simultaneously seeks to provide dimensionality reduction and a high degree of discriminability by combining together the learning mechanism of a neural-network-based PCA and a backpropagation learning algorithm. The joint discrimination-compression algorithm is applied to infrared imagery to detect military vehicles. [J426]

"Rank-deficient robust Capon filter bank approach to complex spectral estimation"

We consider nonparametric complex spectral estimation using an adaptive filtering-based approach where the

finite-impulse response (FIR) filter bank is obtained via a rank-deficient robust Capon beamformer. We show that, by allowing the sample covariance matrix to be rank deficient, we can achieve much higher resolution than existing approaches, which is useful in many applications, including radar target detection and feature extraction. Numerical examples are provided to demonstrate the performance of the new approach as compared to the existing data-adaptive and data-independent FIR filtering-based spectral estimation methods. [J427]

"Image residue approach for masked targets detection and estimation"

We propose a new approach to the detection of masked targets and the estimation of target parameters with significant computational savings over standard approaches to this problem based on the CLEAN algorithm. In particular, our approach implements the CLEAN process efficiently because only a few select samples are used instead of using all samples from the matched filter output. For situations in which the signal amplitude and phase need to be estimated, we propose a modified data model for the algorithm so that these parameters and the image residues can be estimated simultaneously. We also provide a detection algorithm having a quantitative way for selecting detection samples and residue samples such that the detection performance is optimized. [J428]

"Passive coherent location radar systems. Part 2: waveform properties"

Resolution and ambiguity in both range and Doppler are parameters of fundamental importance in the design and subsequent performance of any radar system. In this paper, practical measurements of transmitted waveforms are reported and used to illustrate their effects on the resulting system design and performance. In particular, the 'self-ambiguity' which enables the limits on range and Doppler resolution to be evaluated is computed. The bistatic form of the ambiguity function is subsequently presented and used to illustrate how these best case parameters vary as a function of transmitter, receiver and target locations. Understanding the forms that these functions can take and subsequently the implications for system performance is most important if this type of radar is to be used effectively. It is shown that the radar designer does in fact have some limited freedoms to improve system performance. Finally, the implications of transmitter waveform and bistatic geometry on target detection, location and imaging are discussed. [J429]

"Multi-static entirely passive detection of moving targets and its limitations"

The concept of fully passive detection of moving targets based on thermal radiation in the microwave range is presented. The classical approach for target detection, based on a single receiver, allows detection of the target in the case when its temperature is significantly higher than the background. The fundamental problem, i.e., distinction between stationary and moving targets, may be solved using a multilateral system, and examining the range-Doppler correlation function among signals obtained from diverse sensor localisation in the multi-static constellation. The range equation and some limitations of the presented method are discussed. [J430]

"Probability hypothesis density-based multitarget tracking with bistatic range and Doppler observations"

R.P.S. Mahler's probability hypothesis density (PHD) provides a promising framework for the passive coherent location of targets observed via multiple bistatic radar measurements. A particle filter implementation of the Bayesian PHD filter is applied to target tracking using both range and Doppler measurements from a simple non-directional receiver that exploits non-cooperative FM radio transmitters as its 'illuminators of opportunity'. Signal-to-noise ratios, probabilities of detection and false alarm and bistatic range and Doppler variances are incorporated into a realistic two-target scenario. Bistatic range cells are used in calculating the birth particle proposal density. The tracking results are compared to those obtained when the same tracker is used with range-only measurements. This is done for two different probabilities of false alarm. The PHD particle filter handles ghost targets well and has improved tracking performance when incorporating Doppler measurements along with the range measurements. This improved tracking performance, however, comes at the cost of requiring more particles and additional computation. [J431]

"Application of feature extraction methods for landmine detection using the Wichmann/Niitek ground-penetrating radar"

Ground-penetrating radar (GPR) has been proposed as an alternative to classical electromagnetic induction techniques for the landmine detection problem. The Wichmann/Niitek system provides a good platform for novel GPR-based antitank mine detection and classification algorithm development due to its extremely high SNR. When the GPR sensor is mounted on a moving vehicle, the target signatures are hyperbolas in a time-domain data record. The goal of this work is to extract useful features that exploit this knowledge in order to improve

target detection. The algorithms can be divided into two steps: feature extraction and classification. Preprocessing is also considered to remove both stationary effects and nonstationary drift of the data and to improve the contrast of the desired hyperbolas. The algorithm is evaluated using real data over primarily plastic antitank mines collected with a fielded GPR sensor at a government test site. [J432]

"Editorial"

The authors state that 2004 has seen a major change to the operation of IEE journals. The entire process of submitting, reviewing, and accepting papers for publication is now carried out online, through a software package called Manuscript Central. The new scheme was introduced in April 2004. The authors acknowledge the roles of various groups in the production of each issue of the IEE journals. They also offer their congratulations to Dr M. Kirscht (his paper entitled 'Detection and imaging of arbitrarily moving targets with single-channel SAR' has been awarded the 2004 Clarke-Griffiths Memorial Premium). [J433]

"Signal processing for perpendicular recording channels with intertrack interference"

Signal processing techniques for perpendicular magnetic recording channels with intertrack interference (ITI) are studied in this paper. Both single-track and joint-track equalization and detection algorithms are considered. Modified minimum mean-square error equalization methods are used to select optimum generalized partial response targets for ITI channels with either dominant additive white Gaussian noise or media noise. Simulation results show that good targets for single-track detection of ITI-free channels may not be acceptable for channels with ITI. Short targets are just slightly worse than longer targets for joint-track detection, making it possible its use in practical systems with ITI. [J434]

"Enhanced visibility of maneuvering targets for high-frequency over-the-horizon radar"

This paper describes a processing algorithm based on high-order ambiguity function (HAF) that increases visibility of maneuvering targets in HF over-the-horizon radar (OTHR). For the presence of the echo backscattered by the target that has significantly varying radial velocity within a coherent integration time (CIT), it is difficult for traditional coherent processing to centralize energy and peaks in Doppler spectrum. Due to the polynomial phase property in the Doppler spectrum of maneuvering target radar echo, HAF is introduced as an efficient parametric tool to estimate the parameters of the polynomial-phase model. And a compensation process follows to eliminate the coherent integration loss (CIL) caused by irregular motion of target. Finally, this method is generalized to the case of multiple maneuvering targets. The corresponding information of acceleration and higher-order radial components after motion decomposition can be extracted directly and is benefit for consequent missions, such as detection and tracking. The experimental results are given to illuminate the validity and efficiency of the proposed method. [J435]

"An electromagnetic approach based on neural networks for the GPR investigation of buried cylinders"

In this letter, neural networks (NNs) are used to reconstruct the geometric and dielectric characteristics of buried cylinders. The NN is designed to work with input data extracted from the transient electric fields scattered by the target. To this aim, a simple simulation of a typical ground-penetrating radar setting is performed and different sets of data examined. Moreover, different neural network algorithms have been exploited, and results have been compared. Finally, the "robustness" of the proposed approach has been tested against noisy data and against uncertainties in the modelization. [J436]

"Detection of stationary foliage-obscured targets by polarimetric millimeter-wave Radar"

This paper introduces a technique to detect the presence of foliage-obscured targets using millimeter-wave radars operating at near-grazing incidence. Radar return from a scene where a target is concealed behind foliage consists of both foliage backscatter return and a polarimetrically distorted and reduced target return. A data acquisition and signal processing technique that takes advantage of temporal decorrelations in foliage is proposed to enhance target detection and resolve it from foliage. Furthermore, an inversion technique is proposed to remove the polarimetric distortions in the target response. The techniques are verified through a series of indoor and outdoor experiments. [J437]

"Multifunction millimeter-wave systems for armored vehicle application"

There is an emerging need for millimeter-wave capabilities on military vehicles; in order to make such capabilities more affordable, we have been experimenting with the notion of combining multiple functions into a single device. The functions to be performed simultaneously include: 1) active protection (AP) radar for point

defense against antitank threats; 2) surveillance radar for airborne and ground targets; 3) trunking radio for mobile ad hoc networking at a high data rate (>100 Mb/s); and 4) combat identification (ID). Due to a unique combination of characteristics, millimeter-wave radios, radars, and other sensors are attractive for military vehicle use. These characteristics include: 1) smaller profile/footprint of the high-gain antennas; 2) adequate weather penetration; 3) antijam, low probability of intercept, low probability of detection; and 4) wide bandwidth. For the combination of applications identified, this need is best met via a system operating near the 35-GHz atmospheric transmission window. Current mobile millimeter-wave ground-based systems (AP radar, wide-band communication, and combat ID) utilize highly directional steerable beams. Mechanical beam steering is usually done, resulting in restricted beam agility. Nevertheless, mechanical beam-steering performance is acceptable for AP radar and combat ID systems (but not for Joint Tactical Radio networked communications). A true multifunction system, however, requires beam-steering speeds that far exceed capabilities of even the best mechanical technologies. This is due to the need to support either networking or simultaneous multifunctions via time-shared beam steering. Thus, a true multifunction system must steer its beam anywhere in the upper hemisphere in less than 1 ms. Phased arrays are the obvious solution to these needs. Unfortunately, past phased-array technologies were unaffordable for Army vehicle application-hence, the multiplicity of systems. However, a new trend in development of affordable phased-array Ka-band antennas enables development of affordable Ka-band multifunction systems. [J438]

"Efficient blobs-to-tracks assignment for ASDE-radar data processing"

The data associatio problem ith sensors providing multiple detections per target is addressed i the paper. This is the case of the ASDE (airport surface detection equipment) radar, used for tracking ground targets moving on a airport surface. Blobs reconnectio and assignment to tracks is jointly carried out i the proposed coupled scheme, ith a extended distance considering all available estimations regarding target positions and attributes. The system takes into account constraints for orst-case computatio requirements, so guaranteeing real-time operation. A heuristic is used to prune the number of hypotheses to be evaluated and keep it belo a fixed bound, guiding the search to the appropriate decisions under such limitations. The system has bee evaluated i some complex scenarios generated by simulation, analysing the trade-off bet ee performance and computation, and it is compared ith a conventional decoupled scheme performing one-to-one associatio of detections to tracks. [J439]

"Target detectio ith high frequency surface ave radar in co-channel interference"

OSMAR2003 high frequency surface ave radar (HFS R) system became operational i the autum of 2003. Apart from providing surveillance of over 40000 square kilometres of the sea environment such as surface current and sea state, the radar facility has the potential of detecting and tracking ships i all eather. Susceptibility of HFS R to external co-channel interference (CCI) may degrade performance significantly. I the paper, the characteristics of co-channel interference are described, and the authors present a comparative analysis of spatial domai and temporal domai interference mitigatio algorithms for target detection. Experimental results confirm that adaptive spatial domai interference suppressio using subarrays and temporal domai interference suppressio based o classical einer predictio filters are both helpful techniques for target detectio i a small-scale antenna array he the incident interference and the target signal have different incoming directions, but the spatial domai technique is likely to distort the angular response of the target signal simultaneously. Alternatively, he the incident interference and the backscattering target signal have the same incoming direction, the adaptive spatial domai algorithm ill simultaneously degrade the target signal hile providing effective interference mitigation, but the temporal domai technique ca ork ell o target detectio hile maintaining distortionless output of the target signal. [J440]

"Time reversal imaging of obscured targets from multistatic data"

The methods employed in time-reversal imaging are applied to radar imaging problems using multistatic data collected from sparse and unstructured phased array antenna systems. The theory is especially suitable to problems involving the detection and tracking (locating) of moving ground targets (MGT) from satellite based phased array antenna systems and locating buried or obscured targets from multistatic data collected from phased array antenna systems mounted on unmanned aerial vehicles (UAV). The theory is based on the singular value decomposition (SVD) of the multistatic data matrix K and applies to general phased array antenna systems whose elements are arbitrarily located in space. It is shown that the singular vectors of the K matrix together with knowledge of the Green function of the background medium in which the targets are embedded lead directly to classical time-reversal based images of the target locations as well as super-resolution images based on a generalized Multiple-Signal-Classification algorithm recently developed for use with the K matrix. The theory is applied in a computer simulation study of the TechSat project whose goal is the location of MGTs from an unstructured and sparse phased array of freely orbiting antennas located above the ionosphere. [J441]

"Monopulse Radar detection and localization of multiple unresolved targets via joint bin Processing"

If several closely spaced targets fall within the same radar beam and between two adjacent matched filter samples in range, monopulse information from both of these samples can and should be used for estimation, both of angle and of range (i.e., estimation of the range to sub-bin accuracy). Similarly, if several closely spaced targets fall within the same radar beam and among three matched filter samples in range, monopulse information from all of these samples should be used for the estimation of the angles and ranges of these targets. Here, a model is established, and a maximum likelihood (ML) extractor is developed. The limits of the number of targets that can be estimated are given for both case A, where the targets are in a beam and in a range "slot" between the centers of two adjacent resolution cells (that is, from detections in two adjacent matched filter samples), and case B, where the targets are in two or more adjacent slots (among three or more adjacent samples). A minimum description length (MDL) criterion is used to detect the number of targets between the matched filter samples, and simulations support the theory. [J442]

"Optimization of waveform and detection threshold for range and range-rate tracking in clutter"

We address an optimization problem to obtain the combined sequence of waveform parameters (pulse amplitudes and lengths, and FM sweep rates) and detection thresholds for optimal range and range-rate tracking in clutter. The optimal combined sequence minimizes a tracking performance index under a set of parameter constraints. The performance index includes the probability of track loss and a function of estimation error covariances. The track loss probability and the error covariances are predicted using a hybrid conditional average algorithm. The effect of the false alarms and clutter interference is taken into account in the prediction. A measurement model in explicit form is also presented which is developed based on the resolution cell in the delay-Doppler plane for a single Gaussian pulse. Numerical experiments were performed to solve the optimization problem for several examples. [J443]

"A novel algorithm for ship detection in SAR imagery based on the wavelet transform"

Carrying out an effective control of fishing activities is essential to guarantee a sustainable exploitation of sea resources. Nevertheless, as the regulated areas are extended, they are difficult and time consuming to monitor by means of traditional reconnaissance methods such as planes and patrol vessels. On the contrary, satellite-based synthetic aperture radar (SAR) provides a powerful surveillance capability allowing the observation of broad expanses, independently from weather effects and from the day and night cycle. Unfortunately, the automatic interpretation of SAR images is often complicated, even though undetected targets are sometimes visible by eye. Attending to these particular circumstances, a novel approach for ship detection is proposed based on the analysis of SAR images by means of the discrete wavelet transform. The exposed method takes advantage of the difference of statistical behavior among the ships and the surrounding sea, interpreting the information through the wavelet coefficients in order to provide a more reliable detection. The analysis of the detection performance over both simulated and real images confirms the robustness of the proposed algorithm. [J444]

"Adaptive learning approach to landmine detection"

We consider landmine detection using forward-looking ground penetrating radar (FLGPR). The two main challenging tasks include extracting intricate structures of target signals and adapting a classifier to the surrounding environment through learning. Through the time-frequency (TF) analysis, we find that the most discriminant information is TF localized. This observation motivates us to use the over-complete wavelet packet transform (WPT) to sparsely represent signals with the discriminant information encoded into several bases. Then the sequential floating forward selection method is used to extract these components and thereby a neural network (NNW) classifier is designed. To further improve the classification performance and deal with the problem of detecting mines in an unconstraint environment, the AdaBoost algorithm is used. We integrate the feature selection process into the original AdaBoost algorithm. In each iteration, AdaBoost identifies the hard-to-learn examples and a new set of features which provide the specific discriminant information for these hard samples is extracted adaptively and a new classifier is trained. Experimental results based on measured data are presented, showing that a significant improvement on the classification performance can be achieved. [J445]

"EM-ML algorithm for track initialization using possibly noninformative data"

Initializing and maintaining a track for a low observable (LO) (low SNR, low target detection probability and high false alarm rate) target can be very challenging because of the low information content of measurements. In addition, in some scenarios, target-originated measurements might not be present in many consecutive scans because of mispointing, target maneuvers, or erroneous preprocessing. That is, one might have a set of

noninformative scans that could result in poor track initialization and maintenance. In this paper an algorithm based on the expectation-maximization (EM) algorithm combined with maximum likelihood (ML) estimation is presented for tracking slowly maneuvering targets in heavy clutter and possibly noninformative scans. The adaptive sliding-window EM-ML approach, which operates in batch mode, tries to reject or weight down noninformative scans using the Q-function in the M-step of the EM algorithm. It is shown that target features in the form of, for example, amplitude information (AI), can also be used to improve the estimates. In addition, performance bounds based on the supplemented EM (SEM) technique are also presented. The effectiveness of new algorithm is first demonstrated on a 78-frame long wave infrared (LWIR) data sequence consisting of an FI Mirage fighter jet in heavy clutter. Previously, this scenario has been used as a benchmark for evaluating the performance of other track initialization algorithms. The new EM-ML estimator confirms the track by frame 20 while the ML-PDA (maximum likelihood estimator combined with probabilistic data association) algorithm, the IMM-MHT (interacting multiple model estimator combined with multiple hypothesis tracking) and the EVIM-PDA estimator previously required 28, 38, and 39 frames, respectively. The benefits of the new algorithm in terms of accuracy, early detection, and computational load are illustrated using simulated scenarios as well. [J446]

"Universal equations for radar target detection"

Two equations express detection probability and detectability factor for all Swerling targets and for partially correlated intermediate cases. [J447]

"Convolutional models for buried target characterization with ground penetrating Radar"

Identification of buried antipersonnel landmines with ground penetrating radar (GPR) establishes a need for application-specific scattering models and associated estimation algorithms relating the measured scattered field to target characteristics such as size, material composition and burial depth. To this end, starting from integral representations of the scattered field, we derive frequency- and time-domain convolutional models for the GPR response of buried dielectric and metal mine-like targets, including simple analytical expressions for the target transfer function/impulse response. The main steps in the derivation are the linearization of the scattering problem by either the Born or the Physical Optics approximation, the application of a new far-field backscattering representation of the half-space Green's tensor, and the introduction of point source/receiver models for the GPR antennas and the receiver chain. Using three-dimensional finite-difference time-domain (FDTD) and measured data examples, we illustrate the validity of the convolutional models and how they can be used to characterize buried targets. For the characterization, we make use of a deconvolution algorithm, termed "subset selection deconvolution", which uses our target impulse response approximations as a priori information on the form of the impulse response to be estimated. The results demonstrate the possibility to determine target size and depth from the estimated impulse response with millimeter accuracy under laboratory conditions, both of which are valuable information for landmine identification. [J448]

"Adaptive imaging for forward-looking ground penetrating radar"

Most of the current forward-looking ground-penetrating radar (FLGPR) systems use conventional delay-and-sum (DAS) based methods to form radar images for detection of the target (such as a landmine). However, DAS is a data-independent approach which is known to suffer from low resolution and poor interference and clutter rejection capability. We present a data-adaptive imaging approach for FLGPR image formation based on APES (amplitude and phase estimation) and rank-deficient RCB (robust Capon beamforming). Due to the data-adaptive nature of both APES and RCB, our approach has better resolution and much better interference and clutter rejection capability than the standard DAS-based imaging methods. The excellent performance of the proposed method is demonstrated using experimental data collected via two FLGPR systems recently developed by PSI (Planning Systems, Inc.) and SRI (Stanford Research Institute). [J449]

"Track-before-detect procedures for early detection of moving target from airborne radars"

In this paper we present a family of track-before-detect (TBD) procedures for early detection of moving targets from airborne radars. Upon a sectorization of the coverage area, the received echoes are jointly processed in the azimuth-range-Doppler domain and in the time domain through a Viterbi-like algorithm that exploits the physically admissible target transitions between successive illuminations, in order to collect all of the energy back-scattered during the time on target (TOT). A reduced-complexity implementation is derived assuming, at the design stage, that the target does not change resolution cell during the TOT in each scan. The constant false alarm rate (CFAR) constraint is also englobed in the proposed procedures as well as the possibility of working with quantized data. Simulation results show that the proposed algorithms have good detection and tracking capabilities even for high target velocities and low quantization rates. [J450]

"Radar detection in clutter"

Clutter is defined as any unwanted radar return. The presence of clutter in a range/Doppler cell complicates the detection of a target return signal in that cell. In order to quantify the effect of clutter on the probability of detection, we must first specify sets of models suitable for representing the clutter and target. The simplest and most common model for clutter is based on the gamma density. We include two additional models, the NCG and NCGG clutter models for low grazing angles. They are motivated by physical arguments, the latter of which can accommodate the well-known phenomenon of speckle. Using one of these models for clutter together with one of several models for targets, we determine, in a range/Doppler cell, expressions for probabilities of detection of a target in the presence of clutter. It is important to control the probability of false alarms. The presence of clutter in a cell necessitates an increase in the detection threshold setting in order to control false alarms, thus lowering the probability of detection. If the clutter level is unknown, then we need to take measurements of the clutter and use it to adjust the threshold. The more clutter samples we take, the better the estimate of the clutter level and the less is the resulting detection loss. Using the expressions for the probability of detection in clutter, we can quantify the detection loss for a pair of commonly used constant false-alarm rate (CFAR) techniques and investigate how the loss varies with different parameter values, especially with regard to the number of clutter samples taken to estimate the clutter level. [J451]

"Robust adaptive radar detection in the presence of steering vector mismatches"

In this paper, we consider the problem of robust radar detection in the presence of Gaussian disturbance with unknown covariance matrix. We design and assess three new robust adaptive detectors, capable of operating in the presence of unknown discrepancies between the nominal and the actual steering vector. Remarkably the new decision rules exhibit a bounded constant false alarm rate (CFAR) behavior and allow, through the regulation of a design parameter, to trade off target sensitivity with sidelobes energy rejection. Finally, computer simulations show that the proposed detectors achieve a visible performance improvement, in many situations of practical interest, over the traditional adaptive detection algorithms, especially in the presence of severe steering vector mismatches. [J452]

"Particle filter track-before-detect application using inequality constraints"

{no data available} [J453]

"Sensor systems signal processing platform"

A field programmable gate array-based computing platform for high-speed sensors such as short-range radars is presented. The circuit performs necessary A/D conversions, raw data stream compression and target detection, and constructs a message structure suitable for external displays. In the prototype, USB is the connecting path to a laptop computer. An elementary pulse radar is utilized as an application example. An application interest would be in collision avoidance systems. Observed data transfer rates with real radar input signals were 36 Mbytes/s when typical target detection algorithms were applied. [J454]

"Ultra-wideband low-cost phased-array radars"

Emerging radar applications require phased arrays that can operate over wide bandwidths to support multiband/multifunction operation. In response to that need, this paper presents a cost-effective implementation for extremely wide-band phased-array radars. Two designs are demonstrated, one operating from 3 to 12 GHz and the other operating from 8 to 20 GHz. These designs incorporate ultra-wideband antipodal tapered slot antennas, a novel cross-polarization suppressed array architecture, piezoelectric true-time-delay phase shifters, and broad-band high-power monolithic amplifiers. The resulting systems provide target detection and beam steering over the complete operating bandwidths. These results exceed the state-of-the-art for phased-array radars in terms of bandwidth and cost and should have direct applications in the development of ultra-wideband and multifunction radar systems. [J455]

"Use of dynamic radar signature for multistatic passive localisation of helicopter"

The passive radar concept is very attractive with regard to the covertness and detectability of a low-altitude flying target by use of low-frequency opportunistic signals. Detection performances are described in a large number of published papers showing the feasibility of passive detection. Accurate localisation of a target is more problematic, because it requires appropriate opportunistic signals for range compression as well as a large receiving antenna for accurate angular measurement. The introduced concept considers the exploitation of the dynamic signatures returned by helicopters to facilitate their localisation. A multistatic configuration with at least three receivers is considered. Flash echoes observed on each of the bistatic radars are detected and processed

in a coherent manner to derive a set of angles used to triangulate the target position. Simulations are described including an approximate modelling of the bistatic radar cross-section. Analysis of different multistatic configurations is carried out. Further possible improvements of the concept are also introduced. [J456]

"Fast versus slow scan radar operation for coherent small target detection in sea clutter"

Small maritime surface targets can be difficult to distinguish from sea clutter in radar backscattered signals, but discrimination may be improved by using coherent detectors within the dwell time of a scanning radar. Non-coherent integration, coherent integration, the Kelly detector and the adaptive linear quadratic detector are considered. Target detectability may also be improved by combining the results of a single dwell across multiple scans. Overall target detection times of 2, 5 and 10 s are considered and the trade-off between within-scan dwell time and multiple scan processing gain is investigated. Analysis of high-range-resolution coherent X-band data of small boats reveals that faster scan rates with corresponding shorter dwell times provide improved target detection performance over slower scan rates and longer dwell times. [J457]

"Optimal dwell time for approach-warning radar"

An analysis of radar signals is provided with details appropriate in the design of short range long dwell time radar systems, e.g. missile warning radar. It considers nonuniform amplitude return details from target range translation during long dwell times and provides an expression for dwell time that optimizes signal-to-noise ratio (SNR). [J458]

"On the Impact of Covariance Contamination for Adaptive Detection in Hyperspectral Imaging"

Adaptive detection has been a staple in areas such as radar and sonar for a number of years. A key tenet of adaptive detectors is their use of a "noise only" covariance estimate from a secondary data set. When samples bearing the target signal are included in this covariance estimate, it becomes contaminated. The impact of covariance contamination is evaluated for three popular adaptive detection statistics. Multiple test cases are presented using real data, not simulations, and it is shown that significant contamination occurs with as few as eight target samples included in a 100 000+ sample covariance estimate. In addition to number of samples, sensitivity of the detection statistic to contamination from targets present also depends on algorithm type. Hyperspectral imaging (HSI) data offer insight into the impact of covariance contamination on adaptive detection and how it is related to signal-to-noise ratio (SNR) and spectral similarity. [J459]

"A Classification Approach Based on SVM for Electromagnetic Subsurface Sensing"

In clearing terrains contaminated or potentially contaminated by landmines and/or unexploded ordnances (UXOs), a quick wide-area surveillance is often required. Nevertheless, the identification of dangerous areas (instead of the detection of each subsurface object) can be enough for some scenarios/applications, allowing a suitable level of security in a cost-saving way. In such a framework, this paper describes a probabilistic approach for the definition of risk maps. Starting from the measurement of the scattered electromagnetic field, the probability of occurrence of dangerous targets in an investigated subsurface area is determined through a suitably defined classifier based on a support vector machine. To assess the effectiveness of the proposed approach and to evaluate its robustness, selected numerical results related to a two-dimensional geometry are presented. [J460]

"Efficient robust AMF using the FRACTA algorithm"

The FRACTA algorithm has been shown to be an effective space-time adaptive processing (STAP) methodology for the airborne radar configuration in which there exists nonhomogeneous clutter, jamming, and dense target clusters. Further developments of the FRACTA algorithm are presented here in which the focus is on the robust, efficient implementation of the FRACTA algorithm. Enhancements to the FRACTA algorithm include a censoring stopping mechanism, an alternative data blocking approach for adaptive power residue (APR) censoring, and a fast reiterative censoring (RC) procedure. Furthermore, a coherent processing interval (CPI) segmentation scheme for computing the adaptive weights is presented as an alternative approach to computing the adaptive matched filter (AMF) weight vector that allows for lower sample support and reduced computational complexity. The enhanced FRACTA algorithm, denoted as FRACTA.E, is applied to the KASSPER I challenge datacube which possesses dense ground target clusters that are known to have a significant deleterious effect on standard adaptive matched filtering (AMF) processors. It is shown that the FRACTA.E algorithm outperforms and is considerably more computationally efficient than both the original FRACTA algorithm and the standard sliding window processing (SWP) approach. Furthermore, using the KASSPER I datacube, the FRACTA.E algorithm is shown to have the same detection performance as the clairvoyant algorithm where the exact range-dependent clutter covariance matrices are known. [J461]

"Multiple model nonlinear filtering for low signal ground target applications"

The design and implementation of a multiple model nonlinear filter (MMNLF) for ground target tracking using ground moving target indicator (GMTI) radar measurements is described. Like the well-known interacting multiple model Kalman filter (IMMKF), the MMNLF is based on the theory of hybrid stochastic systems. However, since it models the probability distribution for the target in a region, rather than just the distribution's first and second moments, a nonlinear filter is able to capture more fine-grained detail of the target motion and requires fewer models than typical IMMKF implementations. This is illustrated here with a two-model MMNLF in which one motion model incorporates terrain constraints while the second is a nearly constant velocity (CV) model. Another feature of the MMNLF is that it enables incorporation of prethresholded measurements. To implement the filter, the target state conditional probability density is discretized on a set of moving grids and recursively updated with sensor measurements via Bayes' formula. The conditional density is time updated between sensor measurements using alternating direction implicit (ADI) finite difference methods, generalized for this hybrid application. In simulation testing against low signal-to-interference-plus-noise ratio (SINR) targets, the MMNLF is able to maintain track in situations where single model filters based on either of the component models or filters that use thresholded data fail. Potential applications of this work include detection and tracking of foliage-obscured moving targets. [J462]

"Nonparametric rank detectors under K-distributed clutter in radar applications"

This correspondence deals with a comparative analysis of parametric detectors versus rank ones for radar applications, under K-distributed clutter and nonfluctuating and Swerling II target models. We show that the locally optimum detectors (LODs) (optimum for very low signal-to-clutter ratio (SCR)) under K-distributed clutter are not practical detectors; on the contrary, asymptotically optimum detectors (optimum for high SCR) are the practical ones. The performance analysis of the parametric log-detector and the nonparametric (linear rank) detector is carried out for independent and identically distributed (IID) clutter samples, correlated clutter samples, and nonhomogeneous clutter samples. Some results of Monte Carlo simulations for detection probability (Pd) versus SCR are presented in curves for different detector parameter values. [J463]

"Buried cable sensor with intruder location"

A buried cable sensor has been added to the Intrepid family of outdoor perimeter intrusion sensors. The sensor with the trademarked name "MICROTRACK" is similar to the "MICROPOINT" fence sensor with precise detection location, sensitivity leveling, and free format zoning. Intruder location is accomplished with low-power ultra wideband frequency stepped radar driving the sensor cables. Target range resolution also allows the use of sensitivity leveling for each individual range bin. This will compensate for differences in soil conductivity along the length of the cable and for metal objects, which may be located in the near field radiation. The design of the MICROTRACK sensor was presented at the 2002 Carnahan Conference in Atlantic City. It has been described as FM-CW radar, however it differs from the generic form in that the frequency is stepped rather than continuously swept and phase code modulation is added to discriminate against interference. The wide bandwidth of the MICROTRACK sensor fills in the s typical of a single frequency radar and provides a more uniform field profile along the entire length of the sensor cables. This describes the testing that has been performed to characterize the system for different environmental conditions. Southwest Microwave, Inc. has procured an open field site of 31 acres of flat desert land for testing the buried cable. Another site in Canada is used for testing with an additional set of weather and soil conditions. Detection patterns, proximity to stationary objects, and various environmental factors will be discussed. Extensive measurements of both electric and magnetic fields along the length and perpendicular to the sensor cables show a detailed map of the multiple frequency surface wave. When the cables are buried, the uniformity of the field is degraded slightly but no deep s are observed. Site testing has confirmed major benefits of the MICROTRACK sensor:-Uniform Detection Zone-Elimination of Deep Nulls-Precise Target Location-Sensitivity Leveling. [J464]

"Detection of media defects in perpendicular magnetic recording channels"

Two new algorithms for detection of media defects in perpendicular magnetic recording channels are proposed. These algorithms are based on amplitude thresholding of the channel reliability information. The performance of these algorithms is evaluated for low-density parity-check coded channels using generalized partial response targets with different dc-components. [J465]

"Adaptive detection algorithm for full pixel targets in hyperspectral images"

The problem of full pixel target detection (FPTD) in hyperspectral images, assuming that the target spectral signature is known, is considered. We use the replacement target model (RTM). It exploits the fact that in FPTD

problems the target completely fills the image pixel obscuring or replacing the background. The derivation of an RTM-based detection strategy is one of the original contributions of this work. It is assumed that both the background and the target classes are characterised by the Gaussian model and both share the same covariance matrix. Assuming that both the background mean vector and the covariance matrix are unknown, the fully adaptive detector (FAD) is derived. It is shown that the performance of the FAD in typical operating conditions can be approximated by those of the adaptive detector (AD) derived by assuming that the background mean vector is known. The AD is theoretically analysed, its performances are derived and its CFAR behaviour is demonstrated. It is also stated that, in practice, the AD design methodology can be adopted to design FAD automatic target detectors. This issue is proved by simulation in a case study in which the model parameters are estimated from a hyperspectral dataset acquired by the airborne visible/infrared imaging spectrometer (AVIRIS). [J466]

"Ionospheric decontamination and sea clutter suppression for HF skywave Radars"

In this paper, a cascaded correction and suppression method of reducing ionospheric phase path contamination and sea clutter to enable detection of targets travelling at speeds near the Bragg Doppler is addressed. The Hankel rank reduction (HRR) technique based on singular value decomposition (SVD) has been used to estimate the ionospheric phase distortion and suppress the sea clutter. Simulation results show that such a technique is helpful for the worse conditions when the target masking effect happens even after ionospheric phase decontamination. Finally, an attempt to combine another phase decontamination algorithm based on the piecewise polynomial phase modeling with the clutter cancellation stage for faster phase fluctuation is discussed briefly and some results are given. [J467]

"Recursive track-before-detect with target amplitude fluctuations"

A particle-based track-before-detect filtering algorithm is presented. This algorithm incorporates the Swerling family of target amplitude fluctuation models in order to capture the effect of radar cross-section changes that a target would present to a sensor over time. The filter is designed with an existence variable, to determine the presence of a target in the data, and an efficient method of incorporating this variable in a particle filter scheme is developed. Results of the algorithm on simulated data show a significant gain in detection performance through accurately modelling the target amplitude fluctuations. [J468]

"Modified gain extended Kalman filter with application to bearings-only passive manoeuvring target tracking"

The feasibility of Song and Speyer's modified gain extended Kalman filter using bearings-only measurements is explored for underwater applications. A much simpler version of the modified function introduced by Galkowski and Islam is considered for the development of this algorithm. This algorithm estimates target motion parameters and detects target manoeuvre, using zero mean chi-square distributed random sequence residuals, in sliding window format. During the period of target manoeuvring, the covariance of the process noise is increased sufficiently in such a way that the disturbance in the solution is less. When a target manoeuvre is completed, the covariance of process noise is lowered. The performance of this algorithm is evaluated in Monte Carlo simulation and results are shown for various typical geometries. [J469]

"Electromagnetic time-reversal imaging of a target in a cluttered environment"

Electromagnetic time-reversal imaging is addressed for a target situated in a cluttered background. We first investigate the theory of electromagnetic time-reversal imaging, followed by an experimental demonstration. A transmitter-receiver antenna array is connected to a network analyzer and applied to transmit wideband waveforms for detecting a target within a cluttered environment. We assume the cluttered background is fixed, thus the target signature is extracted by observing changes manifested by the introduction of a target. A numerical algorithm is required for computation of the Green's function employed within the time-reversal imager, with this implemented here via ray tracing. Example time-reversal images of different cluttered backgrounds and different targets are presented using measured data, with comparisons to a traditional radar imaging technique. Results show that the time-reversal imagery yields good focusing at the target, significantly better than when the background is not accounted for. [J470]

"A full duplex capable retrodirective array system for high-speed beam tracking and pointing applications"

A retrodirective array capable of full duplex communication is presented. The system is based purely on analog circuits for all signal-processing tasks including target tracking, beam pointing, and carrier recovery. Two types of

receiver architectures are used, i.e., AM diode detectors for near-omni directional coverage and a digital beamforming receiver to enhance signal-to-interference ratio. This paper also discusses this technology in the context of development of a radar target/communication device, which is intended to both facilitate radar imaging and establish a self-tracking communication link between the ground terminal and mobile radar station. Demonstration of 10-Mb/s data receiving and transmitting functions are presented along with its automatic beam-steering ability and radiation patterns, as well as details about each major circuit component used in the array. [J471]

"On the fractal dimension of sea surface backscattered signal at low grazing angle"

Fractal analysis of sea surface backscattering signal (sea clutter in radar terminology) represents a novel technique for the study of sea surface roughness. When Kirchhoff's assumption is satisfied, the fractal dimension of the signal is linearly related to the fractal dimension of the sea surface. Moreover, such a relationship is independent of transmitted frequency, polarization, time, space, sea wave propagation direction, incident angle (within the constraint of Kirchoff's assumption) and significant wave height. Nevertheless, for a low grazing angle, the Kirchhoff approximation does not hold and the behavior of the sea clutter fractal dimension cannot be theoretically predicted. The purpose of this paper is to investigate the fractal dimension of the sea clutter at low grazing angle, in order to extend the theoretical results. Moreover, the effects of the presence of a target on the sea surface are analyzed by means of the fractal dimension. Such an analysis is performed by using live recorded clutter data. In detail, the fractal dimension's dependence on space, time, sea wave propagation direction, sea wave height, transmitted polarization and presence of targets is investigated. A discussion on the use of the sea clutter fractal dimension for sea surface monitoring is addressed. [J472]

"Millimeter-wave measurements of foliage attenuation and ground reflectivity of tree stands at nadir incidence"

In this paper, the phenomenology of wave propagation through foliage and forest ground reflectivity is investigated for assessing the feasibility of foliage-covered target detection at millimeter-wave frequencies. An experimental procedure for simultaneous measurements of foliage attenuation and ground reflectivity is outlined. This measurement procedure is implemented for two different tree stands, one mostly coniferous and the other deciduous, using a nadir-looking, high-resolution, 35-GHz radar positioned above the tree canopy. Statistics of the two-way attenuation and ground reflectivity for these two well-characterized stands are derived. Strong spatial and angular fluctuations in the two-way foliage attenuation coefficient are observed. The mean, standard deviation, and median of the measured two-way attenuation factor at Stand 1 (mostly coniferous trees with 0.140 trees/m2stocking density and 45.45 Kg/m2green biomass) are -25.4, -18.3, and -48.2 dB, respectively, while the mean, standard deviation, and median of the measured two-way attenuation factor at Stand 2 (deciduous trees with 0.1055 trees/m2stocking density and 30.90 Kg/m2green biomass) are -15.4, -12.7, and -33.6 dB, respectively. The mean attenuation rates of Stand 1 and Stand 2, derived from the measured two-way attenuation factor, are 0.40 and 0.24 Np/m, respectively. Only a small percentage of the data had two-way foliage attenuation values exceeding 70 dB. The mean, standard deviation, and median of the power reflectivity of the forest floor at Stand 1 are -14.2, -11.0, and -21.1 dB, respectively, while for Stand 2, the same statistical measures are -16.0, -14.3, and -22.2 dB, respectively. The results demonstrate the potential for using MMW nadir-looking radars for the detection of targets underneath foliage-cover. [J473]

"Detection, location, and imaging of fast moving targets using multifrequency antenna array SAR"

In this correspondence, we generalize the linear antenna array synthetic aperture radar (SAR) from transmitting single-wavelength signals to transmitting multiple-wavelength signals (called multifrequency antenna array SAR). We show that, using multifrequency antenna array SAR, not only the clutters can be suppressed but also the locations of both slow and fast moving targets can be accurately estimated: A robust Chinese remainder theorem (CRT) is developed and used for the location estimation of fast and slowly moving targets. Simulations of SAR imaging of ground moving targets are presented to show the effectiveness of the multifrequency antenna array SAR imaging algorithm. [J474]

"A deep parametric study of resistor-loaded bow-tie antennas for ground-penetrating radar applications using FDTD"

Resistor-loaded bow-tie antennas are analyzed thoroughly to find out their performance on ground-penetrating radar (GPR) applications. The analysis is done with the finite-difference time-domain (FDTD) technique. The antenna is pulse driven and enclosed in a rectangular conducting cavity. The ability to detect a buried conducting sheet using two such identical antennas for transmitting and receiving is investigated. Simulations are carried out for various antenna parameters like end resistor values, flare angle, and antenna length. The gap

between the two antennas and their height above the ground are also varied. Moreover, the results are obtained for different sizes, depths, and positions of the buried sheet. It is studied how the broadband impedance characteristics and better target discrimination with low clutter can be achieved by optimally selecting these antenna parameters. Also, it is shown that apart from the total parallel end resistance, the individual end resistor values and the number of resistors connected have no significant effect on the input impedance and the received signal. [J475]

"Pattern recognition of multiple signals from ground penetrating radar for metal and plastic objects"

The author describes methods for pattern recognition of multiple time signals of embedded targets in water or soil. The received time signals are investigated using characteristic features of metal and plastic pipes in water for better detection of plastic and for soil with noisy signals. The classification of time signals is done by statistical signal parameters, ARMAX, Prony modelling, a new difference vector method of the model transfer function H(z) in the coefficient vector feature space, principal component analysis (PCA), and the classification (more than the estimation or identification) of radar targets via complex frequencies (CNR-complex natural resonances) of these multiple time signals. [J476]

"Maneuver detection using the radar range rate measurement"

Tracking maneuvering targets with radar is complicated because radar cannot directly measure target accelerations. We use the range rate measurement to calculate a new statistic that is a surrogate measurement of target acceleration under a constant rate turn model. Its distribution is found via simulation. A threshold test of the statistic turns out to be a reliable detector of a maneuver. A tracker that uses a threshold test of the new statistic of accelerations to detect maneuvers and set. the process noise in a Kalman filter tracker is developed and compared with other, common maneuvering track filters. The new method compares favorably to a two mode interacting multiple model (IMM) and a tracker that switches process noise levels based on the position measurement innovations. [J477]

"Polarization diversity detection of distributed targets in compound-Gaussian clutter"

We deal with the problem of polarimetric detection of compound-Gaussian clutter with unknown distributed targets in covariance matrix. Since no uniformly most powerful (UMP) detector exists for the problem at hand, we devise and assess two classes of suboptimum receivers. The former contains two detectors, designed according to the Wald and the generalized likelihood ratio tests, which resort to secondary data, free of signal components and with the same covariance structure of the cells under test, for estimating the clutter spectral properties. The latter contains a detector which achieves adaptivity without exploiting the training set All the decision rules ensure the constant false alarm rate (CFAR) property with respect to the texture statistics but they are not theoretically CFAR with respect to the disturbance covariance matrix. Finally, we present simulation results, based also on real clutter data, showing that the Wald test receiver achieves in general a better detection performance and a stronger robustness than its counterparts. [J478]

"Distributed CA-CFAR and OS-CFAR detection using fuzzy spaces and fuzzy fusion rules"

The analysis of distributed CA-CFAR and OS-CFAR detection using fuzzy fusion rules in homogeneous and non-homogeneous backgrounds is presented. Each detector computes the value of the membership function to the false alarm space from the samples of the reference cells and transmits it to the fusion centre. These values are combined according to fuzzy fusion rules to produce a global membership function to the false alarm space. The simulation results indicate that the fuzzy fusion rule corresponding to the algebraic product operator gives better results than the binary AND and binary OR for a homogeneous background and performs robustly in the presence of interfering targets and clutter-edge situations. [J479]

"Detection of sea-surface radar targets based on fractal model"

A novel method for detecting radar targets based on fractal characteristics of sea-surface scattering is proposed, in which the fractional Brownian motion model is used. The experiments show that the method is reliable and can improve the accuracy of detection. [J480]

"Robust adaptive beamforming for HF surface wave over-the-horizon radar"

Adaptive beamforming is used to enhance the detection of target echoes received by high frequency (HF) surface wave (HFSW) over-the-horizon (OTH) radars in the presence of spatially structured interference. External interference from natural and man-made sources typically masks the entire range-Doppler search space and is characterized by a spatial covariance matrix that is time-varying or nonstationary over the coherent

processing interval (CPI). Adaptive beamformers that update the spatial filtering weight vector within the CPI are likely to suppress such interference most effectively, but the intra-CPI antenna pattern fluctuations result in temporal decorrelation of the clutter which severely degrades subclutter visibility after Doppler processing. A robust adaptive beamformer that effectively suppresses spatially nonstationary interference without degrading subclutter visibility is proposed here. The proposed algorithm is computationally efficient and suitable for practical implementation. Its operational performance is evaluated using experimental data recorded by the Iluka HFSW OTH radar, located near Darwin in far north Australia. [J481]

"An asymptotically unbiased E-pulse-based scheme for radar target discrimination"

This communication proposes an E-pulse-based scheme for radar target discrimination that provides asymptotically correct results for any level of additive white noise contaminating the radar signal. After multiple sampling of the signal dispersed by the target, it is analytically shown that the cross correlation between the output signals of the E-pulse designed for the standard target, corresponding to two different sampling periods, is asymptotically, regardless of the amount of contaminating noise. The results obtained by simulation have allowed us to propose a discrimination criterion that produces better results than the original E-pulse technique at very low signal-to-noise ratio (SNR) levels. [J482]

"Millimeter-Wave Radar Targets and Clutter [JBook Review]"

{no data available} [J483]

"Waveform fusion in sonar signal processing"

In active sonar systems, proper selection of the transmitted waveform is critical for target detection and parameter estimation, especially with the existence of clutter (reverberation). Two commonly used waveforms (constant frequency (CF) and linear frequency modulated (LFM)) are studied. Their characteristics are complementary both with respect to their accuracies and their sensitivity to the blind zero-Doppler ridge. Several fusion schemes of the two kinds of waveforms are explored and fusion results are studied both analytically and from simulation. It is concluded that fusion of the information of different waveforms can be not only more robust, but in some cases outright preferable, in term of detection probability and estimation accuracy. [J484]

"Pulse width considerations for a short range millimeter wave radar"

Simple means for optimizing the pulse width of a basic tracking short-range millimeter wave radar are shown. Ground-based or maritime use is assumed. The cases discussed include volume clutter due to rain or other particles within the antenna's main beam and surface clutter due to grass, soil, or snow. Depending on the available RF hardware and desired lowest detectable target RCS, pulses as short as 20 ns look feasible. Modern signal processing methods enable the detection of targets close to the noise limit. It seems, therefore, appropriate to discuss the relevance of using 3 dB beamwidths for clutter cell calculations. Experiments suggest that more accurate predictions are obtained by using 1 dB widths instead. The lack of comprehensive data for very small grazing angles and the less surveyed small-scale topography of radar environments set some constraints for straightforward implementations. Preliminary results indicate averaged surface clutter RCS levels less than -12 dBsm at V-band for small grazing angles. [J485]

"Super-resolution imaging for point reflectors near transmitting and receiving array"

This paper presents subsurface imaging techniques using the well-known MUSIC algorithm to localize point reflectors in cross-borehole radar arrangements. Radar signals received by a spatial array have to be decorrelated, in general, as a preprocessing step when the MUSIC algorithm is implemented. Since most of the decorrelation techniques are based on planar wave incidence model, it is difficult to apply the decorrelation technique for signals from radar targets in the near field of the array. In this paper, we introduce a decorrelation technique with transmitting and receiving array for targets near the array and apply the MUSIC algorithm for estimating the two dimensional position of the point targets in crosshole tomographic measurement. Further, an expanded version of the algorithm to eliminate the direct wave is also derived. Simulation results show that this method offers much higher resolution and accuracy than the conventional diffraction stack method. The paper also discusses the relationship between the SNR ratio and the minimum target separation to be resolved. [J486]

"Model-based adaptive detection of range-spread targets"

The authors consider the problem of detecting range-distributed targets in the presence of structured disturbance modelled as an autoregressive Gaussian process with unknown parameters. The focus is on two different scenarios. The first assumes that all the data vectors from the cells under test share the same covariance matrix

(homogeneous environment). The second refers to the case of data vectors characterised by completely different covariances (heterogeneous environment). Four detectors exploiting the asymptotic generalised likelihood ratio criterion are devised and assessed. Remarkably, they ensure the constant false alarm rate (CFAR) property with respect to the disturbance power level, and two of them are asymptotically CFAR with respect to the disturbance covariance matrix. Finally the performance assessment, based also on real radar data, has shown that these detectors achieve, in general, satisfactory detection performances. [J487]

"Discrimination mode processing for EMI and GPR sensors for hand-held land mine detection"

Signal processing algorithms for hand-held mine detection sensors are described. The goals of the algorithms are to provide alarms to a human operator indicating the likelihood of the presence of a buried mine. Two modes of operations are considered: search mode and discrimination mode. Search mode generates an initial detection at a suspected location and discrimination mode confirms that the suspected location contains a land mine. Search mode requires that the signal processing algorithm generate a detection confidence value immediately at the current sample location and no delay in producing an alarm confidence is tolerable. Search mode detection has a high false-alarm rate. Discrimination mode allows the operator to interrogate the entire suspected location to eliminate false alarms. It does not require that the signal processing algorithm produce an alarm confidence immediately for the current sample location, but rather allows the system to process all the data acquired over the region before producing an alarm. This paper proposes discrimination mode processing algorithms for metal detectors (MDs), or electromagnetic induction sensors (EMIs), ground-penetrating radars (GPRs), and their fusion. The MD discrimination mode algorithm employs a model-based approach and uses the target model parameters to discriminate between mines and clutter objects. The GPR discrimination mode algorithm uses the consistency of detection as well as the shape of the detection peaks over several sweeps to improve the discrimination accuracy. The performances of the proposed algorithms were examined on a dataset collected at a government test site, and performance was compared with baseline techniques. Experimental results showed that the proposed method can reduce the probability of false alarm by as much as 70% at a 100% correct detection rate and performed comparable to the best human operator on a blind test with data collected at approximately 1000 locations. [J488]

"Effective CLEAN algorithms for performance-enhanced detection of binary coding radar signals"

With binary coding waveform as radar pulse compression signal, the sidelobe of the matched processing result of the received signals is a serious interference to the effective detection of multiple targets. In this paper, the CLEAN algorithms are introduced to eliminate such sidelobes and significantly improve the target detection performance of binary coding radar signals. A novel modified CLEAN algorithm is proposed to remove the sidelobe interferences in formulating target range profile when wideband binary coding signals are used. The effectiveness of the CLEAN algorithms is demonstrated through the processing results. [J489]

"Rank-order filters for FOPEN target detection"

Issues associated with the radar detection of military targets that are concealed or camouflaged by forest clutter are described. The specific sensor platform can be categorized as an ultrawideband (UWB) foliage penetration (FOPEN) synthetic aperture radar (SAR). The discussion illustrates the fact that many contemporary approaches to FOPEN target detection are computationally intensive and/or require the implementation of elaborate training procedures. Alternative approaches, based the application of a set of simple rank-order filters (alternately known as order statistical or L filters), are presented. Initial results indicate impressive performance levels (in terms of probability of detection as a function of false-alarm rate) with respect to baseline constant false-alarm rate computations. A number of avenues for future investigations are cited. [J490]

"Tracking a maneuvering target using neural fuzzy network"

A fast target maneuver detection and highly accurate tracking technique using a neural fuzzy network based on a Kalman filter is proposed in this paper. In the automatic target tracking system, there exists an important and difficult problem: how to detect the target maneuvers and fast response to avoid miss-tracking? The traditional maneuver detection algorithms, such as variable dimension filter (VDF) and input estimation (IE) etc., are computation intensive and difficult to implement in real time. To solve this problem, neural network algorithms have been issued recently. However, normal neural networks such as backpropagation networks usually produce the extra problems of low convergence speed and/or large network size. Furthermore, the way to decide the network structure is heuristic. To overcome these defects and to make use of neural learning ability, a developed standard Kalman filter with a self-constructing neural fuzzy inference network (KF-SONFIN) algorithm for target tracking is presented in this paper. By generating possible target trajectories including maneuver information to train the SONFIN, the trained SONFIN can detect when the maneuver occurred, the magnitude of maneuver

values and when the maneuver disappeared. Without having to change the structure of the Kalman filter or modeling the maneuvering target, this new algorithm, SONFIN, can always find an economic network size with a fast learning process. Simulation results show that KF-SONFIN is superior to traditional IE and VDF methods in estimation accuracy. [J491]

"Investigation of broadband electromagnetic induction scattering by highly conductive, permeable, arbitrarily shaped 3-D objects"

Operating as low as tens of hertz and as high as hundreds of kilohertz, new broadband electromagnetic induction (EMI) sensors have shown promise for classification of unseen buried metallic objects. The three-dimensional (3-D) and bodies-of-revolution (BOR) numerical studies reported here are designed to explain key scattering sensitivities that may either be useful in or may limit object classification capability. The target is excited either by a spatially uniform oscillating primary magnetic field or by the oscillating field from a loop antenna. The problem is formulated in terms of Poison's equation for scalar potential outside the object, where conductivity and electric field values are low and consequent conduction currents are generally negligible. The Helmholtz equation for vector potential applies inside the highly conducting and permeable object. In both regions, the electromagnetic phenomena of interest are magneto-quasi-static (MQS). The simulation algorithm uses the method of auxiliary sources (MAS), with auxiliary magnetic charges and auxiliary magnetic current elements distributed on auxiliary surfaces. These surfaces generally conform to but do not coincide with physical surfaces, providing extraordinarily efficient and accurate 3-D solutions. Comparisons to available analytical solutions and experimental data validate the solutions. The simulations and data illuminate broadband MQS scattering phenomenology for both magnetic and nonmagnetic metallic objects. Distinctive sensitivities are shown and signature effects analyzed relative to the scatterer's shape and aspect ratio, orientation, sharp points and edges, finite wall thickness in hollow bodies, and compound structure in which a geometrically complex body consists of a number of distinct sections, e.g., fins. [J492]

"Multiple radar targets detection by exploiting induced amplitude modulation"

This work deals with the problem of detecting and estimating multiple radar targets present in the same range-azimuth resolution cell of a surveillance radar system with a mechanically rotating antenna. In the first part of the work, we tackled the problem of estimating target complex amplitudes, Doppler frequencies, and directions of arrival, and a consistent estimator based on the asymptotic maximum likelihood (AML) method was derived. In this second part, we tackle the "detection problem," which consists of determining the number of targets. First, the target parameters are estimated, assuming a maximum number of possible targets. Subsequently, these estimates are used in a successive hypotheses test procedure. The statistic of the test at each step of the procedure is derived by using an asymptotic expression of the generalized likelihood ratio test (GLRT) statistic. Performance of the proposed algorithm is investigated through both asymptotical analysis (as concerning the probability of false alarm) and Monte Carlo simulation. [J493]

"Statistical analysis of multilook SAR interferograms for CFAR detection of ground moving targets"

This paper examines the statistics of the phase and magnitude of multilook synthetic aperture radar (SAR) interferograms toward deployment of along-track interferometry (ATI) for slow ground moving-target indication (GMTI). While the known probability density function (pdf) of the interferogram's phase (derived under the assumption of Gaussian backscatter) is shown to agree almost perfectly for a wide variety of backscatter conditions, the corresponding magnitude's pdf tends to deviate strongly in most cases. Motivated by this discrepancy, a novel distribution is derived for the interferogram's magnitude. This pdf, called the polynomial or p-distribution, matches the real data much more accurately, particularly for heterogeneous composite terrain. For extremely heterogeneous terrain, such as urban areas, both pdfs for interferometric phase and magnitude fail and are extended. Based on these statistics, a completely automatic detection scheme with constant false-alarm rates (CFARs) for slow moving targets is proposed. All involved parameters required to determine the detection thresholds are estimated from the sample data. It is demonstrated, on the basis of experimental airborne SAR data, that this detector is capable of detecting slow moving vehicles within severe ground clutter. [J494]

"Probabilistic data association techniques for target tracking in clutter"

In tracking targets with less-than-unity probability of detection in the presence of false alarms (FAs), data association-deciding which of the received multiple measurements to use to update each track-is crucial. Most algorithms that make a hard decision on the origin of the true measurement begin to fail as the FA rate increases or with low observable (low probability of target detection) maneuvering targets. Instead of using only one measurement among the received ones and discarding the others, an alternative approach is to use all of the validated measurements with different weights (probabilities), known as probabilistic data association (PDA).

This paper presents an overview of the PDA technique and its application for different target tracking scenarios. First, it describes the use of the PDA technique for tracking low observable targets with passive sonar measurements. This target motion analysis is an application of the PDA technique, in conjunction with the maximum-likelihood approach, for target motion parameter estimation via a batch procedure. Then, the PDA technique for tracking highly maneuvering targets and for radar resource management is illustrated with recursive state estimation using the interacting multiple model estimator combined with PDA. Finally, a sliding window (which can also expand and contract) parameter estimator using the PDA approach for tracking the state of a maneuvering target using measurements from an electrooptical sensor is presented. [J495]

"Improvement in target detection performance of pulse coded Doppler radar based on multicarrier modulation with fast Fourier transform (FFT)"

A new approach is proposed for improved target detection of radar systems. This approach is based on multicarrier modulation (MCM) with fast Fourier transforms, i.e. it uses IFFT for modulation in transmitters and FFT for demodulation in receivers. With this approach the required constant false alarm rate (CFAR) detection threshold for target detection in radar based on multicarrier modulation is lower than that required in the case of a single carrier radar system. The paper presents the target detection performance of multicarrier frequency radar in comparison with that of single carrier frequency radar in terms of single pulse detection thresholds. The multicarrier radar system proposed uses a 32-bit complementary code with 8 subcarriers. The detection thresholds required for detection of targets buried in noise, clutter and jamming are computed for a 32-bit complementary pulse coded Doppler radar system based on multicarrier modulation. The paper shows that the technique based on multicarrier modulation improves the target detection performance of a 32-bit complementary pulse coded Doppler radar system with reference to its detection performance when the same system uses a single carrier. This approach for radar target detection with the proposed technique is investigated with extensive simulations, and results are presented. [J496]

"Detection of a manoeuvring air target in sea-clutter using joint time-frequency analysis techniques"

Traditionally, radar signals have been analysed in either the time or the frequency domain. Joint time-frequency representations characterise signals over a time-frequency plane. They thus combine time-domain and frequency-domain analyses to yield a potentially more revealing picture of the temporal localisation of a signal's spectral components. Therefore, for air target returns with time-vary ing frequency content, joint time-frequency representations offer a powerful analysis tool. A concise review of time-frequency transforms is provided as background and is needed to appreciate how time-frequency processing methods can improve conventional time or frequency processing methods. The authors use time-frequency analysis techniques for the detection of a manoeuvring aircraft using high frequency (HF) radar in heavily cluttered regions. They compare the ability of different time-frequency transforms to resolve several experimental aircraft returns. The relative speeds of the different transforms are also quantitatively studied. The results clearly demonstrate that time-frequency analysis techniques can significantly improve the detection performance of the HF radar and add considerable physical insight over what can be achieved by conventional Fourier transform methods currently used by HF radars. [J497]

"Analysis of high-resolution land clutter"

Results are presented of an analysis of land clutter from the fixed site high-resolution BYSON radar at Malvern. Digital terrain elevation data are used to determine the imaged ground regions and the normalised-log estimator U is measured to investigate the stability of the long-tailed clutter distribution. Operational target detectors must maintain a constant false alarm rate over the entire scene, but small areas of non-Gaussian backscatter cause the majority of false alarms. To overcome this, a variable CFAR detector is tested and compared to standard CA and CAGO processors. The performance of the empirically determined variable CFAR is superior, but results suggest that there is no simple statistical model for land clutter of this kind as the false alarms within a particular scene are strongly correlated with the environment. [J498]

"Target fluctuation models and their application to radar performance prediction"

The authors address the design, analysis, and experimental validation of statistical models for the description of targets fluctuations. First some classical distributions commonly employed for the statistical characterisation of the target amplitude returns are reviewed. Then, the authors focus on the shadowed Rice and the two-state Rayleigh-chi target models, discussing their physical justification and relevant analytical properties. The capabilities of the considered models to fit real target data collected by the McMaster IPIX radar in 1993 are also studied. Finally, the performance of the optimum detector (in the Neyman-Pearson sense) for targets with uniformly distributed phases in the presence of shadowed Rice and two-state Rayleigh-chi fluctuations is studied

and analytical expressions are provided for the detection probability. [J499]

"Robust shape tracking in the presence of cluttered background"

Many object-tracking algorithms are based on low-level features detected in the image. Typically, the object shape and position are estimated to fit the observed features. Unfortunately, image analysis methods often produce invalid features (outliers) which do not belong to the object boundary. These features have a strong influence on the shape estimates, leading to meaningless tracking results. This paper proposes a robust tracking algorithm which is able to deal with outliers, inspired in the probabilistic data association filter proposed in the context of point tracking. The algorithm is based on two key concepts. First, middle level features (strokes) are used instead of low-level ones (edge points). Second, two labels (valid/invalid) are considered for each stroke. Since the stroke labels are unknown all labeling sequences are considered and a probability (confidence degree) is assigned to each of them. In this way, all the strokes contribute to track the moving object but with different weights. This allows a robust performance of the tracker in the presence of outliers. Experimental tests are provided to assess the performance of the proposed algorithm in lip and gesture tracking and surveillance applications. [J500]

"A high precision Doppler radar based on optical fiber delay loops"

The proposed theory shows that, by using optical fiber delay lines or loops, it is no longer necessary to compress pulses with matched filters for optimum detection and it is possible to suppress interference from undesirable zones. The suppression leads to lessening of Doppler and range ambiguity. The theory further shows that it is feasible to measure Doppler beating with high precision based on a single pulse. Thus, with a single pulse, there is no Doppler and range ambiguity; interference from undesirable range zones due to Doppler range fold-over will no longer present; and the troublesome ground clutter problem would be greatly suppressed. The high precision Doppler beating provides a mechanism to reveal intrinsic characteristics of a target without time average blurring or masking. New information can be acquired on targets of interest for purpose of passive identification. [J501]

"Trained detection of buried mines in SAR images via the deflection-optimal criterion"

In this paper, we apply a deflection-optimal linear-quadratic detector to the detection of buried mines in images formed by a forward-looking ground-penetrating synthetic aperture radar. The detector is a linear-quadratic form that maximizes the output SNR (deflection), and its parameters are estimated from a set of training data. We show that this detector is useful when the signal to be detected is expected to be stochastic, with an unknown distribution, and when only a small set of training data is available to estimate its statistics. The detector structure can be understood in terms of the singular value decomposition; the statistical variations of the target signature are modeled using a compact set of orthogonal "eigenmodes" (or principal components) of the training dataset. Because only the largest eigenvalues and associated eigenvectors contribute, statistical variations that are underrepresented in the training data do not significantly corrupt the detector performance. The resulting detection algorithm is tested on data that are not in the training set, which has been collected at government test sites, and the algorithm performance is reported. [J502]

"Joint integrated probabilistic data association: JIPDA"

A new recursive filter for multi-target tracking in clutter is presented. Multiple tracks may share the same measurement(s). Joint events are formed by creating all possible combinations of track-measurement assignments and the probabilities for these joint events are calculated. The expressions for the joint event probabilities incorporate the probabilities of target existence of individual tracks, an efficient approximation for the cluster volume and a priori probability of the number of clutter measurements in each cluster. From these probabilities the data association and target existence probabilities of individual tracks are obtained, which allows track state update and false track discrimination. A simulation study is presented to show the effectiveness of this approach. [J503]

"On the use of permanent symmetric scatterers for ship characterization"

The symmetric scattering characterization method (SSCM) has been recently introduced for high-resolution characterization of certain targets under coherent conditions. SSCM is based on the Poincarer' sphere representation, which supports a high-resolution decomposition of symmetric target scattering, as well as assessment and validation of the backscatter coherence. In this paper, the SSCM is investigated for ship characterization using Convair-580 polarimetric synthetic aperture radar (SAR) data. It is shown that the target Poincarer' parameters permit identification of dominant scatterers with a significant symmetric scattering component. The polarization orientation angle of these quasi-symmetric scatterers is used to derive an estimate

of the ship's pitch angle, under certain conditions. The effect of SAR system focus setting errors and Doppler centroid mistracking on the SSCM performance is investigated. It is shown that the SSCM is sensitive to the system focus setting and Doppler centroid shift. The first-order effects of these errors can be removed prior to the application of the SSCM method. [J504]

"Polarization state conformation and its application to change detection in polarimetric SAR data"

For polarimetric SAR (POLSAR) images, it is ideal that scattering geometries of the same target should display resemblance between multidate images, which are used in change detection applications, since the scattering mechanisms may change due to the data acquisition geometry. However, sometimes it is difficult to achieve these conditions. An attempt is made to maximize the resemblance between the scattering geometries in multidate images for a specific target. An algorithm is developed based on the polarimetric basis transformation along with the polarization signatures. As a result, the resemblance between the scattering mechanisms of the same target in both images is maximized. The effects predicted by the theory are confirmed by the change detection analysis of POLSAR data acquired by the Jet Propulsion Laboratory Spaceborne Imaging Radar-C mission. [J505]

"Multitarget particle filter track before detect application"

The paper deals with a radar 'track before detect' application in a multitarget setting. 'Track before detect' is a method to track weak objects on the basis of raw radar measurements, e.g. the reflected power of the target plus noise. In classical target tracking, the tracking process is performed on the basis of pre-processed measurements that are constructed from the original measurement data every time step. In this way no integration over time takes place and information is lost. The authors give details of a modelling setup and a particle filter based algorithm to deal with a 'multiple target track before detect' situation. Using simulations it is shown that with this method, it is possible to track multiple, closely spaced, weak targets. [J506]

"Integrated object and road border tracking using 77 GHz automotive radars"

Radar sensors are widely used in automotive on-board systems such as adaptive cruise control, which tracks the preceding vehicle and keeps a safe distance. The authors go a step further and exploit the potential of a high resolution radar sensor for the estimation of the road borders and the reconstruction of the traffic scenario based on object tracking. A FMCW millimetre wave radar is mounted in the front bumper of a vehicle and delivers object lists to the central fusion processor, where detections are considered as measurements to an integrated model based road border estimation system. The algorithm presented is designed to improve the prediction of paths and trajectories of the ego-vehicle in future enhanced collision warning and collision avoidance systems. Given the characteristics and limitations of a radar system, such as heavy clutter, the algorithms are tested with real data and perform reliably in highway and extra-urban scenarios and are competitive with data fusion and stereo vision systems, but with lower computational load. [J507]

"Polynomial time algorithm for data association problem in multitarget tracking"

The aim of this work is to propose a semigreedy algorithm for solving the data association problem (DAP) arising in multitarget tracking. The DAP is characterized as a maximum weighted set partitioning problem (MWSPP). A semigreedy algorithm that first generates a number of different solutions using a polynomial number of operations and then selects the best among the solutions generated is presented. Theoretically we prove that the value of the solution returned by the algorithm approximates the value of the optimal solution within a guaranteed factor. This factor only depends on the dimension of the sliding window used. Computational experiments indicate that the quality of the solutions returned is quite satisfactory. [J508]

"Target-aspect-dependent RCS: the effect on assumed beam angle"

Traffic speed enforcement is becoming more reliant on automated speed-detection devices, particularly the use of photographically linked slant radar devices. We have conducted an analysis of whether target-aspect-dependent radar cross section (RCS) could have an effect on the accuracy of speed measurements. It was found that there is the potential for a 2.5% error (for a radar aligned at 22° to the road, with a -3 dB beamwidth of 5°) in the speed measured by the radar devices. This is because of the interference between the RCS and the radar beam pattern, if only the main lobe is considered. There are cases, however, when the interference between the RCS and the radar beam patterns are such that the strongest return occurs in the first sidelobe. In these cases, the potential speed error is about 7%. This would be unlikely to occur in practice, however, because of the inverse fourth-power relationship with range. We have not included the details of RCS sidelobe returns in the analysis. [J509]

"Buried small objects detected by UWB GPR"

A ground penetrating radar (GPR) using short-pulse is developed to detect small and shallow metal objects buried underground. A bistatic mode in which the GPR system uses separate transmitting and receiving antennas is applied. A modified fat dipole antenna is developed for the transmitting and receiving antennas. The prototype of the system is tested in the real environment and 2D visualization of raw data is achieved. We show that the developed system has a good ability to detect underground metal objects, and even small targets of several centimeters. [J510]

"Chaotic lidar"

A novel chaotic lidar (CLIDAR) system that utilizes a chaotic laser as the light source is proposed and studied. In CLIDAR, the detection and ranging are realized by correlating the signal waveform reflected back from the target with a delayed reference waveform. Benefiting from the very broad bandwidth of the chaotic waveform that can be easily generated by a semiconductor laser, a centimeter-range resolution is readily achieved. The correlation performance of CLIDAR is studied both numerically and experimentally. The power spectra, phase portraits, time series, and correlation traces of the chaotic waveforms obtained at different operating conditions are compared. The relation between the complexity of the attractor and the correlation property is examined. The correlation dimension and the largest positive Lyapunov exponent of each waveform are calculated. To compare the correlation performance of the waveforms quantitatively, peak sidelobe levels of the correlation traces with different correlation lengths and relative noise levels are investigated. Preliminary experiments show a subcentimeter accuracy in ranging with a 3-cm-range resolution, which currently is limited by the bandwidth of the oscilloscope used. [J511]

"Operating limits for distortion reduction by the augmentation technique in nonlinear transistor amplifiers"

In airborne military phased array radar systems, detection capability is influenced as much by receiver linearity as it is by system noise performance. The extremely wide dynamic range of the target returns in such systems leads to challenging receiver design compromises between amplifiers exhibiting low distortion or low thermal noise. Conventional methods that are used to improve linearity, such as increasing device size, bias current or supply voltage, inevitably result in enhanced thermal noise, higher power consumption and heat dissipation. In military aircraft, where weight and space are at a premium, these effects are difficult to accommodate. Consequently a method of amplifier linearisation is required that has minimal impact on the power consumption, size and noise figure of the receiver system. A possible solution to this problem, that has recently been advocated, relies on a process termed 'augmentation'. This solution is explored for application to weakly nonlinear receiver amplifiers and easy-to-use relationships are presented to enable designers to assess the frequency limits of the technique for particular devices and processes. [J512]

"Small-target detection in sea clutter"

Sea clutter in marine surveillance radar makes the task of detecting small targets a very challenging problem. In this paper, a set of three signal processing techniques designed to suppress unwanted sea clutter radar echo and achieve target detection with no prior knowledge of the ocean and environmental conditions is presented. These include signal averaging, time-frequency representation, and morphological filtering. Datasets from real marine radar operating in staring mode are used to illustrate the performance of the new approaches. [J513]

"Application of the biorthogonal multiresolution time-domain method to the analysis of elastic-wave interactions with buried targets"

The biorthogonal multiresolution time-domain (Bi-MRTD) method is introduced for the analysis of elastic-wave interaction with buried targets. We provide a detailed discussion on implementation of the perfectly matched layer and on treatment of the interface between two different materials. The algorithm has also been parallelized by the use of the message-passing interface. The numerical results show that numerical dispersion can be significantly improved by using biorthogonal wavelets as bases, as compared to the conventional pulse expansion employed in the finite-difference time-domain (FDTD) method. We demonstrate that with comparison to the second-order FDTD, the Bi-MRTD yields significant CPU time and memory savings for large problems, for a fixed level of accuracy. [J514]

"Speckle filtering in polarimetric SAR data based on the subspace decomposition"

In this paper, a new approach to speckle filtering of synthetic aperture radar (SAR) data is presented. We define

a parameter space consisting of two orthogonal subspaces-the signal subspace and the noise subspace. Then, the full polarimetric information from the signal subspace is obtained after speckle filtering. In this way, edges of different kinds of targets are preserved. The effectiveness of this method is demonstrated using the National Aeronautics and Space Administration Jet Propulsion Laboratory airborne L-band polarimetric SAR data. [J515]

"Mitigation techniques for non-Gaussian sea clutter"

This paper deals with the problem of coherent radar detection of targets embedded in clutter modeled as a compound-Gaussian process. We first provide a survey on clutter mitigation techniques with a particular emphasis on adaptive detection schemes ensuring the constant false-alarm rate (CFAR) property with respect to all of the clutter parameters. Thus, we propose a novel decision rule based on a recursive covariance estimator, which exploits the persymmetry property of the clutter covariance matrix. Remarkably, the devised receiver is fully CFAR in that its threshold can be set independently of the clutter distribution as well as of its covariance, even if the environment is highly heterogeneous; namely, the disturbance distributional parameters vary from cell to cell. At the analysis stage, we compare the performance of the novel detector with some classical radar receivers such as that of Kelly and the adaptive matched filter both in the presence of simulated as well as on real radar data, which statistical analysis has shown to be compatible with the compound-Gaussian model. The results show that the new receiving structure generally provides higher detection performance than the others and, for a fluctuating target, it uniformly outperforms the counterparts. We also provide a discussion on the CFAR behavior of the analyzed receivers as well as on their computational complexity. [J516]

"Acoustooptic correlation processing in random noise radar"

A new technique has been developed that permits coherent processing of backscatter data acquired by a radar system transmitting ultrawideband (UWB) random noise waveforms and processing the received signals using a heterodyne correlation receiver. This technique has been used in various applications, such as Doppler estimation, polarimetry, interferometry, buried-object detection, synthetic aperture radar (SAR) imaging, inverse SAR (ISAR) imaging, foliage penetration imaging, etc. One of the major advantages of the noise radar system is its inherent immunity to external interference. In such a radar system, the correlation receiver consists of a programmable variable-delay line, a mixer followed by a lowpass filter. One drawback of this type of receiver is that it sequentially processes the target returns, thus limiting the system response time and the dynamic detection range. We have recently integrated a novel heterodyning acoustooptic (AO) time-integrating correlation receiver that uses a traveling-wave AO deflector for wideband signal processing. The transmit waveform modulates the intensity of a laser diode that is multiplied by the traveling-wave modulation produced by the AO deflector, and the correlation is time-integrated on a charge-coupled device photodetector array. The principal advantages of this AO correlation receiver are its ability to generate a large range of variable delays, as well as to perform the signal correlation operation in parallel. Compared to the conventional sequential correlation receiver using a variable stepped delay line and correlator, implementation of the AO variable-delay line and heterodyning correlator can 1) reduce the processing time and greatly increase the processing gain due to the parallel correlation mechanism and 2) greatly increase the number of range cells depending on the number of resolvable spots of the AO deflector. This results in rapid data acquisition, longer integration time on parallel detector pixels (3000 pixels), and improved SNR. It is also shown that this radar has more range gates (up to 1000), which ultimately improves the detectable range resolution. Furthermore, several field experiments performed with different target arrangements demonstrate that the acoustooptic variable-delay line and c-orrelator is able to profile various targets instantaneously and with very high SNR. [J517]

"Generalized optimization of polarimetric contrast enhancement"

A generalized optimization of polarimetric contrast enhancement (GOPCE) is proposed in this letter. For this problem, it is not only necessary to find the optimal polarization states such that the received power ratio of a desired target and clutter is maximal, but also necessary to find three optimal coefficients such that the ratio of two factors associated with the desired target and clutter is maximal, where both the factors consist of three parameters, i.e., the Cloude entropy and two special similarity parameters. The optimal coefficients of the GOPCE are obtained by solving an eigenvalue problem. Using an example, we demonstrate that the GOPCE can be employed for detecting roads in a forest area by using polarimetric synthetic aperture radar data. [J518]

"Ship detection based on coherence images derived from cross correlation of multilook SAR images"

A new simple technique is presented to extract ships from synthetic aperture radar (SAR) images. The procedure is to compute the cross-correlation values between two images extracted by moving windows of a small size from the multilook SAR intensity (or amplitude) images. A coherence image, consisting of the cross-correlation

values of the intensity images, is then produced. Ships are deterministic targets, so that their interlook subimages possess higher degree of coherence than the uncorrelated random images of the surrounding sea surface. The main advantage of this method over the conventional constant false-alarm rate is its ability to detect, under favorable conditions, "invisible" images of ships embedded in the speckled image of the sea surface. The technique is tested using a RADARSAT-1 image in which one known and several unknown ships are present. The use of complex images and the exploitation of short decorrelation times of small-scale ocean waves to obtain an extra look are also discussed. [J519]

"Robust adaptive matched filtering using the FRACTA algorithm"

An effective method is developed for selecting sample snapshots for the training data used to compute the adaptive weights for an adaptive match filter (AMF); specifically a space/time adaptive processing (STAP) airborne radar configuration is considered. In addition, a new systematic robust adaptive algorithm is presented and evaluated against interference scenarios consisting of jamming, nonhomogeneous airborne clutter (generated by the Research Laboratory STAP (RLSTAP) or knowledge-aided sensor signal processing and expert reasoning (KASSPER) high-fidelity clutter models or using the multi-channel airborne radar measurement (MCARM) clutter data base), internal system noise, and outliers (which could take the form of targets themselves). The new algorithm arises from empirical studies of several combinations of performance metrics and processing configurations. For culling the training data, the generalized inner product (GIP) and adaptive power residue (APR) are examined. In addition two types of data processing methods are considered and evaluated: sliding window processing (SWP) and concurrent block processing (CBP). For SWP, a distinct adaptive weight is calculated for each cell-under-test (CUT) in a contiguous set of range cells. For one configuration of CBP, two distinct weights are calculated for a contiguous set of CUTs. For the CBP, the CUTs are in the initial training data and there are no guard cells associated with the CUT as there would be for SWP. Initial studies indicate that the combination of using the fast maximum likelihood (FML) algorithm, reiterative censoring, the APR metric, CBP, the two-weight method, and the adaptive coherence estimation (ACE) metric (we call this the FRACTA algorithm) provides a basis for effective detection of targets in nonhomogeneous interference. For the KASSPER data, FRACTA detects 154 out of 268 targets with one false alarm (PF≈3Ч10-5) whereas the FML algorithm with SWP detects 11 with one false alarm. The clarvoyant processor (where each range cell's covariance matrix is known) detects 192 targets with one false alarm. [J520]

"Design and application of quadratic correlation filters for target detection"

We introduce a method for designing and implementing quadratic correlation filters (QCFs) for shift-invariant target detection in imagery. The QCFs are a quadratic classifier that operates directly on the image data without feature extraction or segmentation. In this sense, the QCFs retain the main advantages of conventional linear correlation filters while offering significant improvements in other respects. Not only is more processing required to detect peaks in the outputs of multiple linear filters, but choosing a winner among them is an error prone task. On the other hand, all channels in a QCF work together to optimize the same performance metric and produce a combined output that leads to considerable simplification of the postprocessing scheme. In addition, QCFs also yield better performance than their linear counterparts for comparable throughput requirements. Two different methods for designing basis functions that optimize the QCF performance criterion are presented. An efficient architecture for implementing QCFs is discussed along with a case study of the proposed approach for detecting targets in LADAR imagery. [J521]

"Radar detection and preclassification based on multiple hypothesis"

This work presents a single-scan-processing approach to the problem of detecting and preclassifying a radar target that may belong to different target classes. The proposed method is based on a hybrid of the maximum a posteriori (MAP) and Neyman-Pearson (NP) criteria and guarantees the desired constant false alarm rate (CFAR) behavior. The targets are modeled as subspace random signals having zero mean and given covariance matrix. Different target classes are discriminated based on their different signal subspaces, which are specified by their corresponding projection matrices. Performance is investigated by means of numerical analysis and Monte Carlo simulation in terms of probability of false alarm, detection and classification; the extra signal-to-noise power ratio (SNR) necessary to classify once target detection has occurred is also derived. [J522]

"Angle estimation for two unresolved targets with monopulse radar"

Most present-day radar systems use monopulse techniques to extract angular measurements of sunbeam accuracy. The familiar "monopulse ratio" is a very effective means to derive the angle of a single target within a radar beam. For the simultaneous estimation of the angles of two closely-spaced targets, a modification on the monopulse ratio was derived in (Blair and Pearce, 2001), while (Sinha et al., 2002) presented a maximum

likelihood (ML) technique via numerical search. In this paper it is shown that the ML solution can in fact be found explicitly, and the numerical search of ((Sinha et al., 2002) is unnecessary. However, the ML solution requires the signal to noise ratio (SNR) for each target to be known, and hence we generalize it so it requires only the relative SNR. Several versions of expectation maximization (EM) joint angle estimators are also derived, these differing in the degree to which prior information on SNR and on beam pattern are assumed. The performances of the different direction-of-arrival (DOA) estimators for unresolved targets are studied via Monte Carlo, and it is found that most have similar performance: this is remarkable since the use of prior information (SNR, relative SNR, beam pattern) varies widely between them. There is, however, considerable performance variability as a function of the two targets' off-boresight angles. A simple combined technique that fuses the results from different approaches is thus proposed, and it performs well uniformly. [J523]

"Detection of moving targets in wideband SAR"

A likelihood ratio is proposed for moving target detection in a wideband (WB) synthetic aperture radar (SAR) system. WB is defined here as any systems having a large fractional bandwidth, i.e., an ultra wide frequency band combined with a wide antenna beam. The developed method combines time-domain fast backprojection SAR processing methods with moving target detection using space-time processing. The proposed method reduces computational load when sets of relative speeds can be tested using the same clutter-suppressed subaperture beams. The proposed method is tested on narrowband radar data. [J524]

"A comparison of two Cramer'r-Rao bounds for nonlinear filtering with Pd"

The paper presents a comparative study of two recently reported Cramer'r-Rao lower bounds (CRLBs) for nonlinear filtering, both applicable when the probability of detection is less than unity. The first bound is the information reduction factor CRLB; the second is the enumeration method CRLB. The enumeration method is accurate but computationally expensive. We prove in the paper that the information reduction factor bound is overoptimistic, being always less than the enumeration CRLB. The theory is illustrated by two target tracking applications: ballistic object tracking and bearings-only tracking. The simulations studies confirm the theory and reveal that the information reduction factor CRLB rapidly approaches the enumeration CRLB as the scan number increases. [J525]

"Space-time registration of radar and ESM using unscented Kalman filter"

Space and time alignments are the prerequisites for the successful fusion of multiple sensors. A space-time registration model is proposed to estimate the system biases and to perform time synchronization together for mobile radar and electronic support measure (ESM) systems. A space-time registration model for radar and ESM is first developed, and an unscented Kalman filter (UKF) is proposed to estimate the space-time biases and target states simultaneously. The posterior Cramer-Rao bounds (PCRBs) are derived for the proposed UKF registration algorithm for ESM detection probability less than or equal to one. Theoretical analyses are performed to evaluate the accuracy and robustness of the proposed method. Computer simulations show that the UKF registration algorithm is indeed effective and robust for different radar and ESM tracking scenarios. [J526]

"Physics-based detection of targets in SAR imagery using support vector machines"

Radar scattering from an illuminated object is often highly dependent on the target-sensor orientation. In conjunction with physics based feature extraction, the exploitation of aspect-dependent information has led to successful improvements in the detection of tactical targets in synthetic aperture radar (SAR) imagery. While prior work has attempted to design detectors by matching them to images from a training set, the generalization capability of these detectors beyond the training database can be significantly improved by using the principle of structural risk minimization. In this paper, we propose a detector based on support vector machines that explicitly incorporates this principle in its design, yielding improved detection performance. We also introduce a probabilistic feature-parsing scheme that improves the robustness of detection using features obtained from a two-dimensional matching-pursuits feature extractor. Performance is assessed by considering the detection of tactical targets concealed in foliage, using measured foliage-penetrating SAR data. [J527]

"Iterated wavelet transformation and signal discrimination for HRR radar target recognition"

This paper explores the use of wavelets to improve the selection of discriminant features in the target recognition problem using high range resolution (HRR) radar signals in an air to air scenario. We show that there is statistically no difference among four different wavelet families in extracting discriminatory features. Since similar results can be obtained from any of the four wavelet families and wavelets within the families, the simplest wavelet (Haar) should be used. We use the box classifier to select the 128 most salient pseudo range bins and then apply the wavelet transform to this reduced set of bins. We show that by iteratively applying this approach,

the classifier performance is improved. We call this the iterated wavelet transform . The number of times the feature reduction and transformation can be performed while producing improved classifier performance is small and the transformed features are shown to quickly cause the performance to approach an asymptote. [J528]

"Computer simulation of aerial target radar scattering recognition, detection, and tracking"

First Page of the Article [J529]

"Interacting multiple model filter with error monitoring and recovery technique of perception net"

The paper is concerned with the problem of tracking a manoeuvring target. The error monitoring and recovery technique of the perception net is utilised to improve the tracking performance for a highly manoeuvring target. The interacting multiple model (IMM) filter is well known as being the most cost-effective hybrid-state estimation scheme. Both the detection of a manoeuvring target and the compensation of the estimated state can be achieved by employing a properly implemented error monitoring and recovery technique. IMM and full IMMPDA filters which employ an error monitoring and recovery technique show a better tracking performance compared with the conventional IMM and IMMPDA filters for a highly manoeuvring target, even in a clutter environment. They also reduce the peak values of the estimation errors when manoeuvring starts and finishes. The effectiveness of the proposed method is validated through simulations by comparing it with a conventional IMM filter. A similar evaluation is performed for a conventional IMMPDA filter. [J530]

"A new ultrawide-bandwidth dielectric-rod antenna for ground-penetrating radar applications"

A new ultrawide-bandwidth dielectric-rod antenna is presented with its application in detecting shallow targets, such as antipersonnel (AP) mines. The lowest hybrid mode is launched and guided along a circular-dielectric waveguide. The end of the waveguide is tapered to a point where electromagnetic waves are radiated out with field behavior similar to that radiated from a Hertzian dipole in the forward direction. The low antenna clutter and weak antenna-ground interaction are two unique features. Its near-field radiation properties are investigated by directly probing the fields and by numerical simulation with a three-dimensional finite-difference time-domain technique. Both measurement and numerical simulation results are presented for the detection of buried AP mines using a prototype dielectric-rod antenna operated at a frequency range from 1 to 6 GHz. [J531]

"Moderately rough dielectric interface profile reconstruction via short-pulse quasi-ray Gaussian beams"

A new technique for estimating the coarse-scale profile of a moderately rough interface between air and a homogeneous dielectric halfspace is presented. The proposed approach is based on space-time sparsely sampled reflected field observations and uses a quasi-ray Gaussian beam fast-forward model, coupled with a compact parameterization of the surface profile in terms of B-splines, from which the profile estimation problem is posed as a nonlinear optimization problem. Numerical experiments are presented to assess accuracy, reliability, and computational efficiency. The proposed approach finds applications in adaptive schemes for rough surface underground imaging of shallowly buried targets via ultra wide-band ground penetrating radars. [J532]

"Multiple moving target detection and trajectory estimation using a single SAR sensor"

A novel methodology is presented for determining the velocity and location of multiple moving targets using a single strip-map synthetic aperture radar (SAR) sensor. The so-called azimuth position uncertainty problem is therefore solved. The method exploits the structure of the amplitude and phase modulations of the returned echo from a moving target in the Fourier domain. A crucial step in the whole processing scheme is a matched filtering, depending on the moving target parameters, that simultaneously accounts for range migration and compresses two-dimensional signatures into one-dimensional ones without losing moving target information. A generalized likelihood ratio test approach is adopted to detect moving targets and derive their trajectory parameters. The effectiveness of the method is illustrated with synthetic and real data covering a wide range of targets velocities and signal-to-clutter ratios (SCRs). Even in the case of parallel to platform moving target motion, the most unfavorable scenario, the proposed method yields good results for, roughly, SCR >10 dB. [J533]

"Acoustic and electromagnetic wave interaction: estimation of Doppler spectrum from an acoustically vibrated metallic circular cylinder"

The idea of using acoustically induced Doppler spectra as a means of target detection and identification is introduced. An analytical solution for the calculation of the bistatic scattered Doppler spectrum from an acoustically excited, vibrating, metallic, circular cylinder is presented. First, the electromagnetic scattering solution

of a slightly deformed circular cylinder is obtained using a perturbation method. Then, assuming the vibration frequency is much smaller than the frequency of the incident electromagnetic wave, a closed form expression for the time-frequency response of the bistatic scattered field is obtained which can be used directly for estimating the Doppler spectrum. The acoustic scattering solution for an incident acoustic plane wave upon a solid elastic cylinder is applied to give the displacement of the cylinder surface as a function of time. Results indicate that the scattered Doppler frequencies correspond to the mechanical vibration frequencies of the cylinder, and the sidelobe Doppler spectrum level is, to the first order, linearly proportional to the degree of deformation and is a function of bistatic angle. Moreover, the deformation in the cylinder, and thus the Doppler sidelobe level, only becomes sizeable near frequencies of normal modes of free vibration in the cylinder. Utilizing the information in the scattered Doppler spectrum could provide an effective means of buried object identification, where acoustic waves are used to excite the mechanical resonances of a buried object. [J534]

"A multiple-model prediction approach for sea clutter modeling"

Accurate modeling of sea clutter is an important problem in remote sensing and radar signal processing applications. Due to a recent discovery that sea clutter, the electromagnetic wave backscatter from a sea surface, is chaotic rather than purely random, computational intelligence techniques such as neural networks have been applied to develop new models for sea clutter. In this paper, we propose using the multiple neural network model approach to construct a predictive model for sea clutter. The motivation comes from the observation that the sea usually has some unpredictable motions that result in impulsive events such as sea spikes. Although a single nonlinear model could describe the Bragg scattering reasonably as shown in the literature, it is usually incapable of capturing sea spikes motions. Therefore, target detection performance might be degraded when such a clutter model is employed. Using a multiple radial basis function (RBF) net predictor, we found that a sea clutter signal with different underlying dynamics from sea spikes to normal motions can be modeled accurately. The multiple model (MM) approach automatically assigns different RBF predictors to model sea spikes and other mechanisms like Bragg scattering. The proposed multiple RBF neural network uses the expectation-maximization algorithm and multistep prediction for training, and hence it is suitable for real-time signal processing. Using real-life radar clutter data collected at the east coast of Canada, the proposed MM approach is shown to be effective in isolating and characterizing various components of sea clutter and, therefore, provides a promising model for clutter suppression in radar detection. [J535]

"Correlation between horizontal and vertical monopulse measurements"

Many radar systems use the monopulse ratio to extract angle of arrival (AOA) measurements in both azimuth and elevation angles. The accuracies of each such measurement are reasonably well known: each measurement is, conditioned on the sum-signal return, Gaussian-distributed with calculable bias (relative to the true AOA), and variance. However, we note that the two monopulse ratios are functions of basic radar measurements that are not entirely independent, specifically in that the sum signal is common to both. The effect of this is that the monopulse ratios are dependent, and a simple explicit expression is given for their correlation; this is of considerable interest when the measurements are supplied to a tracking algorithm that requires a measurement covariance matrix. The system performance improvement when this is taken into account is quantified: while it makes little difference for a tracking radar with small pointing errors, there are more substantial gains when a target is allowed to stray within the beam, as with a rotating (track-while-scan) radar or when a single radar dwell interrogates two or more targets at different ranges. But in any case, the correct covariance expression is so simple that there is little reason not to use it. We additionally derive the Cramer-Rao lower bound (CRLB) on joint azimuth/elevation angle estimation and discover that it differs only slightly from the covariance matrix corresponding to the individual monopulse ratios. Hence, using the individual monopulse ratios and their simple joint accuracy expression is an adequate and quick approximation of the optimal maximum likelihood procedure for single resolved targets. [J536]

"Radar measurement extraction in the presence of sea-surface multipath"

In the presence of sea-surface multipath monopulse radar signals from a low elevation target have three alternative paths in addition to the direct (radar-to-target) path due to reflections from the sea surface. The specular reflection causes significant signal fading. The diffuse reflection causes an approximately constant bias to the in-phase component of the monopulse ratio, which is the standard extractor of the direction of arrival (DOA) in the monopulse processing. The diffuse reflection also causes higher standard deviation to the in-phase component of the monopulse ratio. We propose a maximum likelihood (ML) angle extraction technique for low elevation targets of known average signal strength having a Rayleigh fluctuation. The results show that this method reduces the error of the estimated angle compared with the conventional monopulse ratio estimator. Subsequently, the ML angle extractor is modified for the unknown average signal strength case. This modified angle extractor has only a small performance degradation compared with the known average signal strength

case, but it performs much better than the monopulse ratio based estimator. An algorithm to calculate the accuracy of the estimated angle (or height) is also presented. This angle extractor reduces the root-mean-square error (RMSE) by more than 50% in the signal processing stage when used in a low flying target tracking scenario. The same algorithm can be used to track sea skimmers. [J537]

"Distributed target detection in compound-Gaussian noise with Rao and Wald tests"

The problem of detecting distributed targets in compound-Gaussian noise with unknown statistics is considered. At the design stage, in order to cope with the a priori uncertainty, we model noise returns as Gaussian vectors with the same structure of the covariance matrix, but possibly different power levels. We also assume that a set of secondary data, free of signal components, is available to estimate the covariance matrix of the disturbance. Since no uniformly most powerful test exists for the problem at hand we devise and assess two detection strategies based on the Rao test, and the Wald test respectively. Remarkably these detectors ensure the constant false alarm rate property with respect to both the structure of the covariance matrix as well as the power levels. Moreover, the performance assessment, conducted also in comparison with the generalized likelihood ratio test based receiver, shows that the Wald test outperforms the others and is very effective in scenarios of practical interest for radar systems. [J538]

"Modeling and parameter optimization of agile beam radar tracking"

In the work presented here, we address parameter optimization for agile beam radar tracking to minimize the radar resources that are required to maintain a target under track. The parameters to be optimized include the track-revisit interval as well as the sequence of pairs of target signal strengths and detection thresholds associated with successive illumination attempts in each track-revisit. The effects of false alarms and clutter interference are taken into account in the modeling of target detection and in the characterization of tracking performance. Based on the detection model and tracker characterization, the parameter optimization problem is formulated. Typical examples of the optimization problem are numerically solved. The optimal solution gives an off-line scheduling of the parameter set. It also provides insight into the selection of a near-optimal parameter set that is appropriate for real-time implementation. [J539]

"Application of frequency correlation function to radar target detection"

Analysis of high-resolution 35 GHz synthetic aperture radar (SAR) imagery of terrain reveals that when point targets, such as vehicles, are viewed at angles close to grazing incidence, they are often difficult to distinguish from tree trunks because the radar cross section (RCS) intensities of the vehicles are comparable to the upper end of the RCS exhibited by tree trunks. To resolve the point target/tree trunk ambiguity problem, a detailed study was conducted to evaluate the use of new detection features based on the complex frequency correlation function (FCF). This paper presents an analytical examination of FCF and its physical meaning, the results of a numerical simulation study conducted to evaluate the performance of a detection algorithm that uses FCF, and the corroboration of theory with experimental observations conducted at 35 and 95 GHz. The FCF-based detection algorithm was found to correctly identify tree trunks as such in over 90% of the cases, while exhibiting a false alarm rate of only 3%. [J540]

"Use of genetic algorithms in ISAR imaging of targets with higher order motions"

Genetic algorithms (GA) are proposed for inverse synthetic aperture radar (ISAR) imaging. GA is used for motion parameters search in place of exhaustive search in the adaptive joint time-frequency (AJTF) algorithm. While maintaining the same accuracy, GA has lower computational complexity, especially for targets with higher order motions. [J541]

"Direct-path filtering of DAB waveform from PCL receiver target channel"

Signal space projection techniques are introduced to filter the direct-path signal component from the passive coherent location (PCL) receiver target channel. Filter performance is characterised using ambiguity function analysis of the digital audio broadcast (DAB) waveform, considered here as a PCL waveform of opportunity. For ideal DAB phase reference synchronisation, the direct-path component is perfectly eliminated. For non-ideal phase synchronisation, the direct-path component is sufficiently attenuated to permit target detection; approximately 22 dB of direct-path signal attenuation is demonstrated. [J542]

"Single-reference near-field calibration procedure for step-frequency ground penetrating radar"

The antenna system of ground penetrating radar is usually positioned in the vicinity of the ground surface to obtain sufficient spatial resolution for detecting small targets. Therefore, received signals are subject to errors

caused by unwanted reflections and coupling. A near-field calibration procedure taking into account these effects as well as antenna dispersion is presented. For practical convenience, only a metal plane is used here as a calibration standard. Calibration data are measured for a set of distances between the antenna and metal plane. The reference reflections in all positions are computed using polynomial representation of the reflected signal. Then, error coefficients are obtained by a solution of a linear system of equations in the least squares sense. Experimental verification of the proposed calibration technique demonstrated efficient removal of artefacts caused by unwanted reflections. Moreover, peaks in the radar range profile become sharper after calibration if the antenna is dispersive. Consequently, the ground response in the form of an exponential term can be effectively subtracted from the received signal. This helps to reveal and discriminate shallow underground targets obscured by strong reflection of the ground surface. Experimental examples are given to illustrate the performance of the method. [J543]

"Netted radar sensing"

Future radar applications are beginning to stretch monostatic radar systems beyond their fundamental sensitivity and information limits. Networks of smaller radar systems can offer a route to overcome these limitations; for example, networks of radar sensors can counter stealth technology whilst simultaneously providing additional information for improved target classification. More generally, multiple independent sensors can provide an energetically more efficient collector of radar scatter. The relative merits of non-coherent and coherent networks are introduced and the balance between increased performance, complexity, and cost is discussed. [J544]

"Comparison of Doppler clutter cancellation techniques for naval multi-function radars"

The authors describe a comparison of fixed and adaptive clutter cancellation processes applied to measured multi-function radar (MFR) data in a littoral environment. The adaptive filters require estimates of the clutter covariance, and comparisons of different strategies for obtaining this are made. The results for the adaptive filters generally show substantially improved target detectabilities over non-adaptive filters. [J545]

"Three-band biorthogonal interpolating complex wavelets with stopband suppression via lifting scheme"

Wavelet research has primarily focused on real-valued wavelet bases. However, the complex filterbanks provide much convenience for complex signal processing. For example, in radar and sonar signal processing, the complex signals from the I/Q receiver can be efficiently processed with complex filterbanks rather than real filterbanks. Specifically, the positive and negative Doppler frequencies imply different physical content in the moving target detector (MTD) and moving target identification (MTI); therefore, it is significant to design complex multiband filterbanks that can partition positive and negative frequencies into different subbands. We design two novel families of three-band biorthogonal interpolating complex filterbanks and wavelets by using the three-band lifting scheme. Unlike the traditional three-band filterbanks, the novel complex filterbank is composed of three channels, including the lowpass channel, the positive highpass channel whose passband distributes in the positive frequency region, and the negative highpass channel in the negative frequency region. Such a filterbank/wavelet naturally provides the ability to extract positive frequency components and negative frequency components from complex signals. Moreover, a novel set of design constraints are introduced to manipulate the stopband characteristic of highpass filters and are referred to as stopband suppression, which strengthens the traditional constraints of vanishing moments. Finally, a numerical method is given to further lower stopband sidelobes. [J546]

"Security from space"

Satellites have gained a prominent role in the US's toughened homeland protection plan and many companies are set to benefit. Satellites have an important role in monitoring and protecting infrastructure and many companies are planning to capitalise on America's emergent homeland security market. According to an October 2002 study by the Electronics and IT Association, they could be competing for up to чп-worth of business, which could grow to $12bn by 2008. Of course, only a small percentage of this would go to satellite companies, but this has not stemmed the flow of new ideas. As part of the Homeland Security initiative, NASA and the Department of Transportation are considering how commercial satellite imagery could be applied to other potential terrorist targets such as airports. By developing interactive digital maps, they hope to illustrate their use not only in planning airport security improvements, but also in guiding rescuers through the devastation following an incident. Eventually, it is envisaged that real-time ground radar data could be incorporated to help detect suspicious aircraft or vehicle movements. [J547]

"CFAR detection of targets with unknown Doppler shifts"

The generalised likelihood ratio test for detecting a target signal with unknown Doppler shift in coloured interference with known covariance matrix is shown to have the constant false alarm rate (CFAR) property provided that the covariance matrix is Toeplitz. The asymptotic density function of the test statistic is derived. [J548]

"Detection and imaging of arbitrarily moving targets with single-channel SAR"

In synthetic aperture radar (SAR) images, moving targets cause imaging errors such as defocusing and/or displacement, depending on the direction of their motion. To obtain a correct and focused image of the moving targets, knowledge of the target parameters, position and velocity, is necessary. An algorithm for detection, parameter estimation, and imaging of ground-based targets, moving in arbitrary directions, is presented. The algorithm is based on evaluation of a sequence of single-look SAR images which is generated from conventional, single-channel SAR raw data. The position and velocity of the moving targets are estimated by applying two observation models, whereby aliasing due to a motion induced Doppler shift is considered. In this way, the moving targets can be detected almost independently of their moving direction. The estimated parameters are used to compensate for the imaging errors in the SAR images. Finally, the real motion of the targets in the scene is visualised in a compensated image sequence. [J549]

"Localised three-dimensional adaptive spatial-temporal processing for airborne radar"

Radar space-time adaptive processing (STAP) techniques have classically focused on azimuth-Doppler adaptivity while placing minimal emphasis on elevation. Elevation adaptivity offers significant clutter suppression improvement, allowing further suppression of interference sources having identical Doppler and azimuth as the expected target. Work is presented which incorporates elevation adaptivity using two approaches: a factored approach and a joint domain approach, both greatly improving clutter suppression performance. The proposed concepts are validated using results based on simulated range ambiguous airborne radar data. Target detection improvements on the order of 8 dB and 10 dB (as compared to standard 2D-JDL processing) are demonstrated for the factored and joint domain approaches, respectively, using an 8 Ч 8 nonuniform rectangular array. [J550]

"Radar imaging of moving targets in foliage using multifrequency multiaperture polarimetric SAR"

Because of the low signal-to-clutter ratio, it is a difficult problem to detect and image moving targets in foliage. In this paper, a multifrequency multiaperture polarimetric synthetic aperture radar (MFMA POLSAR) system is proposed for imaging of moving targets in foliage. The MFMA POLSAR extends the multifrequency antenna array SAR (MF-SAR) system to multiple polarizations. Full polarization is used in MFMA POLSAR to achieve an optimal polarization adaptive to the environment such that the images obtained by different apertures are of the best coherence that is used to obtain the highest accuracy of the phase estimation. It is also shown that the MFMA POLSAR cannot only accurately locate both the slow and the fast moving targets but also reveal moving targets in foliage. [J551]

"Target detection trials with a millimeter wave radar system"

Unobstructed, large RCS targets, similar radar targets surrounded by moving foliage, and small targets in severe clutter have been used as test cases for two pre-processing algorithms and several threshold levels in an experimental millimeter wave radar system. The rather conventional "six-out-of-eight" pulse radar selection method with binary output has been compared to an algorithm that accepts a target if the pre-defined trigger level is crossed by the average of the eight consecutive pulses. In this case, however, the output is an analog value corresponding to the relative average video amplitude. In terms of plotted video, this process seems to give a slightly better combination of false alarm rate and detection probability. Large targets are easier to detect from foliage clutter with the conventional method. [J552]

"Techniques for improving STAP performance in high PRF applications"

A novel beamforming architecture is presented in which space-time adaptive processing (STAP) for clutter suppression in airborne radar is implemented with tap delays of multiple PRIs. The resulting output is combined with the unadapted output. This can result in improved detection performance for targets obscured by clutter that covers only a small proportion of the unambiguous Doppler extent, as often occurs in high PRF modes [J553]

"Millimeter wave radar with clutter measurements"

A portable millimeter wave test radar system, also suitable for battery operation, gives interesting possibilities for clutter recordings at hard-to-reach sites. The designed system covers all common radar frequencies from the Ka- to V-bands and enables spatial detection of targets or clutter elements within an adjustable time gate,

whereby spatial clutter profiles of rain can be analyzed. The construction allows full operation with non-scanning antennas as well. This is advantageous when measuring temporal RCS variations of selected targets or surface clutter from snow dunes. [J554]

"High-resolution time-frequency distributions for manoeuvring target detection in over-the-horizon radars"

A novel high-resolution time-frequency representation method is proposed for source detection and classification in over-the-horizon radar (OTHR) systems. A data-dependent kernel is applied in the ambiguity domain to capture the target signal components, which are then resolved using root-MUSIC based coherent spectrum estimation. This two-step procedure is particularly effective for analysing a multicomponent signal with time-varying complex time-Doppler signatures. By using the different time-Doppler signatures, important target manoeuvring information, which is difficult to extract using other linear and bilinear time-frequency representation methods, can be easily revealed using the proposed method [J555]

"X-band wideband experimental airborne radar for SAR, GMTI and maritime surveillance"

Defence Research and Development Canada-Ottawa has completed Phase I in the development of a new multimode X-band wideband experimental airborne radar (XWEAR) to support studies in synthetic aperture radar (SAR) imaging, inverse SAR (ISAR), ground moving target indication (GMTI) radar and maritime surveillance radar with particular focus on small target detection and long-range surface surveillance. Specific areas of interest include research into SAR imaging techniques for fixed and moving targets, time-frequency analysis of ocean and land moving targets, space-time adaptive processing for application to GMTI, investigation into the electromagnetic backscatter properties of the ocean surface, generation of signatures for automatic target recognition and feature extraction, and analysis on the immunity of wide bandwidth systems against electronic countermeasures. Phase I culminated with the flight trialling of the SAR and maritime surveillance modes. Phase II will see the trialling of the wide area surveillance GMTI (WAS GMTI) and integrated SAR-GMTI modes. A description of the experimental radar is given along with an overview of its data collection capability. Distinguishing features include operation at X-band, single-channel operation for SAR and maritime surveillance, and two-channel operation for WAS-GMTI and integrated SAR-GMTI. The new radar maximises the use of an existing digital scan converter as a controller, and commercially available components including the transmitter, A/D converters and computer boards. The timing circuitry, waveform generator, single- and dual-channel receivers are custom built [J556]

"Early detection of target manoeuvres under a specific false alarm rate"

Two improvements in fading memory average for manoeuvre detection are given. First, according to the characteristics of fading memory average, the exact detection threshold is derived by a Markov chain approach. In conventional algorithms, which ignore the dynamic and dependent properties of fading memory average, only approximate threshold values are computed for a given false alarm rate. Secondly, the univariate fading memory average is further extended to the multivariate form to increase the speed of detection. The multivariate Markov chain approach, which is an extension of the Markov chain approach, can provide exact thresholds for the multivariate fading memory average. Monte Carlo simulation results verify not only the accuracy of the thresholds through both the univariate and multivariate Markov chain approaches, but also the superior detection speed of the proposed multivariate fading memory average. Under the same false alarm rates, the mean time to detection in the multivariate algorithm is 26% less than that in the univariate algorithm. [J557]

"Spatial adaptive subspace detection in OTH radar"

The work presented here addresses the problem of target detection against spatially structured interference composed of jamming plus noise, where for practical reasons, the received target wavefront may also deviate from the traditional plane wave model. This detection problem arises in over-the-horizon (OTH) radar systems where spatially distributed targets often compete for detection against directional interference that is spread over the entire range-Doppler search space. Conventional detection processing schemes are compared with a recently proposed adaptive subspace detector (ASD) that takes both the spatial structure of the interference and the possibility of target wavefront distortions into account. Experimental array data recorded by the Jindalee sky-wave and Iluka surface-wave OTH radar systems, located in central and northern Australia respectively, is used to evaluate detection performance. [J558]

"Adaptive CFAR detection for clutter-edge heterogeneity using Bayesian inference"

Radar constant false alarm rate (CFAR) detection is addressed in this correspondence. Motivated by the frequently encountered problem of clutter-edge heterogeneity, we model the secondary data as a probability

mixture and impose a hierarchical model for the inference problem. A two-stage CFAR detector structure is proposed. Empirical Bayesian inference is adopted in the first stage for training data selection followed by a CFAR processor using the identified homogeneous training set for target detection. One of the advantages of the proposed algorithm is its inherent adaptivity; i.e., the threshold setting is much less sensitive to the nonstationary environment compared with other standard CFAR procedures. [J559]

"Automatic spectral target recognition in hyperspectral imagery"

Automatic target recognition (ATR) in hyperspectral imagery is a challenging problem due to recent advances of remote sensing instruments which have significantly improved sensor's spectral resolution. As a result, small and subtle targets can be uncovered and extracted from image scenes, which may not be identified by prior knowledge. In particular, when target size is smaller than pixel resolution, target recognition must be carried out at subpixel level. Under such circumstance, traditional spatial-based image processing techniques are generally not applicable and may not perform well if they are applied. The work presented here investigates this issue and develops spectral-based algorithms for automatic spectral target recognition (ASTR) in hyperspectral imagery with no required a priori knowledge, specifically, in reconnaissance and surveillance applications. The proposed ASTR consists of two stage processes, automatic target generation process (ATGP) followed by target classification process (TCP). The ATGP generates a set of targets from image data in an unsupervised manner which will subsequently be classified by the TCP. Depending upon how an initial target is selected in ATGP, two versions of the ASTR can be implemented, referred to as desired target detection and classification algorithm (DTDCA) and automatic target detection and classification algorithm (ATDCA). The former can be used to search for a specific target in unknown scenes while the latter can be used to detect anomalies in blind environments. In order to evaluate their performance, a comparative and quantitative study using real hyperspectral images is conducted for analysis. [J560]

"Generalised wideband ambiguity function of a coherent ultrawideband random noise radar"

A coherent ultrawideband (UWB) random noise radar system has been developed and field tested at the University of Nebraska-Lincoln (UNL). A heterodyne correlation technique based on a time-delayed and frequency-shifted replica of the transmit waveform is used to inject coherence within this system. The radar's combined range and range rate resolution characteristics were investigated using the generalised wideband ambiguity function. As in the narrowband random noise waveform case, range and range rate resolutions can be controlled independently, the former being inversely related to the transmit bandwidth, while the latter is inversely related to the bandwidth of the integrating filter. It is also shown that UWB waveforms are not suitable for accurate range rate estimation due to the extended Doppler-spread parameter, i.e. the product of the transmit bandwidth and the target range rate, unless the correlator is matched in the delay rate as well. [J561]

"On the use of complex SAR image spectral analysis for target detection: assessment of polarimetry"

The objective of this paper is to assess the joint use of the magnitude and the phase of a synthetic aperture radar (SAR) polarimetric image for point target detection and analysis. We first consider a single-look complex (SLC), single polarized radar image including point targets embedded in clutter. A series of sublooks are generated from this SLC image, both in azimuth and in range in order to analyze the inherent speckle effects. The two-looks internal Hermitian product (2L-IHP) is defined and is further shown to qualitatively increase the target/environment contrast. The processing of azimuth and range spectra preliminary to the 2L-IHP derivation (spectral whitening, generation and overlapping of sublooks) is described. A simulation tool is developed to model a point target behavior. Then, the polarimetric extension of the 2L-IHP is proposed, and the optimized polarimetric 2L-IHP is defined. The gain is twofold: in comparison with single polarization, polarimetry is shown to enhance detection capabilities, but also to provide additional information for target analysis. [J562]

"Manoeuvring target detection in over-the-horizon radar using adaptive clutter rejection and adaptive chirplet transform"

In over-the-horizon radar (OTHR) systems, the signal-to-clutter ratio (SCR) used for moving target detection is very low. For slowly moving targets such as ships, the SCR is typically from -50 dB to -60 dB and their Doppler frequencies are close to that of the clutter. For manoeuvring targets, such as aircraft and missiles, the Doppler frequencies are time-varying when a long integration time is considered. When a target does not move uniformly, the Fourier transform based target detection techniques, including super-resolution spectrum techniques, may fail to work appropriately. In such situations, the Doppler signatures are time-varying and, therefore, time-frequency analysis techniques can be used for manoeuvring target detection. In addition, clutter rejection is also required for target detection due to the low SCR. The existing adaptive clutter rejection

algorithms combine clutter rejection with spectrum analysis methods, which usually assume uniformly moving target (i.e. sinusoidal Doppler signature) models. An adaptive clutter reject algorithm is proposed together with the adaptive chirplet transform technique for manoeuvring target detection in a multipath environment. Simulation results using a simulated manoeuvring target signal with received raw OTHR clutter data show that targets with SCR below -50 dB can be detected by using the proposed algorithm [J563]

"Multi-mode ENVISAT ASAR interferometry: techniques and preliminary results"

The paper focuses on the interferometric capabilities of current and future SAR systems, like ENVISAT, RADARSAT-2, etc. The authors introduce a technique to obtain interferometric surveys by combining two images, coming from any SAR mode, together with a digital elevation mode (DEM). The DEM is exploited during the interferogram generation to provide, at one time, effective noise removal and compensation for the topographic-dependent fringes. The final product is a 'differential' (topography-compensated) interferogram to be used for monitoring over landslides, upswelling, etc. An innovative technique is also discussed to estimate local coherence maps, to be used for classification and change detection. Such a technique exploits windows whose shapes and sizes adapt locally to the target features, to attain at one time the highest resolution and the best statistical confidence. Finally, applications involving the various ENVISAT ASAR modes are discussed. [J564]

"An indirect estimate of RCS of conducting target in random medium"

This paper discusses an indirect estimate of the radar cross section (RCS) of a conducting cylinder with a partially convex cross-section under the condition that backscattering enhancement occurs in a random medium. Once we evaluate the spatial coherence length (SCL) of the incident waves around the cylinder in the random medium, we may estimate the RCS approximately from the RCS in free space with beam wave incidence in which the spot size equals the SCL. This method is restricted only to the case where the SCL is larger than the target size. [J565]

"PAMIR-a wideband phased array SAR/MTI system"

Air- and spaceborne imaging radar systems in forthcoming surveillance and reconnaissance tasks have to meet increasingly severe demands. The next generation of top-level synthetic aperture radar (SAR) systems will comprise, among others, high resolution and long-range imaging capabilities, highly sensitive ground moving target indication and a multitude of sophisticated operational modes. The variety of tasks can be fulfilled only by the use of a reconfigurable phased array antenna together with a comprehensive wideband system design and a multichannel capability. At FGAN a new experimental X-band radar has been conceived, which will possess in its final upgrade an electronically steerable phased array consisting of 16 autonomous and reconfigurable subapertures, five independent receive channels, and a total signal bandwidth of about 1.8 GHz. The sensor is called PAMIR (Phased Array Multifunctional Imaging Radar). It is envisaged to demonstrate SAR imaging at a very high resolution and for a long range. The fine resolution will also be achieved with inverse SAR (ISAR) imaging of ground moving objects. Furthermore, the number of receive channels will allow ground-moving target indication (GMTI) by space-time adaptive processing and single-pass interferometric SAR (IfSAR) with a very high 3-D resolution. In its current stage of extension PAMIR is operable with one receive channel and a mechanically steerable antenna array. The system design and the intended capabilities of PAMIR are described. Ground-based and airborne experimental results concerning high-resolution SAR and ISAR imaging are also presented. [J566]

"DORT method as applied to ultrawideband signals for detection of buried objects"

The decomposition of the time reversal operator (DORT) method, originally developed in acoustics, allows detection of scatterers embedded in the probed domain and provides some very robust means for focusing an incident wave onto a given scatterer. Hence, this method is very helpful for clutter reduction. Here, it is applied to the detection of buried cylindrical objects with the help of electromagnetic ultrawideband signals. It is shown that when the set of antennas is located on a piece of line above an interface, the use of the DORT method remains simple, whatever the polarization, provided the contribution from the target can be separated from that of the interface. Using wideband signals also permits one to excite natural resonances of the buried scatterer, which can easily be extracted from the eigenvalues of the time reversal operator. Numerical examples based on a finite-difference time-domain algorithm are given. [J567]

"Ultra-wideband multistatic SAR for the detection and location of landmines"

Techniques for improving the signal to clutter ratio of an ultra-wideband SAR designed to detect small mine-like objects in the surface of the ground were investigated. In particular, images were collected using different bistatic antenna configurations in an attempt to decorrelate the clutter with respect to the targets. The images were

converted to a reference depression angle, summed, and then converted to ground coordinates. The resulting target strengths were then compared with the amplitude distribution of the ground clutter to show the improvement obtained. While some improvement was demonstrated, this was for the relatively easy scenario of targets on the surface partially obscured by grass. Detection based on thresholding the raw RF signal (the bipolar response) rather than the envelope (baseband I2+Q2) was also considered to further enhance target-to-clutter ratios. [J568]

"Tracking evasive move-stop-move targets with a GMTI radar using a VS-IMM estimator"

We present the design of a variable structure interacting multiple model (VS-IMM) estimator for tracking evasive ground targets using ground moving target indicator (GMTI) reports obtained from an airborne sensor. In order to avoid detection by the GMTI sensor, the targets use a "move-stop-move" strategy, where a target deliberately stops or moves at a very low speed for some time before accelerating again. In this case, when the target's radial velocity (along the line of sight from the sensor) falls below a certain minimum detectable velocity, the target is not detected by the sensor. Under these conditions, the use of an estimator, which does not take care of this move-stop-move motion explicitly, will result in broken tracks. The tracker proposed here handles the evasive move-stop-move motion via the VS-IMM estimator, where the tracker mode set is augmented with a "stopped-target" model when the estimated speed of the target falls below a certain threshold. Using this additional stopped-target model, the target track is kept "alive" even in the absence of a measurement. A simulated scenario is used to illustrate the selection of design parameters and the operation of the tracker. Performance measures are presented to contrast the benefits of the VS-IMM estimator, which uses the stopped-target model, over a standard IMM estimator. [J569]

"Time-frequency analysis for plastic landmine detection via forward-looking ground penetrating radar"

Time-frequency analysis techniques are used for buried plastic landmine detection with a forward-looking ground penetration radar (GPR) system. Several time-frequency distributions are considered to characterise and interpret the scattering phenomena of both targets and clutter. An ambiguity function based detector is also presented, which employs principal component analysis and feature selection for data dimensionality reduction and linear discriminant analysis for signal classification. Experimental results based on the SRI (Stanford Research Institute) experimentally measured forward-looking GPR data are presented, showing a significant detection performance improvement over the conventional detector [J570]

"Closed-form four-channel monopulse two-target resolution"

A novel closed-form solution to resolve the directions of arrival (azimuth and elevation) of two sources using a single snapshot (monopulse) of four independent channels is presented. Both phase comparison monopulse and amplitude comparison monopulse are solved. Exceptions where the two targets cannot be resolved are also discussed. Numerical simulation result of a practical phased-array configuration validates the effectiveness of the new solution. [J571]

"MDL approach for multiple low observable track initiation"

In this paper the track initiation problem is formulated as multiple composite hypothesis testing using maximum likelihood estimation with probabilistic data association (ML-PDA). The hypothesis selection is based on the minimum description length (MDL) criterion. We first review some well-known approaches for statistical model selection and the advantage of the MDL criterion. Then we present one-dimensional examples to illustrate the MDL criterion used in multiple composite hypothesis testing and the performance limit of the ML-PDA for track initiation is interpreted in terms of the sharpness of the hypothesis testing. Finally, we apply the MDL approach for the detection and initiation of tracks of incoming tactical ballistic missiles in the exo-atmospheric phase using a surface-based electronically scanned array (ESA) radar. The targets are characterized by low signal-to-noise ratio (SNR), which leads to low detection probability and high false alarm rate. The target acquisition problem is formulated using a batch of radar scans to detect the presence of up to two targets. The ML-PDA estimator is used to initiate the tracks assuming the target trajectories follow a deterministic state propagation. The approximate MDL criterion is used to determine the number of valid tracks in a surveillance region. The detector and estimator are shown to be effective even at 4.4 dB average SNR. [J572]

"Expanded Swerling target models"

Radar target fluctuation models were first introduced by Swerling in the 1950s and they proved to be very useful. Swerling soon realized, however, that his original four models were inadequate and generalized them through use of the gamma distribution. These generalized results still had serious limitations in modeling fluctuating

targets. For some targets the Swerling I correlated model produced an overly pessimistic value for PDat large signal-to-noise ratios (SNRs) while the Swerling III correlated model produced an overly optimistic one. As a result, other fluctuation models, such as the log-normal and Weibull, remain useful in spite of their own limitations. Two new models that expand on the generalized Swerling model are presented here. They are physically motivated and can produce the desired PDlevels at high SNR values. They are described in detail and both the moment generating functions (MGFs) and PDexpressions are determined. They provide a significant advance in our modeling capabilities through their flexibility for modeling many different types of target radar cross section (RCS) responses. These new models apply to both the case where the pulse-to-pulse target responses are correlated as well as the case where they are uncorrelated, thereby overcoming the limitations of the log-normal and Weibull models. [J573]

"M-correlated sweeps performance analysis of mean-level CFAR processors in multiple target environments"

This paper is devoted to the detection performance evaluation of the mean-level (ML) constant false-alarm rate (CFAR) detectors processing M-correlated sweeps in the presence of interfering targets. The consecutive pulses are assumed to be fluctuating according to the Swerling I model. Exact expressions are derived for the detection probability of the conventional mean-level detector (MLD) and its modified versions under Rayleigh fluctuating target model. Performance for independent sweeps can be easily obtained by setting the sweep-to-sweep correlation coefficient equal to zero. Results are obtained for both homogeneous and nonhomogeneous background environments. It is shown that for fixed M, the relative improvement over the single sweep case increases as the correlation between sweeps decreases. For the same parameter values, the minimum MLD has the best performance in the presence of extraneous target returns among the reference noise samples [J574]

"Tracking considerations in selection of radar waveform for range and range-rate measurements"

The conventional approach for tracking system design is to treat the detection and tracking subsystems as completely independent units. However, the two subsystems can be designed jointly to improve system (tracking) performance. It is known that different radar signal waveforms result in very different resolution cell shapes (for example, a rectangle versus an eccentric parallelogram) in the range/range-rate space, and that there are corresponding differences in overall tracking performance. We develop a framework for the analysis of this performance. An imperfect detection process, false alarms, target dynamics, and the matched filter sampling grid are all accounted for, using the Markov chain approach of Li and Bar-Shalom. The role of the grid is stressed, and it is seen that the measurement-extraction process from contiguous radar "hits" is very important. A number of conclusions are given, perhaps the most interesting of which is the corroboration in the new measurement space of Fitzgerald's result for delay-only (i.e., range) measurements, that a linear FM upsweep offers very good tracking performance [J575]

"CFAR detection of distributed targets in non-Gaussian disturbance"

The subject of detection of spatially distributed targets in non-Gaussian noise with unknown statistics is addressed. At the design stage, in order to cope with the a priori uncertainty, we model noise returns as Gaussian vectors with the same structure of the covariance matrix, but possibly different power levels (heterogeneous environment). We also assume that a set of secondary data, free of signal components, is available to estimate the correlation properties of the disturbance The proposed detector assumes no a priori knowledge about the spatial distribution of the target scatterers and ensures the constant false alarm rate (CFAR) property with respect to both the structure of the covariance matrix and the power levels. Finally, the performance assessment, conducted modeling the disturbance as a spherically invariant random process (SIRP), confirms its validity to operate in real radar scenarios [J576]

"Strengths and limitations of the Fourier method for detecting accelerating targets by pulse Doppler radar"

The Fourier transform method has been generally used in pulse Doppler radar for detecting targets that are moving with acceleration, despite the phenomenon known as Doppler smearing which limits the performance of the method. Examples of accelerating targets are manoeuvring aircraft and missiles. The authors quantify the effects of Doppler smearing. In using a pulse Doppler radar to detect a nonaccelerating target in additive white Gaussian noise and to estimate its radial velocity, the Fourier method provides an output signal-to-noise ratio (SNR) that increases linearly with the number of pulses. When the target is accelerating, the Fourier method may still be used to detect the target and estimate its median velocity, provided the acceleration is small enough in the sense described. For a given acceleration, when the number of pulses is increased, the output SNR of the Fourier method varies as a concave function, increasing to a maximum and then decreasing, before the method

fails catastrophically. Thus the number of pulses and the acceleration have to be matched to achieve optimum performance. Empirical formulas for the dependence of the optimum SNR and the optimum number of pulses on the acceleration are given. The results are shown to be relevant to the design of generalised likelihood ratio test detectors that apply a search over a grid [J577]

"Quasi-magnetostatic solution for a conducting and permeable spheroid with arbitrary excitation"

Broad-band electromagnetic induction (EMI) methods are promising in the detection and discrimination of subsurface metallic targets. In this paper, the quasi-magnetostatic solution for a conducting and permeable prolate spheroid under arbitrary excitation by a time-harmonic primary field is obtained by using the separation of variables method with vector spheroidal wave functions. Numerical results for the induced dipole moments are presented for uniform axial and transverse excitations, where the primary field is oriented along the major and minor axis of the prolate spheroid, respectively. They show that the EMI frequency responses are sensitive to the orientation and permeability of the spheroid. An approximation is also developed that aims to extend the exact solution to higher frequencies by assuming slight penetration of the primary field into the spheroid. Under this approximation, a system of equations that refers only to the external field expansions is derived. It is shown that, for spheroids with high relative permeability, this approximation is in fact capable of yielding an accurate broad-band response even for highly elongated spheroids [J578]

"Characterisation of objects and general ocean phenomena by use of target adaptive multifrequency multistatic matched illumination acoustics"

Through modelling and detailed experimental investigations there exists in most cases a considerable amount of a priori information about the target and the background scene. Some of the signatures are very dominant and specific in nature, and some are less so and may overlap signatures related to other targets or background clutter. The authors investigate phenomena of interest in the maximum number of signature domains and present the basic matched illumination sonar concept. Subsequently they illustrate a set of specific application areas with emphasis on classification of submerged objects and their wakes against a background of gravity waves, internal waves and turbulence. Some experimental results displaying the capability of the technique are presented [J579]

"Performance characterisation of hybrid STAP architecture incorporating elevation interferometry"

Radar space-time adaptive processing (STAP) techniques have classically focused on azimuth-Doppler adaptivity while placing minimal emphasis on elevation. Elevation beamforming offers significant clutter suppression improvement, allowing further suppression of interference sources having identical Doppler and azimuth. This work incorporates elevation adaptivity through an interferometric approach, greatly improving clutter suppression while providing an often overlooked target height discrimination capability. A mathematical construct encapsulating the multistage processing framework is developed for the proposed technique. This framework allows extension of the traditional factored time-space (FTS) technique into the azimuth-Doppler-elevation hypercube and represents a subclass of more generalised hybrid methods. The proposed concept is validated through results based on simulated airborne radar data. Target detection improvement of the order of 25 dB, when compared to standard two-dimensional FTS processing, is demonstrated for an 8 Ч 8 nonuniform rectangular array. Elevation pattern data are provided to illustrate achievable null width/depth capabilities. These data also indicate target height discrimination is inherently provided and further development is warranted [J580]

"Pade approximations to matched-filter amplitude probability functions: Rayleigh mixtures and multiple observations"

Techniques are presented for deriving approximations to the statistical functions that characterize linear sums of matched-filter outputs. They are derived using two techniques: (1) Pade approximations to the multidimensional characteristic function (CF), and (2) discrete Rayleigh mixtures based on an exact or approximate form of the Rayleigh parameter probability density function. The Pade-based approximations are used for modeling the "clutter-only" case and computing detection thresholds, whereas the Rayleigh mixtures are best suited for modeling the "target-plus-clutter" case and computing target detection probabilities [J581]

"Monte Carlo simulations for clutter statistics in minefields: AP-mine-like-target buried near a dielectric object beneath 2-D random rough ground surfaces"

A rigorous three-dimensional (3-D) electromagnetic model is developed to analyze the scattering from anti-personnel (AP) nonmetallic mine-like target when it is buried near a clutter object under two-dimensional (2-D) random rough surfaces. The steepest descent fast multipole method (SDFMM) is implemented to solve for the

unknown electric and magnetic surface currents on the ground surface, on the target and on the clutter object. A comprehensive numerical investigation of two clutter sources; the ground roughness and the nearby benign object, is presented based on using more than 800 random rough surface realizations which could not be achieved without using fast algorithms such as the SDFMM. The statistics of the scattered near-electric fields are computed using the Monte Carlo simulations for both polarizations. For the parameters used here, the results show that the average and the standard deviation of the target signature represent 5-7% and 3-3.5% of the total scattered signal, respectively, while they represent 16-20% and 7-12% of the signal for the clutter object, respectively. This study indicates the high possibility of a false alarm during the detection process when the target is located nearby a realistic object such as a piece of a tree root. [J582]

"Time-domain inverse scattering method for cross-borehole radar imaging"

In this paper, we consider a solution method of the inverse problem of imaging two-dimensional (2D) objects buried underground by cross-hole radar data in the time domain. In addition to less information on the targets due to restriction on the arrangement of transmitters and receivers than for full-view cases such as imaging of objects in free space, the large search region between boreholes makes solving the inverse problem difficult. Although iterative optimization approaches take long computing time, these approaches give much better image qualities for high-contrast objects than linear inversions such as a diffraction tomography. However, the reconstruction in a large search region with limited-view measurements often fails trapped in a local minimum. To overcome this difficulty, we propose a two-step iterative approach: the first step is to reduce the search region to a smaller one and the second step is the accurate reconstruction of the targets in the small region. Both steps are based on an iterative optimization approach, i.e., the forward-backward time-stepping method previously proposed. This two-step approach is tested for detection of tunnel-like objects surrounded by a heterogeneous background medium to evaluate its performance. Numerical results indicate the efficiency of the approach and its ability of circumventing local minima. [J583]

"Polarimetric adaptive detection of range-distributed targets"

We address the problem of polarimetric adaptive detection of range-spread targets in Gaussian noise with unknown covariance matrix. At the design stage, we model the target echo from each polarimetric channel as a deterministic signal known up to a scaling factor (possibly varying from cell to cell), which accounts for the polarimetric scattering properties of the target. We first show the failure of the generalized likelihood ratio test (GLRT) procedure to deal with this kind of problem, and thus, we propose a fully adaptive detector based on the method of sieves. We also derive the analytical expression for the probability of false alarm and show that the newly introduced receiver can be made bounded constant false alarm rate (CFAR). Finally, we present simulation results highlighting the performance gain that can be achieved by resorting to polarization diversity in conjunction with high resolution. [J584]

"Frequency responses of ground-penetrating radars operating over highly lossy grounds"

The finite-difference time-domain (FDTD) method is used to investigate the effects of highly lossy grounds and the frequency-band selection on ground-penetrating-radar (GPR) signals. The ground is modeled as a heterogeneous half space with arbitrary background permittivity and conductivity. The heterogeneities encompass both embedded scatterers and surface holes, which model the surface roughness. The decay of the waves in relation to the conductivity of the ground is demonstrated. The detectability of the buried targets is investigated with respect to the operating frequency of the GPR, the background conductivity of the ground, the density of the conducting inhomogeneities in the ground, and the surface roughness. The GPR is modeled as transmitting and receiving antennas isolated by conducting shields, whose inner walls are coated with absorbers simulated by perfectly matched layers (PML). The feed of the transmitter is modeled by a single-cell dipole with constant current density in its volume. The time variation of the current density is selected as a smooth pulse with arbitrary center frequency, which is referred to as the operating frequency of the GPR. [J585]

"Cramer-Rao bound for nonlinear filtering with Pd<1 and its application to target tracking"

The paper investigates the Cramer-Rao bound for discrete-time nonlinear filtering in the case where the probability of detection of a sensor is less than unity. The theoretical formula involves the evaluation of exponentially growing number of possible miss/detection sequences. An approximation of the theoretical bound for practical applications, such as target tracking, where the number of sensor scans is large, is proposed. An application of the developed techniques to the well-known filtering problem of tracking a re-entry ballistic object is also presented [J586]

"Radiated pulses decay exponentially in materials in the far fields of antennas"

There has been interest in using short-pulse radar to detect targets in lossy clutter. The analysis presented here shows that the energy and peak-power densities of pulses decay exponentially with depth in homogeneous, lossy, dispersive materials, provided the frequency bands of the pulses are separated from DC. Many numerical examples verify the analytical results [J587]

"A linear prediction land mine detection algorithm for hand held ground penetrating radar"

Land mine detection using ground penetrating radar (GPR) is a difficult task because the background clutter characteristics are nonstationary and the land mine signatures are inconsistent. A particularly difficult scenario is the case for which a GPR is mounted on a hand held device with no position or velocity information available to a signal processing algorithm. This paper proposes the use of linear prediction in the frequency domain for land mine detection in this scenario. A frequency domain clutter vector sample is partitioned into subbands. Each subband is modeled by a linear prediction model; the current vector sample is expressed as a linear combination of the past few vector samples plus random noise. The detector first computes the maximum likelihood estimate of the prediction coefficients, and then uses the generalized likelihood method to determine if a land mine is present. The effect of subband processing on the accuracy of the detector is evaluated. Detection results are presented on data collected from a variety of geographical locations. The data sets contain over 2300 mine encounters of different size, shape and content, and a larger number of measurements from locations with no mines. The proposed detector is compared to the baseline differential energy detector. The proposed algorithm reduces the false alarm rate by 60% for all the targets at 90% probability of detection, and 70% for the deep anti-tank mines at 90% probability of detection. [J588]

"Evaluation of EarthRadar unexploded ordnance testing at Fort A.P. Hill, Virginia"

Previously, K. Bakhtar and E. Sagal [ibid. vol. 17, pp. 4-11, 2002] made remarkable claims for the performance of the Bakhtar Associates ground-penetrating radar (GPR) in detecting and classifying buried unexploded ordnance (UXO). In this article, we report the results of the series of blind tests on the EarthRadar carried out during the Fall of 2000 and Spring of 2001, which led to very different conclusions regarding the radar's performance. The contents of this article are excerpted from the final report on the testing, prepared by the Institute for Defense Analyses [J589]

"Three types of distributed CFAR detection based on local test statistic"

Three types of distributed constant false-alarm rate (CFAR) detection based on local test statistic (LTS) are developed under the condition that all the samples in different sensors are independent and identically distributed (IID). They are called R (ratio), S (substract) and P (plus) types. For a two-sensor network and local order statistics CFAR (OS-CFAR) algorithm, we derive their closed-form expressions for false alarm and detection probabilities of detecting a Swerling II target in Gaussian noise. The numerical results show that ρ, the ratio between the noise power levels in two local sensors, has very strong effects on the performances of the S and P type schemes and the centralized detection. They can't hold to be CFAR when there isn't the precise prior knowledge of ρ. Compared with the centralized detection, the distributed detection scheme is more robust for the effect of ρ. Fortunately, the R type scheme is not affected by the ρ at all. It implies that the local CFAR processing can immunize the distributed detection against the ρ [J590]

"Maximum likelihood angle extractor for two closely spaced targets"

In a scenario of closely spaced targets special attention has to be paid to radar signal processing. We present an advanced processing technique, which uses the maximum likelihood (ML) criterion to extract from a monopulse radar separate angle measurements for unresolved targets. This processing results in a significant improvement, in terms of measurement error standard deviations, over angle estimators using the monopulse ratio. Algorithms are developed for Swerling I as well as Swerling III models of radar cross section (RCS) fluctuations. The accuracy of the results is compared with the Cramer Rao lower bound (CRLB) and also to the monopulse ratio technique. A novel technique to detect the presence of two unresolved targets is also discussed. The performance of the ML estimator was evaluated in a benchmark scenario of closely spaced targets-closer than half power beamwidth of a monopulse radar. The interacting multiple model probabilistic data association (IMMPDA) track estimator was used in conjunction with the ML angle extractor [J591]

"Detection of small objects in clutter using a GA-RBF neural network"

Detection of small objects in a radar or satellite image is an important problem with many applications. Due to a recent discovery that sea clutter, the electromagnetic wave backscatter from a sea surface, is chaotic rather than purely random, computational intelligence techniques such as neural networks have been applied to reconstruct the chaotic dynamic of sea clutter. The reconstructed sea clutter dynamical system which usually takes the form

of a nonlinear predictor does not only provide a model of the sea scattering phenomenon, but it can also be used to detect the existence of small targets such as fishing boats and small fragments of icebergs by observing abrupt changes in the prediction error. We applied a genetic algorithm (GA) to obtain an optimal reconstruction of sea clutter dynamic based on a radial basis function (RBF) neural network. This GA-RBF uses a hybrid approach that employes a GA to search for the optimum values of the following RBF parameters: centers, variance, and number of hidden nodes, and uses the least square method to determine the weights. It is shown here that if the functional form of an unknown nonlinear dynamical system can be represented exactly using an RBF net (i.e., no approximation error), this GA-RBF approach can reconstruct the exact dynamic from its time series measurements. In addition to the improved accuracy in modeling sea clutter dynamic, the GA-RBF is also shown to enhance the detectability of small objects embedded in the sea. Using real-life radar data that are collected in the east coast of Canada by two different radar systems: a ground-based radar and a satellite equipped with synthetic aperture radar (SAR), we show that the GA-RBF network is a reliable detector for small surface targets in various sea conditions and is practical for real-life search and rescue, navigation, and surveillance applications [J592]

"MHT extraction and track maintenance of a target formation"

Tracking of a group of targets temporarily operating in formation is relevant for military air-surveillance. An optimal sequential multiple hypothesis tracking (MHT) track extraction and track maintenance method for well-separated single targets embedded in clutter has been described in an earlier paper. However, applied to a group of closely spaced targets, its performance is not acceptable due to data miscorrelation. Here the approach has been generalized to include extraction and maintenance of a maneuvering formation in the presence of clutter. The unknown number of targets and imperfect detection when the group newly appears is modeled within the MHT framework. The generalized method solves the problem very well and can also track a formation after the targets separate [J593]

"Air target detection via bistatic radar based on LEOs communication signals"

The paper discusses the bistatic radar parameters for the case when the transmitter is a satellite emitting communication signals. The model utilises signals from an Iridium-like low Earth orbiting satellite system. The maximum detection range, when thermal noise-limited, is discussed at the theoretical level and these results are compared with experimentation. Satellite-radar signal levels and the power of ground reflections are evaluated [J594]

"Suppression of sea clutter with orthogonal weighting for target detection in shipborne HFSWR"

It is difficult to detect a target submerged in the spread spectrum of the first-order sea clutter in shipborne HFSWR (high frequency surface wave radar). Based on the space-time distribution of the first-order sea clutter, a technique for the detection of a ship in the spread-clutter spectrum is presented, which can completely suppress interference coming from a known incident direction. The influence of orthogonal weighting on the mainbeam directed at the target is slight when interference is outside the mainbeam. Angle measurement can then be accomplished as for an onshore HFSWR. However, suppression of interference coming from within the main target beam would result in this mainbeam splitting into two beams. It is shown that amplitude comparison of the two split beams can be used to determine the azimuth of the target. Processing the results from the experimental data demonstrate reliable ship detection and estimation on the Yellow Sea of China [J595]

"Moving target detection and imaging using an X band along-track monopulse SAR"

Moving target detection and imaging results for an X band spotlight synthetic aperture radar (SAR) system that utilizes an along-track monopulse configuration for its data collection is presented. The theoretical foundation of the processing that is used on these data is based on our earlier work in which a two-dimensional signal subspace processing (adaptive filtering) method was used to calibrate the monostatic and bistatic radars of the monopulse SAR system. The blind calibration of the two channels enables the user to null the stationary scene, and detect the moving targets. Next, a measure that we call SAR ambiguity function is used to estimate the relative speed of a detected moving target. The resultant estimate is then used to image the moving target [J596]

"Prescreening during image formation for ultrawideband radar"

Standard radar image formation techniques waste computational resources by full resolving all areas of the scene, even regions of benign clutter. We introduce a multiscale prescreener algorithm that runs as part of the image formation processing step for ultrawideband (UWB) synthetic aperture radar (SAR) systems. The prescreener processes intermediate radar data generated by a quadtree backprojection image former. As the quadtree algorithm iterates, it is resolving increasingly finer subpatches of the scene. After each quadtree stage,

the prescreener makes an estimate of the signal-to-background ratio of each subpatch and applies a constant false alarm rate (CFAR) detector to decide which ones might contain a target of interest. Whenever the prescreener determines that a subpatch is not near a detection, it cues the image former to terminate further processing of that subpatch. Using a small database of UWB radar field data, we demonstrate that the prescreener is able to decrease the overall computational load of the image formation process. We also show that the new multiscale prescreener method produces fewer false alarms than the conventional two-parameter CFAR prescreener applied to the completely formed image [J597]

"Coaxial range measurement-current trends for mobile robotic applications"

The useful environmental interaction of a mobile robot is completely dependent on the reliable extraction of information from its immediate surroundings. A review of some of the most commonly used coaxial, active sensing methods in robotics is presented. A coaxial sensor results if the transmitter and receiver are geometrically arranged in a coaxial manner. Certain advantages of such configurations are discussed. First, optical sensors, in which a controlled light signal is transmitted, are reviewed with respect to their applicability to mobile robotics. An overview of the literature describing light detection and ranging (LIDAR) systems for range measurement in robotics is given. A review of mobile robot research using sound navigation and ranging (SONAR) is presented where processing algorithms are demonstrated for the correct interpretation of ultrasonic data recorded in indoor environments. Ultrasonic wave reflection is generally dominated by specular reflections. Methods for the interpretation of SONAR data, for correct target classification, and, hence, range estimation are given, based on the acoustic reflection mechanism [J598]

"Finite-difference time-domain simulation of scattering from objects in continuous random media"

A three-dimensional (3D) finite-difference time-domain (FDTD) scheme is introduced to model the scattering from objects in continuous random media. FDTD techniques have been previously applied to scattering from random rough surfaces and randomly placed objects in a homogeneous background, but little has been done to simulate continuous random media with embedded objects where volumetric scattering effects are important. In this work, Monte Carlo analysis is used in conjunction with FDTD to study the scattering from perfectly electrically conducting (PEC) objects embedded in continuous random media. The random medium models under consideration are chosen to be inhomogeneous soils with a spatially fluctuating random permittivities and prescribed correlation functions. The ability of frequency averaging techniques to discriminate objects in this scenarion is also briefly investigated. The simulation scheme described in this work can be adapted and used to help in interpreting the scattered field data from targets in random environments such as geophysical media, biological media, or atmospheric turbulence [J599]

"VHF/UHF radar. 1. Characteristics"

Low-frequency radars have the potential to counter stealth efforts and detect low-flying targets beyond the horizon. This paper gives an overview of the fundamental properties of radars at metric wavelengths, based on research over the past few years conducted at the German Research Institute for High-Frequency Physics and Radar Techniques (FGAN-FHR). It provides an analysis of radar cross-section to underline the anti-stealth properties of the low-frequency range and presents simulations as well as measurement results to demonstrate the beyond-the-horizon detection and foliage penetration capability of metric waves. Specific clutter properties are highlighted [J600]

"Dominant scatterer identification testing with an integrated X-band radar system"

Radar return data from airborne jet aircraft were collected and analyzed to determine the presence of consistent, dominant radar returns of point scatterers on aircraft simulating landing conditions. These measurements were performed by integrating two separate X-band radars into one system with the ability to simultaneously track and image aircraft. Selected processed data from both radar systems were analyzed and are presented for the airborne jet aircraft [J601]

"Improved target classification using optimum polarimetric SAR signatures"

We present a new method for automatic target/object classification by using the optimum polarimetric radar signatures of the targets/objects of interest. The state-of-the-art in radar target recognition is based mostly either on the use of single polarimetric pairs or on the four preset pairs of orthogonal polarimetric signatures. Due to these limitations, polarimetric radar processing has been fruitful only in the area of noise suppression and target detection. The use of target separability criteria for the optimal selection of radar signal state of polarizations is addressed here. The polarization scattering matrix is used for the derivation of target signatures at arbitrary transmit and receive polarization states (arbitrary polarization inclination angles and ellipticity angles). Then, an

optimization criterion that minimizes the within-class distance and maximizes the between-class metrics is used for the derivation of optimum sets of polarimetric states. The results of the application of this approach on real synthetic aperture radar (SAR) data of military vehicles are obtained. The results show that noticeable improvements in target separability and consequently target classification can be achieved by the use of the optimum over nonoptimum signatures [J602]

"Measurements of the propagation parameters of tree canopies at MMW frequencies"

The presence of trees in a given scene can hamper detection of nearby targets by millimeter-wave (MMW) radars especially at near grazing incidence. Proper characterization of scattering and attenuation in tree canopies is important for optimal detection algorithms. In this paper, a new technique for determining the extinction and volume backscattering coefficients in tree canopies using the measured radar backscatter response is proposed and verified experimentally. The technique, which can be applied to already available wideband radar backscatter data, is used to compute the extinction and volume backscattering coefficients of different tree canopies under various physical conditions. The dynamic range of these coefficients are presented and results at 35 GHz are compared with results at 95 GHz [J603]

"Microwave underground propagation and detection"

The detection of buried targets has been a problem of significant interest for decades, with microwave-based sensing constituting an important tool. In this paper, we review the basic issues that characterize microwave-based subsurface sensing. Issues considered include the use of microwaves in the context of an airborne synthetic aperture radar, as well for radars deployed close to the air-soil interface. Rough-surface induced clutter is also discussed. Particular examples are presented for detection of land mines and unexploded ordnance [J604]

"A wavelet transform coder supporting browsing and transmission of sea ice SAR imagery"

A wavelet-transform-based algorithm for sea ice synthetic aperture radar (SAR) image data compression is presented. Compression of the relatively low resolution (100 m) SAR data is necessary to enable the transmission of such images from the Finnish Ice Service to users in the Baltic Sea. On board the ships, the SAR images are used for navigation purposes. Hence, in the visual appearance of the compressed image, special attention must be paid to the sharpness of small details. Several target-dependent features are incorporated in the compression scheme developed. The addition of these features was motivated by an examination of the wavelet coefficient statistics for the SAR data. In the quantization phase, the sensitivity characteristics of the human visual system were taken into account. As a result, the proposed algorithm deviates in several respects from the standard procedures used in wavelet-based compression. The algorithm requires the setting up of multiple user-defined parameters to satisfy the requirements of the users and data. This requires supervision of an expert, but also makes it flexible for many kinds of data and user requirements. The algorithm presented gives satisfactory results with a compression ratio of 20:1. Since only the location of ice-covered areas is of significance for ship traffic, the algorithm introduced contains an option to mask off open sea areas with the aid of an automatic open-water detection procedure. We also report the results of a user evaluation, in which the proposed algorithm is compared to the algorithm currently used by the Finnish Ice Service, as well as to the JPEG standard. The results of the evaluation favor the use of the proposed algorithm. [J605]

"A review of speckle filtering in the context of estimation theory"

Speckle filter performance depends strongly on the speckle and scene models used as the basis for filter development. These models implicitly incorporate certain assumptions about speckle, scene, and observed signals. In this study, the multiplicative and the product speckle models, which have been used for the development of most of the well-known filters, are analyzed, and their implicit assumptions with regard to the stationarity-nonstationarity nature of speckle are discussed. This leads to the definition of two categories of speckle filters: the stationary and the nonstationary multiplicative speckle model filters. The various approximate models used for the multiplicative speckle noise model are assessed as functions of speckle and scene characteristics to derive the requirements on scene signal variations for the validity of both the stationary and nonstationary multiplicative speckle models. Speckle filtering is then studied in the context of estimation theory, so as to develop a procedure for speckle filtering. It is shown that speckle filtering can be effective only in locally stationary scenes. Regions in which the signals are not stationary have to be filtered separately using a priori scene templates for the best matching of nonstationary scene features. The use of multiresolution techniques is crucial for accurate estimation of filter parameters. Under the guidance of the speckle filtering procedure, structural-multiresolution versions of the Lee (1980) and Frost et al. (1982) filters are developed for optimum

application of these filters in the context of nonstationary scene signals. [J606]

"Coordinated target assignment and intercept for unmanned air vehicles"

Presents an end-to-end solution to the cooperative control problem represented by the scenario where M unmanned air vehicles (UAVs) are assigned to transition through N known target locations in the presence of dynamic threats. The problem is decomposed into the subproblems of: 1) cooperative target assignment; 2) coordinated UAV intercept; 3) path planning; 4) feasible trajectory generation; and 5) asymptotic trajectory following. The design technique is based on a hierarchical approach to coordinated control. Simulation results are presented to demonstrate the effectiveness of the approach. [J607]

"Subsurface object sensing with a multifrequency microwave radiometer"

Experimental results are reported for sensing of subsurface objects with a multifrequency radiometer (MFRAD) system. Properties of the MFRAD system are reviewed, and the calibration and experimental procedures are discussed. Results with subsurface metallic, styrofoam, and plastic targets are then provided that demonstrate an oscillatory behavior in brightness temperatures versus frequency in the presence of a subsurface object. Measured data are also compared with a simple layered medium brightness temperature model and show reasonable agreement with predicted trends of brightness temperatures versus frequency. The oscillatory behaviors versus frequency obtained in the presence of both metallic and nonmetallic subsurface objects should prove advantageous for designing object detection procedures. [J608]

"Particle filters for tracking an unknown number of sources"

This paper addresses the application of sequential importance sampling (SIS) schemes to tracking directions of arrival (DOAs) of an unknown number of sources, using a passive array of sensors. This proposed technique has significant advantages in this application, including the ability to detect a changing number of signals at arbitrary times throughout the observation period and that the requirement for quasistationarity over a limited interval may be relaxed. We propose the use of a reversible jump Monte Carlo Markov chain (RJMCMC) step to enhance the statistical diversity of the particles. This step also enables us to introduce two novel moves that significantly enhance the performance of the algorithm when the DOA tracks cross. The superior performance of the method is demonstrated by examples of application of the particle filter to sequential tracking of the DOAs of an unknown and nonstationary number of sources and to a scenario where the targets cross. Our results are compared with the PASTd method. [J609]

"Efficient joint polarisation-space-time processor for nonhomogeneous clutter environments"

A new adaptive radar target detection algorithm which is of significant use in nonhomogeneous clutter environments is developed. The key idea of the proposed algorithm is that the degree of freedom is controlled to avoid a serious detection loss due to limited secondary data vectors, while maintaining high performance of the joint polarisation-space-time processing. The performance of the proposed algorithm is numerically evaluated to illustrate its efficiency in limited secondary data environments. [J610]

"Low angle scattering from 2-D targets on a time-evolving sea surface"

The results of a numerical investigation of the electromagnetic scattering from two-dimensional (2-D) targets on a time-evolving sea surface are presented. The 2-D radar cross section (RCS), or "echo width," is computed as a function of time as the sea surface evolves linearly using the spectrally accelerated generalized forward-backward method. It is shown that the RCS varies with time on the order of seconds, which is much longer than the typical pulse width or pulse repetition rate of search radars. It is also observed that for low-grazing angles of incidence the primary sea surface influence on the RCS comes from the long waves in the ocean spectrum. [J611]

"3-D track initiation in clutter using 2-D radar measurements"

We present an algorithm for initiating 3-D tracks using range and azimuth (bearing) measurements from a 2-D radar on a moving platform. The work is motivated by the need to track possibly low-flying targets, e.g., cruise missiles, using reports from an aircraft-based surveillance radar. Previous work on this problem considered simple linear motion in a flat Earth coordinate frame. Our research extends this to a more realistic scenario where the Earth's curvature is also considered. The target is assumed to be moving along a great circle at a constant altitude. After the necessary coordinate transformations, the measurements are nonlinear functions of the target state and the observability of target altitude is severely limited. The observability, quantified by the Cramer-Rao lower bound (CRLB), is very sensitive to the sensor-to-target geometry. The paper presents a

Maximum Likelihood (ML) estimator for estimating the target motion parameters in the Earth-centered Earth-fixed (ECEF) coordinate frame from 2-D range and angle measurements. In order to handle the possibility of false measurements and missed detections, which was not considered previously, we use the Probabilistic Data Association (PDA) algorithm to weight the detections in a frame. The PDA-based modified global likelihood is optimized using a numerical search. The accuracies obtained by the resulting ML-PDA estimator are quantified using the CRLB for different sensor-target configurations. It is shown that the proposed estimator is efficient, that is, it meets the CRLB. Of particular interest is the achievable accuracy for estimating the target altitude, which is not observed directly by the 2-D radar, but can be only inferred from the range and bearing observations. [J612]

"DOA estimation by exploiting the amplitude modulation induced by antenna scanning"

We propose a beamsplitting-like approach to estimate the directions of arrival (DOA) of multiple radar targets present in the mainlobe of a rotating antenna. The proposed method is based on the maximum likelihood (ML) technique and it avoids the need for a difference channel by exploiting knowledge of the antenna main beam pattern. Two scenarios are considered: multiple targets with unknown deterministic complex amplitudes and multiple targets with Gaussian distributed random complex amplitudes. The performance of the proposed estimator is investigated through Monte Carlo simulation and it is compared with the Cramer-Rao lower bound (CRLB). [J613]

"Identification of ground targets from sequential high-range-resolution radar signatures"

An approach to identifying targets from sequential high-range-resolution (HRR) radar signatures is presented. In particular, a hidden Markov model (HMM) is employed to characterize the sequential information contained in multiaspect HRR target signatures. Features from each of the HRR waveforms are extracted via the RELAX algorithm. The statistical models used for the HMM states are formulated for application to RELAX features, and the expectation-maximization (EM) training algorithm is augmented appropriately. Example classification results are presented for the ten-target MSTAR data set. [J614]

"Nonstochastic adaptive decision fusion in distributed-detection systems"

Implementing the optimal Neyman-Pearson (NP) fusion rule in distributed detection systems requires the sensor error probabilities to be a priori known and constant during the system operation. Such a requirement is practically impossible to fulfil for every resolution cell in a multiflying target multisensor environment. The true performance of the fusion center is often worse than expected due to fluctuations of the observed environment and instabilities of sensor thresholds. This work considers a nonparametric data fusion situation in which the fusion center knows only the number of the sensors, but ignores their error probabilities and cannot control their thresholds. A data adaptive approach to the problem is adopted, and combining P reports from Q independent distributed sensors through a least squares (LS) formulation to make a global decision is investigated. Such a fusion scheme does not entail strict stationarity of the noise environment nor strict invariance of the sensor error probabilities as is required in the NP formulation. The LS fusion scheme is analyzed in detail to simplify its form and determine its asymptotic behavior. Conditions of performance improvement as P increases and of quickness of such improvement are found. These conditions are usually valid in netted radar surveillance systems. [J615]

"Vector subspace detection in compound-Gaussian clutter. Part I: survey and new results"

Deals with the problem of detecting subspace random signals against correlated non-Gaussian clutter exploiting different degrees of knowledge on target and clutter statistical characteristics. The clutter process is modeled by the compound-Gaussian distribution. In the first part of the paper, the optimum Neyman-Pearson (NP) detector, the generalized likelihood ratio test (GLRT), and a constant false-alarm rate (CFAR) detector are sequentially derived both for the Gaussian and the compound-Gaussian scenarios. Different interpretations of the various detectors are provided to highlight the relationships and the differences among them. In particular, we show how the GLRT detector may be recast into an estimator-correlator form and into another form, namely a generalized whitening-matched filter (GWMF), which is the GLRT detector against Gaussian disturbance, compared with a data-dependent threshold. In the second part of this paper, the proposed detectors are tested against both simulated data and measured high resolution sea clutter data to investigate the dependence of their performance on the various clutter and signal parameters. [J616]

"Application of the fractional Fourier transform to moving target detection in airborne SAR"

As a useful signal processing technique, the fractional Fourier transform (FrFT) is largely unknown to the radar signal processing community. In this correspondence, the FrFT is applied to airborne synthetic aperture radar (SAR) slow-moving target detection. For airborne SAR, the echo from a ground moving target can be regarded approximately as a chirp signal, and the FrFT is a way to concentrate the energy of a chirp signal. Therefore,

the FrFT presents a potentially effective technique for ground moving target detection in airborne SAR. Compared with the common Wigner-Ville distribution (WVD) algorithm, the FrFT is a linear operator, and will not be influenced by cross-terms even if multiple moving targets exist. Moreover, to solve the problem whereby weak targets are shadowed by the sidelobes of strong ones, a new implementation of the CLEAN technique is proposed based on filtering in the fractional Fourier domain. In this way strong moving targets and weak ones can be detected iteratively. This combined method is demonstrated by using raw clutter data combined with simulated moving targets. [J617]

"Adaptive resolution of mainlobe and sidelobe detections using model order determination"

This work presents the development and performance evaluation of a methodology for distinguishing between mainlobe and sidelobe detections that arise in adaptive radar systems operating in adverse environments. Various adaptive detection test statistics such as the adaptive matched filter (AMF), the generalized likelihood ratio test (GLRT), and adaptive coherence estimate (ACE), and combinations of these, have been previously analyzed with respect to their sidelobe rejection capabilities. In contrast to these methods which are based on detecting a single target with known direction and Doppler, the present method uses model order determination techniques applied to the AMF or GLRT data observed over the range of unknown angle and Doppler parameters. The determination of model order, i.e., the number of signals present in the data, is made by using least-squares model fit error residuals and applying the Akaike Information Criterion (AIC). Comprehensive computer simulation results are presented which demonstrate substantial improvement in sidelobe rejection performance and detections of multiple sources compared with previous methods. [J618]

"Layover solution in multibaseline SAR interferometry"

In this work, spectral estimation techniques are used to exploit baseline diversity of a multichannel interferometric synthetic aperture radar (SAR) system and overcome the layover problem. This problem arises when different height contributions collapse in the same range-azimuth resolution cell, due to the presence of strong terrain slopes or discontinuities in the sensed scene. We propose a multilook approach to counteract the presence of multiplicative noise, which is due to the extended nature of natural targets; to this purpose we extend the RELAX algorithm to the multilook data scenario (M-RELAX). A thorough performance analysis of nonparametric (beamforming and Capon) and parametric (root MUSIC and M-RELAX) techniques is carried out based on Monte Carlo simulations and Cramer-Rao lower bounds (CRLB) calculation. The results suggest the superiority of parametric methods over nonparametric ones. [J619]

"An ultrafast wide-band millimeter-wave (MMW) polarimetric radar for remote sensing applications"

With the advent of high-frequency radio frequency (RF) circuits and components technology, millimeter-wave (MMW) radars are being proposed for a large number of military and civilian applications. Accurate and high-resolution characterization of the polarimetric radar backscatter responses of both clutter and man-made targets at MMW frequencies is essential for the development of radar systems and optimal detection and tracking algorithms. Toward this end, a new design is developed for ultrafast, wide-band, polarimetric, instrumentation radars that operate at 35 and 95 GHz. With this new design, the complete scattering matrix of a target (magnitude and phase) can be measured over a bandwidth of 500 MHz in less than 2 μs. In this paper, the design concepts and procedures for the construction and calibration of these radars are described. In addition, the signal processing algorithm and data-acquisition procedure used with the new radars are presented. To demonstrate the accuracy and applicability of the new radars, backscatter measurements of certain points and distributed targets are compared with their analytical radar cross section (RCS) and previously measured σ° values, respectively, and good agreements are shown. These systems, which can be mounted on a precision gimbal assembly that facilitates their application as high-resolution imaging radar systems, are used to determine the MMW two-way propagation loss of a corn field for different plant moisture conditions. [J620]

"A group-theoretic analysis of symmetric target scattering with application to landmine detection"

Landmines are generally constructed such that they possess a high level of geometric symmetry and are then buried in a manner that preserves this symmetry. The scattered response of such a symmetric target will likewise exhibit the symmetry of the target, as well as the electromagnetic reciprocity exhibited by all scatterers. Group theory provides a mathematic tool for describing geometric symmetry, and it can likewise be used to describe the symmetries inherent in the bistatic scattering from mines. Specifically, group theory can be used to determine specific forms of the dyadic Green's function of symmetric scatterers, such that multiple scattering solutions can be determined from a knowledge of a single bistatic geometry. Likewise, group theory can be used both to determine and analyze degenerate cases, wherein specific bistatic responses can be identified as zero regardless of target size, shape, or material. These results suggest a method for classifying subsurface targets

as either symmetric or asymmetric. From the group-theoretic analysis, scattering features can be constructed that are indicative of target symmetry, but invariant with respect to other target parameters such as size, shape, or material. These features provide a physically based, target-independent value to aid in mine detection and/or clutter rejection. To test the efficacy of this idea, an extensive collection of bistatic ground-penetrating radar (GPR) measurements was taken for both a symmetric and an asymmetric target. The two targets were easily discernable using symmetry features only, a result that suggests symmetry features can be effective in identifying subsurface targets. [J621]

"Wavelet detection scheme for small targets in sea clutter"

A radar detection scheme based on wavelet determination of scatterer lifetime within the Doppler spectra of non-Gaussian sea clutter is reported. The method is shown to be complementary to simple intensity thresholding when applied to a low-observable time varying target [J622]

"Estimating the effective number of looks in interferometric SAR data"

The probability density function (pdf) of the multi-look interferometric phase between two complex synthetic aperture radar (SAR) images is parameterized by the number of looks and the complex correlation coefficient. In practice, adjacent pixels in a real SAR interferogram, are statistically dependent due to filtering, and hence, the number of looks is usually smaller than the number of samples averaged. It has been shown that compensation with an effective number of looks, rather than an intractable rederivation of the pdf, can account for the statistical dependence. This paper addresses the challenge of how to determine a suitable value for the effective number of looks. It is shown that an optimum value can be found via a maximum-likelihood estimator (MLE) based on the interferometric phase pdf. However, since such an MLE is computationally intensive and numerically unstable, an estimator based on the method of moments (MoM) possessing similar fidelity is proposed. MoM is fast and robust and can be used in operational applications, such as determining constant false alarm rate (CFAR) detection thresholds for moving-target detection in SAR along-track interferometry. [J623]

"Improving intrusion detection radar"

The first monostatic microwave intrusion detection sensor with range cutoff was introduced in 1984. This range cutoff circuit as used in the Model 375 and 385 has proven very effective in preventing nuisance alarms beyond a user-defined range. The Intrepid Digital Transceiver introduced in this paper builds upon this proven technology with the addition of a unique digital signal processing routine that measures range to the intruder. Intrepid Digital Transceiver alternately transmits pulses at two discrete frequencies within K-Band. When an intruder enters the detection zone, the Doppler response at each frequency is digitally recorded. The difference between the two frequencies is controlled so that the phase angle between the two Doppler responses can be used to determine the unambiguous range to the target. As a byproduct of the process targets approaching the transceiver can be distinguished from those moving away from the transceiver. Range information is used to enhance the signal processing. The amount of signal integration is increased with range in proportion to the width of the detection pattern so as to optimize the signal to noise ratio (SNR). [J624]

"Joint estimation of Doppler and time-difference-of-arrival exploiting cyclostationary property"

For the problem of estimating the time-difference-of-arrival (TDOA) of radio waves impinging on one or a pair of antennas for the purpose of actively or passively locating the source of a communications or telemetry signal in the presence of interfering signals and noise, W A. Gardner has developed some effective methods, such as CCCC and SPECCOA etc. However, it is shown that CCCC, SPECCOA and related methods do not apply to moving targets because the Doppler shift changes the cycle frequencies of the signal of interest. Two new methods based on the cyclic cross-ambiguity (CCA) function and the spectrally cyclic cross-ambiguity (SCCA) function are introduced in the paper for the joint TDOA and Doppler estimation, and their consistency in estimating the TDOA and Doppler is also discussed. Practical experiments, utilising FM radio signals emitting from a remote FM transmitter to detect the planes and estimate the values of TDOA and Doppler, have been carried out. Experimental results demonstrate the efficiency of the CCA and SCCA methods in the estimation of TDOA and Doppler [J625]

"Depth-based target segmentation for intelligent vehicles: fusion of radar and binocular stereo"

Dynamic environment interpretation is of special interest for intelligent vehicle systems. It is expected to provide lane information, target depth, and the image positions of targets within given depth ranges. Typical segmentation algorithms cannot solve the problems satisfactorily, especially under the high-speed requirements of a real-time environment. Furthermore, the variation of image positions and sizes of targets creates difficulties for tracking. In this paper, we propose a sensor-fusion method that can make use of coarse target depth

information to segment target locations in video images. Coarse depth ranges can be provided by radar systems or by a vision-based algorithm introduced in the paper. The new segmentation method offers more accuracy and robustness while decreasing the computational load. [J626]

"Full-polarization matched-illumination for target detection and identification"

This paper investigates the optimization of the full-polarization radar transmission waveform and the receiver response to maximize either target detection or identification performance. Application of such full-polarization matched-illumination techniques to simulated VHF-band frequency response data of mobile surface targets yields a significant performance improvement over that corresponding to chirped full-polarization transmission waveforms. [J627]

"Computer simulation of aerial target radar scattering, recognition, detection, and tracking [JBook Review]"

First Page of the Article [J628]

"Detection of oceanic electric fields based on the generalised likelihood ratio test (GLRT)"

Galvanic corrosion phenomena between the hull and the propeller of a ship induce static electric fields in sea water. These signatures can be observed on a vectorial electrical sensor and the authors investigate the design of a detection/localisation method based on the generalised maximum likelihood ratio test (GLRT). Incorporating a spatio-temporal analysis of the signals in the physical model, it is possible to partially estimate the trajectory of the target and to perform a detection decision. The resulting system consists in the calculation of the projection of the observation on a set of parameterised signatures and in selecting the projection that has the largest energy. An original method is proposed in order to determine the convenient partitioning of the set of projection bases. Due to the characteristics of the signals, classical results concerning performance analysis are not convenient and a specific framework is developed in order to analytically determine the behaviour of the system. A comparison with Monte Carlo simulations tends to prove the validity of the theory and the efficiency of the processing. [J629]

"Estimation of non-Rayleigh clutter and fluctuating-target models"

The detection performance prediction for radar and sonar systems requires statistical models of the matched filter output for the 'clutter-only' and 'target-plus-clutter' cases. Two practical techniques are presented for deriving these models from matched filter output data. The first technique is based upon a generalised Gram-Charlier series expansion, whose terms consist of the generalised gamma probability density function and its derivatives. The second technique is based on the Rayleigh mixture model and it is shown that the target-plus-clutter case can be expressed as a convolution of mixture parameters of the separate target-only and clutter-only cases. Numerical examples are presented. [J630]

"Determination of required SNR values [Jradar detection]"

The inverse signal-to-noise ratio (SNR) problem is defined as determining the average SNR X required to achieve a specified probability of detection Pd, given Pfathe false alarm probability, N the integration number, and K a target fluctuation parameter that encompasses the Swerling and Marcum models. Although exact expressions exist for the standard problem of determining Pd given X and the other parameters, these expressions cannot be inverted. We present here approximations for the required SNR over a wide range of parameter values. Over most of the specified parameter ranges, the magnitude of the error in these approximations is less than 1 dB, in fact mostly less than 0.5 dB. If the resulting accuracy is insufficient, then an iterative procedure is necessary and the approximate value Xap' can be used as a starting value. The Marcum case results apply directly to the radiometry inverse problem as well. [J631]

"Multipath and ground clutter analysis for a UWB noise radar"

An ultrawideband (UWB) random-noise radar operating in the 1-2 GHz frequency band has been developed and field-tested up to a 200 m range at the Environmental Remote Sensing Laboratory (ERSL) of the University of Nebraska. A unique heterodyne correlation technique based on a delayed transmitted waveform using a photonic delay line has been used to inject coherence within this system. The performance of this radar in the presence of ground reflections is investigated analytically and experimentally, and the mitigating effects of UWB waveform on multipath-induced interference are analyzed. In addition, the ground clutter statistics, in a look-down mode, are theoretically established and experimentally verified. The performance of this radar in detecting clutter embedded targets with small radar cross section (RCS) is also experimentally examined. [J632]

"Sidelobe blanking with integration and target fluctuation"

In radar systems, sidelobe blanking (SLB) is used to mitigate impulsive interference that enters the radar through sidelobes of the main antenna. SLB employs an auxiliary antenna channel with the output being compared with that of the main antenna channel and a decision is then made as to whether or not to blank the main channel output. SLB performance determination involves the evaluation of several probability functions. Based on the classical Maisel SLB architecture, this work extends previous performance results, in which detection was limited to the case of a single radar pulse with either Marcum or Swerling I target fluctuation. Probability expressions have been generalized to include both an arbitrary number of integrated pulses and target fluctuation models based on the gamma distribution. The Swerling fluctuation models are all special cases of the gamma distribution. Results are derived in terms of two generalized probability functions, one for detection and the other for blanking. With these generalized probability functions, the SLB design and performance results can be determined. Examples are presented and discussed. [J633]

"Range gate straddling loss and joint probability with partial correlation"

Straddling loss arises because a target is not always precisely centered in a gate. This loss cannot be estimated by simply averaging the signal voltage or power over target location. The probability of detection must be averaged. We show how to do this and present results for rectangular gates. We also present an equation for estimating joint probability of partially correlated events. [J634]

"Comparison of GLR and invariant detectors under structured clutter covariance"

This paper addresses a target detection problem in radar imaging for which the covariance matrix of unknown Gaussian clutter has block diagonal structure. This block diagonal structure is the consequence of a target lying along a boundary between two statistically independent clutter regions. Here, we design adaptive detection algorithms using both the generalized likelihood ratio (GLR) and the invariance principles. There has been considerable interest in applying invariant hypothesis testing as an alternative to the GLR test. This interest has been motivated by several attractive properties of invariant tests including: exact robustness to variation of nuisance parameters and possible finite-sample min-max optimality. However, in our deep-hide target detection problem, there are regimes for which neither the GLR nor the invariant tests uniformly outperforms the other. We discuss the relative advantages of GLR and invariance procedures in the context of this radar imaging and target detection application [J635]

"Theory of synthetic aperture radar imaging of a moving target"

Two novel image processing techniques have been developed to refocus a moving target image from its smeared response in the synthetic aperture radar (SAR) image which is focused on the stationary ground. Both approaches may be implemented with efficient fast Fourier transform (FFT) routines to process the Fourier spatial spectrum of the image data. The first approach utilizes a matched target filter that is derived from the signal history along the range-Doppler migration path mapped onto the SAR image from the moving target trajectory in real space. The coherent spatial filter is specified by the apparent target range in the image and the magnitude of the relative target-to-radar velocity. The second approach eliminates the range-dependence by reconstructing the moving target image from a spectral function that is obtained from the SAR image data spectrum via a spatial frequency coordinate transformation [J636]

"Regularized estimation of mixed spectra using a circular Gibbs-Markov model"

Formulated as a linear inverse problem, spectral estimation is particularly underdetermined when only short data sets are available. Regularization by penalization is an appealing nonparametric approach to solve such ill-posed problems. Following Sacchi et al. (see ibid., vol.46, no.1, p.32-38, 1998), we first address line spectra recovering in this framework. Then, we extend the methodology to situations of increasing difficulty: the case of smooth spectra and the case of mixed spectra, i.e., peaks embedded in smooth spectral contributions. The practical stake of the latter case is very high since it encompasses many problems of target detection and localization from remote sensing. The stress is put on adequate choices of penalty functions: following Sacchi et al., separable functions are retained to retrieve peaks, whereas Gibbs-Markov potential functions are introduced to encode spectral smoothness. Finally, mixed spectra are obtained from the conjunction of contributions, each one bringing its own penalty function. Spectral estimates are defined as minimizers of strictly convex criteria. In the cases of smooth and mixed spectra, we obtain nondifferentable criteria. We adopt a graduated nondifferentiability approach to compute an estimate. The performance of the proposed techniques is tested on the well-known Kay and Marple (1982) example [J637]

"Bearings-only tracking of maneuvering targets using a batch-recursive estimator"

We present a new batch-recursive estimator for tracking maneuvering targets from bearings-only measurements in clutter (i.e., for low signal-to-noise ratio (SNR) targets), Standard recursive estimators like the extended Kalman Iter (EKF) suffer from poor convergence and erratic behavior due to the lack of initial target range information, On the other hand, batch estimators cannot handle target maneuvers. In order to rectify these shortcomings, we combine the batch maximum likelihood-probabilistic data association (ML-PDA) estimator with the recursive interacting multiple model (IMM) estimator with probabilistic data association (PDA) to result in better track initialization as well as track maintenance results in the presence of clutter. It is also demonstrated how the batch-recursive estimator can be used for adaptive decisions for ownship maneuvers based on the target state estimation to enhance the target observability. The tracking algorithm is shown to be effective for targets with 8 dB SNR [J638]

"Nonparametric methods for clutter removal"

Methods of clutter rejection are discussed which furnish an inherent counterpart of target tracking and detection algorithms. We describe how nonparametric curve estimation methods reduce the original sensor data to a “signal-plus-noise” model which is well suited for various hypotheses testing and dynamical filtering algorithms. We also verify a “white noise” assumption for the model of residuals [J639]

"Detecting moving targets in SAR imagery by focusing"

A new method for detecting moving targets in a synthetic aperture radar (SAR) image is presented. It involves segmenting a complex-valued SAR image into patches, focusing each patch separately, and measuring the sharpness increase in the focused patch. The algorithm is sensitive to azimuth velocities and is exquisitely sensitive to radial accelerations of the target, allowing it to detect motion in any direction. It is complementary to conventional Doppler-sensing moving target indicators, which can sense only the radial velocity of rapidly moving targets. [J640]

"Super resolution feature extraction of moving targets"

High range resolution (HRR) moving target indicator (MTI) is becoming increasingly important for many military and civilian applications such as the detection and classification of moving targets in strong clutter background. We consider the problem of extracting the HRR features of moving targets with very closely spaced scatterers in the presence of strong stationary clutter, where the range migration and Doppler frequency are taken into account. A relaxation-based algorithm, which is robust and computationally simple, is proposed to deal with the above problem. Numerical results have shown that the proposed algorithm exhibits super resolution and excellent estimation performance [J641]

"Airborne GMTI radar position bias estimation using static-rotator targets of opportunity"

In target tracking systems: using GMTI (ground moving target indicator) radars on airborne platforms, the locations of these platforms are available from GPS-based estimates. However, these estimated locations are subject to errors that are, typically, stationary autocorrelated random processes, i.e., slowly varying biases. In situations where there are no known-location targets to estimate these biases, the next best recourse is to use targets of opportunity at fixed but unknown locations. Such targets can be, e.g., static rotators (ground-based radars with rotating antenna), which yield detections in moving target indicator (MTI) radars. It is shown that these biases can be estimated in such a scenario, i.e., they meet the complete observability condition. Following this, the achievable accuracy for a generic scenario is evaluated. It is shown that accurate georegistration can be obtained even with a small number of measurements [J642]

"Receiver operating characteristics for the coherent UWB random noise radar"

An ultrawideband (UWB) random-noise radar operating in the 1-2 GHz frequency band has been developed and held-tested at a 200 m range at the University of Nebraska. A unique heterodyne correlation technique based on a delayed transmitted waveform using a photonic delay line has been used to inject coherence within this system. The performance of this radar, assuming a point target, has been investigated from a statistical point of view by developing the theoretical basis for the system's receiver operating characteristics (ROC). Explicit analytical expressions for the joint probability density function (pdf) of the in-phase (I) and quadrature (Q) components of the receiver output have been derived under the assumption that the input signals are partially correlated Gaussian processes. The pdf and the complementary cumulative distribution function (cdf) for the envelope of the receiver output are also derived. These expressions are used to relate the probability of detection (Pd) to the probability of false alarm (Pf) for different numbers of integrated samples, and the results

are analyzed [J643]

"Surface movement radar data processing methods for airport surveillance"

An airport surveillance function operating on surface movement radar (SMR) images is proposed and evaluated. The main contributions presented are the statistical error models of the target centroid and attributes extracted from radar images, developed and applied to the design of its main data processing blocks. Besides a multihypothesis image-to-tracks assignment method, a tracking filter using the extracted orientation and a classification scheme based on target attributes is detailed. The error models confidence and processing methods performance are demonstrated through simulation in representative scenarios [J644]

"Time-domain sensing of targets buried under a Gaussian, exponential, or fractal rough interface"

The authors numerically examine subsurface sensing via an ultrawideband ground penetrating radar (GPR) system. The target is assumed to reside under a randomly rough air-ground interface and is illuminated by a pulsed plane wave. The underlying wave physics is addressed through application of the multiresolution time-domain (MRTD) algorithm. The scattered time-domain fields are parametrized as a random process and an optimal detection scheme is formulated, accounting for the clutter and target signature statistics. Detector performance is evaluated via receiver operating characteristics (ROCs) for variable sensor parameters (polarization and incident angle) and for several rough-surface statistical models [J645]

"Sea-clutter modeling using a radial-basis-function neural network"

Recently, neural networks have been proposed for radar clutter modeling because of the inherent nonlinearity of clutter signals. This paper performs an analysis of the practicality of using a radial basis function (RBF) neural network to model sea clutter and to detect small target embedded in sea clutter. An experiment using an instrumental quality radar was carried out on the eastcoast of Canada to create a rich sea clutter and small surface target database. This database contains both staring and scanning data under various environmental conditions. Using data-sets with different characteristics, we investigate the effects of quantization error, measurement noise, generalization of the neural net over ranges and sampling rate on the RBF clutter model. Despite these physical limitations, the RBF model was shown to approach an optimal predictive performance. The RBF predictor was also applied to detect various small targets in this database based on the constant false alarm rate (CFAR) principle. This RBF-CFAR detector was demonstrated to be able to detect small floating targets even in rough sea conditions [J646]

"Enhanced detection of a target in a sea clutter environment using a stepped, ultra-wideband signal and E-pulse cancellation"

A new ultra-wideband technique to detect a sea-skimming missile in a sea-surface clutter background is presented. This technique, based on the E-pulse concept, is shown to be effective in maximizing the target to clutter ratio. Results using both measured and theoretical data from simulated sea surfaces demonstrate the usefulness of this method [J647]

"Robust CFAR detection of random signals in compound-Gaussian clutter plus thermal noise"

An algorithm for detecting a random target signal against a mixture of correlated compound-Gaussian clutter and white Gaussian thermal noise is proposed. The new detection strategy is obtained by extending the generalised matched subspace detector previously derived by Gini and Farina (1999) for only compound-Gaussian clutter. Two different versions of the detection strategy are proposed and compared: the first relies on the estimation of the radar clutter texture component; the second trades-off performance with computational complexity by using the texture mean value in place of its estimate. The texture estimator mean square error is derived in closed form and analysed. Additionally, the robustness of the detector false alarm rate to changes of clutter parameters and the detection performance are numerically investigated by Monte Carlo simulation [J648]

"Moving target detection via airborne HRR phased array radar"

We study moving target detection in the presence of temporally and spatially correlated ground clutter for airborne high range resolution (HRR) phased array radar. We divide the HRR range profiles into large range segments to avoid the range migration problems that occur in the HRR radar data. Since each range segment contains a sequence of HRR range bins, no information is lost due to the division and hence no loss of resolution occurs. We show how to use a vector autoregressive (VAR) filtering technique to suppress the ground clutter. Then a moving target detector based on a generalized likelihood ratio test (GLRT) detection strategy is derived. The detection threshold is determined according to the desired false alarm rate, which is made possible

via an asymptotic statistical analysis. After the target Doppler frequency and spatial signature vectors are estimated from the VAR-filtered data as if a target were present, a simple detection variable is computed and compared with the detection threshold to render a decision on the presence of a target. Numerical results are provided to demonstrate the performance of the proposed moving target detection algorithm [J649]

"Adaptive polarimetric target detection with coherent radar. I. Detection against Gaussian background"

The derivation of a completely adaptive polarimetric coherent scheme to detect a radar target against a Gaussian background is presented. A previously proposed Generalized Likelihood Ratio Test (GLRT) polarimetric detector is extended to the case of a general number of channels; this exploits the polarimetric characteristics of the received radar echoes to improve the detection performance. Together with the fully adaptive scheme, a model-based detector is derived that has a lower estimation loss. A complete theoretical expression is derived for the detection performance of both proposed polarimetric detectors. They are shown to have Constant False Alarm Rate (CFAR) when operating against Gaussian clutter, but to be sensitive to deviations from the Gaussian statistic. The application to recorded radar data demonstrates the performance improvement achievable in practice [J650]

"Senrad: an advanced wideband air-surveillance radar"

The generic characteristics and performance of an experimental long-range air-surveillance radar, known at the Naval Research Laboratory as Senrad, is described. Its distinguishing feature is that it can operate with simultaneous transmissions over a very wide bandwidth-from 850 to 1400 MHz. The technology and type of experimental radar equipment employed are discussed and examples are given of its performance capabilities obtained by means of very wideband operation. The unusually wide bandwidth of this radar allows 1) improved detection and tracking performance because of the absence of the nulls that are common in the antenna elevation radiation-pattern of a single-frequency radar; 2) moving target indication (MTI) without loss of targets due to blind speeds and without the need for multiple PRFs (pulse repetition frequencies); 3) accurate height finding with a fan-beam radar by taking advantage of the multipath time difference as a function of target height; 4) a form of limited target recognition based on high range-resolution; and 5) a reduction of the effectiveness of electronic countermeasures that can seriously degrade more narrowband radars [J651]

"Detection of buried targets using a new enhanced very early time electromagnetic (VETEM) prototype system"

In this paper, numerical simulations of a new enhanced very early time electromagnetic (VETEM) prototype system are presented, where a horizontal transmitting loop and two horizontal receiving loops are used to detect buried targets, in which three loops share the same axis and the transmitter is located at the center of receivers. In the new VETEM system, the difference of signals from two receivers is taken to eliminate strong direct-signals from the transmitter and background clutter and furthermore to obtain a better SNR for buried targets. Because strong coupling exists between the transmitter and receivers, accurate analysis of the three-loop antenna system is required, for which a loop-tree basis function method has been utilized to overcome the low-frequency breakdown problem. In the analysis of scattering problem from buried targets, a conjugate gradient (CG) method with fast Fourier transform (FFT) is applied to solve the electric field integral equation. However, the convergence of such CG-FFT algorithm is extremely slow at very low frequencies. In order to increase the convergence rate, a frequency-hopping approach has been used. Finally, the primary, coupling, reflected, and scattered magnetic fields are evaluated at receiving loops to calculate the output electric current. Numerous simulation results are given to interpret the new VETEM system. Comparing with other single-transmitter-receiver systems, the new VETEM has better SNR and ability to reduce the clutter [J652]

"Adaptive polarimetric target detection with coherent radar. II. Detection against non-Gaussian background"

For pt. I see ibid., vol. 37, no. 4, pp. 1194-1206 (2001).This paper presents the derivation of a polarimetric coherent adaptive scheme to detect a radar target against a non-Gaussian background. This completes the results presented in Part I for the Gaussian background. A Texture Free-Generalized Likelihood Ratio Test (TF-GLRT) detector is derived that exploits the polarimetric characteristics of the received radar echoes to improve the detection performance. The proposed polarimetric detector is shown to have Constant False Alarm Rate (CFAR) when operating against compound-Gaussian clutter with unknown parameters. Its performance is fully characterized by both theoretical analysis and simulation. Moreover, the application to recorded radar data demonstrates the performance improvement achievable in practice [J653]

"Probabilistic modelling of bistatic Doppler shift"

The bistatic Doppler shift depends irreducibly on target position and velocity. This fact renders intractable an analytical assessment of the radar's global ability to counter stationary clutter. To avoid lengthy simulations, an easily applicable numerical solution for the cumulative distribution function of the Doppler shift is provided corresponding to plausible assumptions concerning the underlying probability distribution of the target position and velocity [J654]

"An integrated maritime surveillance system based on high-frequency surface-wave radars. 2. Operational status and system performance"

For pt.1 see ibid., vol.43, no.4, p.28-43 (2001). An integrated maritime surveillance (IMS) system, based on high-frequency surface wave radars (HFSWR), for monitoring surface and low-level air activity within the 200 nautical mile (nm) Exclusive Economic Zone (EEZ) is described in this two-part paper. The science behind the long-range performance of HFSWR was presented in Part 1(Sevgi et al. 2001). The system described was installed on Canada's east coast, where it is being used to demonstrate continuous, all-weather surveillance of the EEZ to beyond 200 nm. The system consists of two land-based HFSWRs and an operations control center (OCC). The two unmanned radars provide coverage of the Grand Banks region of Newfoundland, renowned for its offshore resources, particularly fish and oil. The system has been designed to assist authorities to more efficiently monitor such illegal activities as drug trafficking, smuggling, piracy, illicit fishing and illegal immigration. In addition, the system may be used for tracking icebergs, environmental protection, search and rescue, resource protection, sovereignty monitoring, and remote sensing of ocean surface currents and winds. Extensive performance testing of the system has been conducted using the two fully functional radars. It is shown that the HFSWR system complements existing surveillance assets to dramatically increase the effectiveness of air and surface reconnaissance missions by vectoring them directly to targets of interest [J655]

"FOPEN SAR imaging using UWB step-frequency and random noise waveforms"

The detection and identification of targets obscured by foliage have been topics of great interest. Several synthetic aperture radar (SAR) experiments have demonstrated promising images of terrain and man-made objects obscured by dense foliage, by using either linear frequency modulation (LFM) or step-frequency waveforms. We present here the methodology and results of a comparative study on foliage penetration (FOPEN) SAR imaging using ultrawideband (UWB) step-frequency and random noise waveforms. A statistical-physical foliage transmission model is developed for simulation applications. The foliage obscuring pattern is analyzed by means of the technique of paired echoes. The results of the comparative study demonstrates the ability of a UHF band UWB random noise radar to be used as a FOPEN SAR. Advantages of the random noise radar system include covert detection and immunity to radio frequency interference (RFI) [J656]

"Target perceivability and its applications"

A concept of target perceivability is introduced, which is related to such concepts as target existence and target observability. Its probability provides a basis for an integrated approach to track initiation, confirmation, termination, and refinement of track maintenance algorithms. This paper proposes the concepts of target perceivability and presents a recursion of its probability based on hidden Markov models (HMMs) and their applications to tracker analysis, development, and design, in particular, in the context of the probabilistic data association (PDA) method. Specifically, several important quantities and track life are analyzed; a perceivability-based probabilistic approach to track confirmation and termination is proposed; two versions of perceivability-based PDA trackers are presented. Simulation results are provided to demonstrate their performance [J657]

"Early studies on target models in China"

The introduction of the concept of radar target modeling to Chinese engineers in the early 1960s is described. Their reactions to Swerling's models are discussed [J658]

"Multiframe detector/tracker: optimal performance"

We develop the optimal Bayes multiframe detector/tracker for rigid extended targets that move randomly in clutter. The performance of this optimal algorithm provides a bound on the performance of any other suboptimal detector/tracker. We determine by Monte Carlo simulations the optimal performance under a variety of scenarios including spatially correlated Gaussian clutter and non-Gaussian (K and Weibull) clutter. We show that, for similar tracking performance, the optimal Bayes tracker can achieve peak signal-to-noise ratio gains possibly larger than 10 dB over the commonly used combination of a spatial matched filter (spatial correlator) and a linearized Kalman-Bucy tracker. Simulations using real clutter data with a simulated target suggest similar

performance gains when the clutter model parameters are unknown and estimated from the measurements [J659]

"Air and spaceborne radar systems an introduction [JBook Review]"

First Page of the Article [J660]

"Scattering from lossy dielectric objects buried beneath randomly rough ground: validating the semi-analytic mode matching algorithm with 2-D FDFD"

A new semi-analytic mode matching (SAMM) algorithm is verified by two-dimensional (2-D) finite difference frequency domain (FDFD) simulations of scattering resulting from uniform plane waves incident on randomly rough dielectric half-spaces containing buried dielectric targets. The SAMM algorithm uses moderately low-order modal superpositions of cylindrical waves, each of which satisfies the 2-D-Helmholtz equation in its appropriate region (air, ground, or mine) and then matches all nonzero electric and magnetic field components at each interface by inverting a highly overconstrained dense linear matrix equation by singular value decomposition. That is, the set of cylindrical mode coefficients is found which best fits the boundary conditions in a least squares sense. For smooth ground, coordinate scattering centers (CSCs) are chosen at the mine center and at its image above the plane to model scattering. For randomly rough ground, additional CSCs are located within the rough boundary layer. Excellent agreement between 2-D-FDFD and the 2-D version of SAMM is observed, with 2-D-SAMM being at least an order of magnitude faster. 3-D-SAMM is estimated to be four orders of magnitude faster than 3-D-FDFD, with drastically reduced memory requirements [J661]

"Multiresolution time-domain analysis of plane-wave scattering from general three-dimensional surface and subsurface dielectric targets"

The multiresolution time domain (MRTD) is used to analyze wide-band plane-wave scattering from general dielectric targets embedded in a lossy half-space, with free-space scattering as a special case. A Haar wavelet expansion is used for simplicity, this constituting a generalization of the widely used finite-difference time-domain (FDTD) method. In addition to developing the mathematical formulation, example results are presented for several targets, with the MRTD results validated through comparison with an independent frequency-domain method-of-moments solution and an FDTD model [J662]

"Modeling of ground-penetrating-radar antennas with shields and simulated absorbers"

A three-dimensional (3-D) finite-difference time-domain (FDTD) scheme is employed to simulate ground-penetrating radars. Conducting shield walls and absorbers are used to reduce the direct coupling to the receiver. Perfectly matched layer (PML) absorbing boundary conditions are used for matching the multilayered media and simulating physical absorbers inside the FDTD computational domain. Targets are modeled by rectangular prisms of arbitrary permittivity and conductivity. The ground is modeled by homogeneous and lossless dielectric media [J663]

"Iterative soft decoded partial response channels for hybrid magneto-optical recording"

In this paper, a physical model of readback signals from a hybrid magneto-optical (MO) recording using magnetic flux detection is presented. The minimum mean-square error (MMSE) technique has been used to design generalized partial response (GPR) targets in order to facilitate the application of the trellis based channel detector. A PR target with integer coefficients is proposed as a good approximation to the GPR target. We also address the application of turbo codes and LDPC codes with iterative soft decoding structure to the hybrid magneto-optical (MO) recording channel. The effects of bloom, transition noise and giant magneto-resistive (GMR) sensor nonlinearity on the bit error rate (BER) performance are investigated both for uncoded partial response maximum likelihood (PRML) and iterative soft decoded recording channels. Our results for the hybrid recording channels indicate that turbo/LDPC codes of rate 16/17 can achieve coding gains of about 5 dB over PRML methods for a 10-5target BER at the normalized density S=1.5. Turbo codes with iterative soft decoding are seen to be robust to transition noise [J664]

"Target reflectivity and RCS interactions in integrated maritime surveillance systems based on surface-wave high-frequency radars"

Abnormal fluctuations have been observed in detected power levels of some of the targets during trials of the integrated maritime surveillance system (IMS) based on the Canadian east coast surface-wave high-frequency radar (HFSWR). The power level of most of the surface and air targets fluctuated within measurement-error limits (a few dB) during consecutive detections. These fluctuations have been observed to be more than 15 dB

for a huge oil platform and nearby large tankers. These fluctuations are quite different than those observed in microwave radars, such as pulse-to-pulse or scan-to-scan fluctuations (which are modeled as different Swerling-type targets), and as are mentioned in most of the classical radar handbooks. In order to understand the reason behind these fluctuations, the behavior of the target reflectivity and radar cross section (RCS) of surface and air targets and their mutual RCS interaction were investigated. Powerful numerical techniques were used to model and understand the target reflectivity and RCS interactions, mostly in the resonance regime. Different scenarios were created, and the mutual RCS behavior of nearby large targets (such as oil tankers and/or fixed offshore oil platforms) as they were maneuvering were modeled. It was shown that 10 dB to 20 dB RCS fluctuations should be expected when targets interact, especially in the resonance regime. [J665]

"A new approach to target recognition for LADAR data"

We discuss target detection in LADAR intensity images. Thirteen features, eleven of which come from an asymmetric co-occurrence matrix, are extracted from region-of-interest windows in each image. Two methods of feature selection are applied to the extracted vectors. Random selection leads to a pair of selected features for a nearest-neighbor rule (1-nn) detector. Extended backpropagation leads to six selected features using a modified multilayered perceptron (MLP) network. The 1-nn detector achieves a test-error rate of about 16% at a false-alarm rate of 8%. The MLP has a test-error rate of about 12% with a false-alarm rate of 6% [J666]

"Spaceborne along-track SAR interferometry: performance analysis and mission scenarios"

A system study of a spaceborne along-track synthetic aperture radar (SAR) interferometer is presented. This sensor has been successfully experienced for detecting moving targets by using only airborne installations. Several key issues must be addressed when spaceborne configurations are envisaged. To this end, a quantitative evaluation of system performance and measurement accuracy has been conducted. First, the identification of possible space configurations has been accomplished. In particular, the two antennas can operate on a single satellite or they can be carried along appropriate trajectories by two spacecrafts. Then, an error budget of radial velocity measurement accuracy has been performed. Finally, two possible mission scenarios are dealt in details, and numerical results are reported [J667]

"Selected list of references on radar signal processing"

In recent years an abundance of technical papers and books have been written on several topics of radar signal processing. The detection of radar targets against ground and sea clutter is a problem of great interest in the radar community. The fusion of signals from different radar to improve detection performance is another relevant topic of research and application. These are two of several topics that have been extensively described in the technical literature. Needless to say that the consultation of technical references plays a key role in the daily work of researchers and engineers involved in the radar field. We collected almost 700 references in a single document to facilitate our work and the work of other colleagues of the radar community. The collection of references is by no means exhaustive; the period of screening mainly covers the last two decades [J668]

"Three-dimensional subsurface analysis of electromagnetic scattering from penetrable/PEC objects buried under rough surfaces: use of the steepest descent fast multipole method"

The electromagnetic scattering from a three-dimensional (3D) shallow object buried under a two-dimensional (2D) random rough dielectric surface is analyzed. The buried object can be a perfect electric conductor (PEC) or can be a penetrable dielectric with size and burial depth comparable to the free-space wavelength. The random rough ground surface is characterized with Gaussian statistics for surface height and for surface autocorrelation function. The Poggio, Miller, Chang, Harrington, and Wu (PMCHW) integral equations are implemented and extended. The integral equation-based steepest descent fast multipole method (SDFMM), that was originally developed at UIUC, has been used and the computer code based on this algorithm has been successfully modified to handle the current application. The significant potential of the SDFMM code is that it calculates the unknown moment method surface electric and magnetic currents on the scatterer in a dramatically fast, efficient, and accurate manner. Interactions between the rough surface interface and the buried object are fully taken into account with this new formulation. Ten incident Gaussian beams with the same elevation angle and different azimuth angles are generated for excitation as one possible way of having multiple views of a given target. The scattered electric fields due to these ten incident beams are calculated in the near zone and their complex vector average over the multiple views is computed. The target signature is obtained by subtracting the electric fields scattered from the rough ground only from those scattered from the ground with the hurled anti-personnel mine [J669]

"Complex natural resonances of conducting planar objects buried in a dielectric half-space"

A scheme is presented to incorporate a mixed potential integral equation (MPIE) using Michalski's “formulation C” with the method of moments (MoM) for analyzing the scattering of a plane wave from conducting planar objects buried in a dielectric half-space. The robust complex image method with a two-level approximation is used for the calculation of the Green's functions for the half-space. To further speed up the computation, an interpolation technique for filling the matrix is employed. While the induced current distributions on the object's surface are obtained in the frequency domain, the corresponding time domain responses are calculated via the inverse fast Fourier transform (FFT). The complex natural resonances of targets are then extracted from the late time response using the generalized pencil-of-function (GPOF) method. The authors investigate the pole trajectories as they vary the distance between strips and the depth and orientation of single, buried strips. The variation from the pole position of a single strip in a homogeneous dielectric medium was only a few percent for most of these parameter variations [J670]

"A Monte Carlo study of the rough-sea-surface influence on the radar scattering from two-dimensional ships"

The generalized forward-backward (GFB) method was introduced in Pino et al. (1999) for computing the electromagnetic scattering from two-dimensional targets on a rough surface. The GFB method is used in this article to generate numerical data for a Monte Carlo simulation of the horizontally polarized radar cross section (RCS) of two-dimensional ship-like targets on random rough sea surfaces. The RCS is computed as a function of the incidence angle and wind speed for a large number of surface realizations. It is found that the mean RCS of a given target on a rough surface is generally lower than or equal to the RCS of the same target on a flat surface, while the maximum RCS is usually greater than or equal to the flat-surface case. It is also observed that the variations in the RCS introduced by the rough surface become less significant as the elevation angle approaches grazing [J671]

"Rate 8/9 sliding block distance-enhancing code with stationary detector"

A new distance-enhancing code for partial-response magnetic recording channels eliminates most frequent errors, while keeping the two-step code trellis time invariant. Recently, published trellis codes either have lower code rates or result in time-varying trellises with a period of nine, thus requiring a higher complexity of detectors and code synchronization. The new code introduces dependency between code words in order to achieve the same coding constraints as the 8/9 time-varying maximum transition runlength (TMTR) code, with the same code rate, but resulting in a trellis that has a period of 2. This code has been applied to the E2PR4 and a 32-state generalized partial response (GPR) ISI target. The resulting two-step trellises have 14 and 28 states, respectively. Coding gain is demonstrated for both targets in additive white Gaussian noise [J672]

"Experimental analysis of sea clutter in shipborne HFSWR"

The spreading of the dominant first order Bragg lines in shipborne HFSWR (high-frequency surface wave radar) severely obscures targets with Doppler frequencies within the spreading domain. STAP (space-time adaptive processing) is one of the effective methods for solving the problem. The experimental one-dimensional spreading spectrum and two dimensional space-time spectrum of sea clutter in shipborne HFSWR are given. The eigenvalue distribution of the space-time covariance matrix is also obtained. All experimental results show good agreement with the spreading model of sea clutter and theoretical analysis of the eigenspectrum for a random process, which is of advantage for sea clutter suppression and target detection in shipborne HFSWR with STAP [J673]

"SAR ATR performance using a conditionally Gaussian model"

A family of conditionally Gaussian signal models for synthetic aperture radar (SAR) imagery is presented, extending a related class of models developed for high resolution radar range profiles. This signal model is robust with respect to the variations of the complex-valued radar signals due to the coherent combination of returns from scatterers as those scatterers move through relative distances on the order of a wavelength of the transmitted signal (target speckle). The target type and the relative orientations of the sensor, target, and ground plane parameterize the conditionally Gaussian model. Based upon this model, algorithms to jointly estimate both the target type and pose are developed. Performance results for both target pose estimation and target recognition are presented for publicly released data from the MSTAR program [J674]

"Moving target feature extraction for airborne high-range resolution phased-array radar"

We study the feature extraction of moving targets in the presence of temporally and spatially correlated ground clutter for airborne high-range resolution (HRR) phased-array radar. To avoid the range migration problems that

occur in HRR radar data, we first divide the HRR range profiles into low-range resolution (LRR) segments. Since each LRR segment contains a sequence of HRR range bins, no information is lost due to the division, and hence, no loss of resolution occurs. We show how to use a vector auto-regressive (VAR) filtering technique to suppress the ground clutter, Then, a parameter estimation algorithm is proposed for target feature extraction. From the VAR-filtered data, the target Doppler frequency and the spatial signature vectors are first estimated by using a maximum likelihood (ML) method. The target phase history and direction-of-arrival (DOA) (or the array steering vector for an unknown array manifold) are then estimated from the spatial signature vectors by minimizing a weighted least squares (WLS) cost function. The target radar cross section (RCS)-related complex amplitude and range-related frequency of each target scatterer are then extracted from the estimated target phase history by using RELAX, which is a relaxation-based high-resolution feature extraction algorithm. Numerical results are provided to demonstrate the performance of the proposed algorithm [J675]

"A sub-millimeter accurate microwave multilevel gauging system for liquids in tanks"

A microwave multilevel gauging system employing a frequency-stepped continuous-wave radar measurement technique is described in this paper. A conventional frequency-modulated continuous-wave radar technique is normally employed only to find the level of the liquid surface in storage tanks. The system described here also detects a second level, e.g., the tank floor or an impurity level. If this second reflection dominates, distance measurement with the inverse Fourier transform (IFT) results in poor resolution and shows a very high range error for small gaps between these two scatterers. For estimating the exact time delay and amplitude of the reflection from each scatterer, an optimal signal-processing algorithm is derived, based on a reference model. Performance of the multiple target-detection reference model is illustrated using measured data obtained with an HP-8510 network analyzer. It is demonstrated that the reference model offers a significant enhancement of resolution over the standard processing IFT algorithm and is insensitive to noise and clutter signals. The described system achieves a time-delay accuracy with a bandwidth of Δf=1 GHz, which corresponds to a range error of ±0.2 mm [J676]

"The ratio of the arithmetic to the geometric mean: a cross-entropy interpretation"

The ratio of the arithmetic mean to the geometric mean is often applied to synthetic aperture radar (SAR) imagery as a heuristic index of target homogeneity. It is shown that this ratio is equivalent to a cross entropy expression, and can therefore be interpreted as a measure of the information contained within the image [J677]

"Multi-aspect target detection for SAR imagery using hidden Markov models"

Radar scattering from an illuminated object is often highly dependent on the target-sensor orientation. In typical synthetic aperture radar (SAR) imagery, the information in the multi-aspect target signatures is diffused in the image-formation process. In an effort to exploit the aspect dependence of the target signature, the authors employ a sequence of directional filters to the SAR imagery, thereby generating a sequence of subaperture images that recover the directional dependence of the target scattering. The scattering statistics are then used to design a hidden Markov model (HMM), wherein the orientation-dependent scattering statistics are exploited explicitly. This approach fuses information embodied in the orientation-dependent target signature under the assumption that. Both the target identity and orientation are unknown. Performance is assessed by considering the detection of tactical targets concealed in foliage, using measured foliage-penetrating (FOPEN) SAR data [J678]

"Object detection using high resolution near-field array processing"

The authors present an algorithm for the detection and localization of an unknown number of objects buried in a halfspace and present in the near field of a linear receiver array. To overcome the nonplanar nature of the wavefield over the array, the full array is divided into a collection of subarrays such that the scattered fields from objects are locally planar at each subarray. Using the multiple signal classification (MUSIC) algorithm, directions of arrival (DOA) of locally planar waves at each subarray are found. By triangulating these DOAs, a set of crossings, condensed around expected object locations, are obtained. To process this spatial crossing pattern, the authors develop a statistical model for the distribution of these crossings and employ hypotheses testing techniques to identify a collection of small windows likely to contain targets. Finally, the results of the hypothesis tests are used to estimate the number and locations of the targets. Using simulated data, they demonstrate the usefulness and performance of this approach for typical background electrical properties and signal to noise ratios [J679]

"Polarimetric processing of coherent random noise radar data for buried object detection"

Random noise polarimetry is a new radar technique for high-resolution probing of subsurface objects and

interfaces. The University of Nebraska has developed a polarimetric random noise radar system based on the heterodyne correlation technique. Simulation studies and performance tests on the system confirm its ability to respond to phase differences in the received signals. In addition to polarimetric processing capability and the simplified system design, random noise radar also possesses other desirable features, such as immunity from radio frequency interference. The paper discusses the theoretical foundations of random noise polarimetry, and presents examples out of the entire data set collected that demonstrate the usefulness of the image processing and Stokes matrix presentation to enhance target detection using the coherent random noise radar [J680]

"Contextual information in SAR target detection"

Established target detection schemes make a statistical decision as to whether the value of a test pixel is more likely to have arisen due to the presence of a target or of clutter. Subject to prior probabilities for the occurrence of targets or clutter. However, such schemes do not take into account the contextual information which is available. For example, it will be known that military vehicles may be more likely to be located in fields close to hedges and woodland edges to provide cover and will often travel in groups. It is demonstrated how such contextual information may be incorporated into a SAR target detection scheme, while maintaining the statistical rigour of established techniques. A theoretical framework is developed in which the prior probability for the presence of a target is modified by the contextual influences via conditional dependencies. The resulting detection scheme is applied to simulated SAR images to obtain target detection rates for various combinations of contextual information. An improvement in performance of about 13% is observed when the context is fully exploited [J681]

"Radar images of penetrable targets generated from ramp profile functions"

Images can be generated for penetrable targets from their scattered fields when the time dependence of the incident electromagnetic (EM) wave takes the form of a ramp function. Previous researchers have developed these concepts for conducting targets. This paper focuses attention on penetrable targets. Ramp response signatures of the targets for cases where the dielectric constant of the target is greater than and also less than that of the ambient medium are included. The latter case can be applied as a signature of antipersonnel mines. The results contained herein are based on: (1) scattering measurements in The Ohio State University ElectroScience Laboratory compact range; (2) scattering computation using an eigenfunction solution and a method of moments solution; and (3) a very limited set of measurements generated from a buried land mine using the ElectroScience Laboratory ground penetrating radar. The targets presented in this paper include metallic and dielectric spheres and actual land mines [J682]

"Discrimination of UXO in soil using broadband polarimetric GPR backscatter"

Polarimetric analysis of ground penetrating radar (GPR) backscatter offers a new means of discriminating subsurface metallic target shapes from one another. Such discrimination is urgently needed to distinguish buried unexploded ordnance (UXO) from other subsurface objects. To illuminate the underlying phenomenology of scattering from objects enveloped in soil, three-dimensional (3D) simulations are performed over a broad frequency band, characteristic of new low frequency GPRs. For moist soil, this means that the subsurface wavelength may range from a fraction of the target size to an order of magnitude larger With a transmitting antenna representation that produces typical subsurface GPR beam features, combined effects of positional, orientation, and frequency diversity are investigated. Despite long wavelengths, results show distinctive features in reflections obtained from contrasting example target shapes. Full polarimetric analysis suggests the capability for inferring the length of elongated targets, aspect ratio and rotational symmetry, and gross shape along the axis for either elongated or flattened bodies of revolution in problematical orientations [J683]

"Correction to: “Novel diffraction tomographic algorithm for imaging two-dimensional targets buried under a lossy earth”"

The paper by T. J. Cui and W. C. Chew, IEEE Trans. Geosci. Remote Sensing, vol. 38, p.2033-41 (2000) is corrected. The authors, in that paper, defined the branch cut of Kayand kbyin an equation (7) as Re(kay,by)⩾0 and Im(kay ,by)⩾0 to make the Sommerfeld-like integral in another equation(5) satisfy the radiation condition. In the inverse-Fourier expression of yet another equation (24), however, they had to choose the branch cut of kbyin a different way, where Re(kby)⩾O and Im(kay,by)⩽, so that the integral in this equation can be convergent. Hence, the kbyin equation (27) must be set in different branch cuts. Although such a procedure gave correct reconstruction results, the mathematical interpretation was confusing. In this correspondence, the authors now modify the mathematical interpretation so that it is clear and easily understood [J684]

"Ground target tracking with STAP radar"

The problem of tracking ground moving targets by a moving radar (airborne, spaceborne) is addressed. Tracking of low Doppler targets within a strong clutter background is of special interest. The motion of the radar platform induces a spreading of the clutter Doppler spectrum so that low Doppler target echoes may be buried in the clutter band. Detection of such targets can be much alleviated by space-time adaptive processing (STAP), which implicitly compensates for the Doppler spread effect caused by the platform motion. Even if STAP is applied, low Doppler targets can be masked by the clutter notch. This physical phenomenon is frequently observed and results in a series of missing detections which may seriously degrade the tracking performance. A new sensor model adapted to STAP is proposed and its benefits to tracking well-separated targets are discussed. By exploiting a priori information on the sensor specific clutter notch, the model in particular provides a more appropriate treatment of missing detections. In this context, the minimum detectable velocity (MDV) proves to be an important sensor parameter, explicitly entering into ground moving target indication (GMTI) tracking [J685]

"Unbiased coherence estimator for SAR interferometry with application to moving target detection"

A new maximum-likelihood estimator (MLE) for estimating the coherence between two synthetic aperture radar (SAR) channels is proposed. In contrast to conventional techniques, this estimator is unbiased for any number of samples and degrees of coherence. The performance of the new MLE is validated with results based on measured along-track interferometric data. It is demonstrated how such accurate coherence estimates can be used to define CFAR-detection thresholds for moving targets [J686]

"SAR imaging of buried objects from MoM modelled scattered field"

Synthetic aperture radar (SAR) images of resonant buried objects are modelled in the presence of ground surface clutter. The method of moments (MoM) is used to model scattered fields from a resonant buried conductor and clutter is modelled as a bivariant Gaussian distribution. A diffraction stack SAR imaging technique is applied to the ultra-wideband waveforms to give a bipolar signal image. A number of examples have been computed to illustrate the combined effects of SAR processing with resonant targets and clutter. SAR images of different targets show differences which may facilitate target identification. To maximise the peak signal-to-clutter ratio, an image correlation technique is applied and the results are shown [J687]

"Investigation into the use of nonlinear predictor networks to improve the performance of maritime surveillance radar target detectors"

Previous research has claimed that sea clutter is a chaotic process with a nonlinear predictor function. Indeed, results have been reported which demonstrate that sea clutter is nonlinearly predictable, and that this predictability can be exploited, using nonlinear predictor networks, to improve the performance of maritime surveillance radars. The aim of the paper is to investigate if nonlinear predictor networks can be used to improve the performance of maritime surveillance radars, using sea clutter data sets provided by the Defence Evaluation and Research Agency (DERA). By presenting prediction results for radial basis function network predictors, Volterra series filter predictors, and linear predictors, it is shown that the clutter predictor functions are well approximated by a linear function, and that nonlinear predictor networks provide little or no improvement in performance. A novel and effective training methodology is used for the radial basis function network predictors [J688]

"Enhanced target detection and identification via optimised radar transmission pulse shape"

The optimisation of the transmission radar pulse shape to maximise either target detection or identity discrimination between the T-72 and M1 main battle tanks is investigated. Significant performance improvements in target detection and identification are obtained using such matched illumination transmission waveforms over that of standard chirped pulses [J689]

"Passive ranging of a low observable ballistic missile in a gravitational field"

In this paper we present an estimation algorithm for tracking the motion of a low-observable target in a gravitational field, for example, an incoming ballistic missile (BM), using angle-only measurements. The measurements, which are obtained from a single stationary sensor, are available only for a short time. Also, the low target detection probability and high false alarm density present a difficult low-observable environment. The algorithm uses the probabilistic data association (PDA) algorithm in conjunction with maximum likelihood (ML) estimation to handle the false alarms and the less-than-unity target detection probability. The Cramer-Rao lower bound (CRLB) in clutter, which quantifies the best achievable estimator accuracy for this problem in the presence of false alarms and nonunity detection probability, is also presented. The proposed estimator is shown

to be efficient, that is, it meets the CRLB, even for low-observable fluctuating targets with 6 dB average signal-to-noise ratio (SNR). For a BM in free flight with 0.6 single-scan detection probability, one can achieve a track detection probability of 0.99 with a negligible probability of false track acceptance [J690]

"MTI data clustering and formation recognition"

Image exploitation technology approaches have generally focused on the detection and spatial analysis of stationary groups of objects on the ground using various sensors. While spatial arrangement is clearly necessary in analyzing military formations, it is usually not sufficient. Typically the arrangement must be examined within some context in order to interpret a pattern of deployment. For moving objects the spatial arrangement of the group relative to the direction of motion is key to recognizing the formation. By examining ground moving target indicator (MTI) radar data over time, motion can be inferred and used to establish a context for interpreting the spatial arrangement of the data. New techniques that exploit the multitemporal nature of MTI data are described. The first is a space-time clustering technique that locates compact groups of objects that persist in time. The technique Is an application of Marr and Hildreth's edge detection methodology to the dual problem of region segmentation, or more accurately, volumetric segmentation of space-time. The second technique is based on the use of the Hough transform for recognizing moving formations such as columns, wedges, and lines abreast by analyzing the shape of clustered MTI detections (specifically the orientation of linear arrangements within the group) with respect to their direction of motion. Preliminary results from simulated MTI data sets are presented [J691]

"Monopulse DOA estimation of two unresolved Rayleigh targets"

This paper provides for new approaches to the processing of unresolved measurements as two direction-of-arrival (DOA) measurements for tracking closely spaced targets rather than the conventional single DOA measurement of the centroid. The measurements of the two-closely spaced targets are merged when the target echoes are not resolved in angle, range, or radial velocity (i.e., Doppler processing). The conditional Cramer Rao lower bound (CRLB) is developed for the DOA estimation of two unresolved Rayleigh targets using a standard monopulse radar. Then the modified CRLB is used to give insight into the boresight pointing for monopulse DOA estimation of two unresolved targets. Monopulse processing is considered for DOA estimation of two unresolved Rayleigh targets with known or estimated relative radar cross section (RCS). The performance of the DOA estimator is studied via Monte Carlo simulations and compared with the modified CRLB [J692]

"Radar power multiplier for acquisition of low observables using an ESA radar"

In this paper the acquisition of a low observable (LO) incoming tactical ballistic missile using the measurements from a surface based electronically scanned array (ESA) radar is presented. We present a batch maximum likelihood (ML) estimator to acquire the missile while it is exo-atmospheric. The proposed estimator, which combines ML estimation with the probabilistic data association (PDA) approach resulting in the ML-PDA algorithm to handle false alarms, also uses target features. The use of features facilitates target acquisition under low signal-to-noise ratio (SNR) conditions. Typically, ESA radars operate at 13-20 dB, whereas the new estimator is shown to be effective even at 4 dB SNR (in a resolution cell, at the end of the signal processing chain) for a Swerling III fluctuating target, which represents a significant counter-stealth capability. That is, this algorithm acts as an effective “power multiplier” for the radar by about an order of magnitude. An approximate Cramer-Rao lower bound (CRLB), quantifying the attainable estimation accuracies and shown to be met by the proposed estimator, is derived as well [J693]

"Improved SAR target detection via extended fractal features"

The utility of the extended fractal (EF) feature is evaluated for the enhancement of the focus of attention (FOA) stage of a synthetic aperture radar (SAR) automatic target recognition (ATR) system. Unlike more traditional SAR detection features that distinguish target pixels from the background only on the basis of contrast, the EF feature is sensitive to both the contrast and size of objects. Furthermore, the structure for the EF feature computational algorithm lends itself to very fast implementation, and it can be shown that the new feature has a CFAR-like (constant false alarm rate) property. We demonstrate the improved performance using the new feature by testing a number of different detection approaches over two databases of SAR imagery [J694]

"Effects of the ground surface on polarimetric features of broadband radar scattering from subsurface metallic objects"

Throughout the world, the problem of buried unexploded ordnance (UXO) poses an enormous, persistent, and expensive problem. While UXO generally consists of sizable bodies of ferrous metal and can therefore be detected, with current technology it is extremely difficult to distinguish them reliably from typically widespread

pieces of clutter. Thus the problem is one of subsurface discrimination. The authors previous modeling work on scattering of ground penetrating radar (GPR) from metallic objects surrounded by an infinite soil-like medium has suggested the utility of a number of key discriminants in broadband fully polarimetric sensing. In particular, resonance structure, induced field rotation and ellipticity, and bistatic observation of scattered signals were shown to offer key information about target shape and size. The authors investigate the effects on signature features of the proximity of a ground surface to the target, for the common case of shallow burial (<1 m). Overall, their analyses suggest that the key discriminants seen in scattering in an infinite medium survive the complex interactions with the ground surface. In some instances, these revealing signatures appear to be strengthened by the presence of a nearby surface. Multiposition backscatter also allows fundamental inferences about target elongation and symmetry when those cannot be obtained from single position viewing [J695]

"Feature-level and decision-level fusion of noncoincidently sampled sensors for land mine detection"

We present and compare methods for feature-level (predetection) and decision-level (postdetection) fusion of multisensor data. This study emphasizes fusion techniques that are suitable for noncommensurate data sampled at noncoincident points. Decision-level fusion is most convenient for such data, but it is suboptimal in principle, since targets not detected by all sensors will not obtain the full benefits of fusion. A novel algorithm for feature-level fusion of noncommensurate, noncoincidently sampled data is described, in which a model is fitted to the sensor data and the model parameters are used as features. Formulations for both feature-level and decision-level fusion are described, along with some practical simplifications. A closed-form expression is available for feature-level fusion of normally distributed data and this expression is used with simulated data to study requirements for sample position accuracy in multisensor data. The performance of feature-level and decision-level fusion algorithms are compared for experimental data acquired by a metal detector, a ground-penetrating radar, and an infrared camera at a challenging test site containing surrogate mines. It is found that fusion of binary decisions does not perform significantly better than the best available sensor. The performance of feature-level fusion is significantly better than the individual sensors, as is decision-level fusion when detection confidence information is also available (“soft-decision” fusion) [J696]

"Matrix CRLB scaling due to measurements of uncertain origin"

In many estimation situations, measurements are of uncertain origin. This is best exemplified by the target-tracking situation in which at each scan (of a radar, sonar, or electro-optical sensor), a number of measurements are obtained, and it is not known which, if any, of these is target originated. The source of extraneous measurements can be false alarms-especially in low-SNR situations that force the detector at the end of the signal processing chain to operate with a reduced threshold-or spurious targets. In several earlier papers, the surprising observation was made that the Cramer-Rao lower bound (CRLB) for the estimation of a fixed parameter vector (e.g., initial position and velocity) that characterizes the target motion, for the special case of multidimensional measurements in the presence of additive white Gaussian noise, is simply a multiple of that for the case with no uncertainty. That is, there is a scalar information-reduction factor; this is particularly useful as it allows comparison in terms of a scalar. In this paper, we explore this result to determine how wide the class of such problems is. It turns out to include many non-Gaussian situations. Simulations corroborate the analysis [J697]

"Multi-aspect detection of surface and shallow-buried unexploded ordnance via ultra-wideband synthetic aperture radar"

An ultra-wideband (UWB) synthetic aperture radar (SAR) system is investigated for the detection of former bombing ranges, littered by unexploded ordnance (UXO). The objective is detection of a high enough percentage of surface and shallow-buried UXO, with a low enough false-alarm rate, such that a former range can be detected. The physics of UWB SAR scattering is exploited in the context of a hidden Markov model (HMM), which explicitly accounts for the multiple aspects at which a SAR system views a given target. The HMM is trained on computed data, using SAR imagery synthesized via a validated physical-optics solution. The performance of the HMM is demonstrated by performing testing on measured UWB SAR data for many surface and shallow UXO buried in soil in the vicinity of naturally occurring clutter [J698]

"Simulations of ground-penetrating radars over lossy and heterogeneous grounds"

The versatility of the three-dimensional (3D) finite-difference time-domain (FDTD) method to model arbitrarily inhomogeneous geometries is exploited to simulate realistic ground-penetrating radar (GPR) scenarios for the purpose of assisting the subsequent designs of high-performance GPR hardware and software. The buried targets are modeled by conducting and dielectric prisms and disks. The ground model is implemented as lossy

with surface roughness, and containing numerous inhomogeneities of arbitrary permittivities, conductivities, sizes, and locations. The impact of such an inhomogeneous ground model on the GPR signal is demonstrated. A simple detection algorithm is introduced and used to process these GPR signals. In addition to the transmitting and receiving antennas, the GPR unit is modeled with conducting and absorbing shield walls, which are employed to reduce the direct coupling to the receiver. Perfectly matched layer absorbing boundary condition is used for both simulating the physical absorbers inside the FDTD computational domain and terminating the lossy and layered background medium at the borders [J699]

"Ultrawide-bandwidth fully-polarimetric ground penetrating radar classification of subsurface unexploded ordnance"

An ultrawide-bandwidth (UWB) ground penetrating radar (GPR) was used to collect fully-polarimetric backscattered data from 10 to 800 MHz using a dual-polarization version of the previously developed dielectric-loaded horn-fed bow-tie (HFB) antenna. Special processing algorithms were developed to extract the polarization, orientation, depth, and length features of the target under investigation. The polarization and resonance features were utilized to discriminate subsurface ordnance from false-alarm objects that do not have elongated bodies. The classification of a specific type of unexploded ordnance (UXO) was also performed using the known length information. The processed results obtained from an initial blind field test show a very encouraging discrimination performance [J700]

"An analytical model for studies of soil modification effects on ground penetrating radar"

Due to the similar dielectric constants of buried nonmetallic targets and dry soils, it is often difficult to detect and identify nonmetallic targets with ground penetrating radar. The addition of properly chosen chemical agents to modify soil properties can potentially provide improved detection. Previous studies using waveguide experiments have shown that the addition of water improves dielectric contrasts but also increases loss so that target detectability is not necessarily improved. The addition of liquid nitrogen to wet soils can reduce background medium loss and restore target visibility, and waveguide studies of target detection through controlled depth of nitrogen penetration have shown that scattering can be significantly enhanced if an optimal amount of nitrogen is added. A simple physical optics (PO) model for scattering from a three-dimensional target buried below a half space is presented, and it is shown that the radar cross section of the target depends on the dielectric contrast with and attenuation in the background medium. The model is validated through comparison with a method of moments code and found to yield accurate predictions for near normal incidence geometries. Analytical studies of target detection with two concepts of soil modification are then described: obtaining an “optimal” homogeneous soil water content and the addition of a large quantity of water along with an optimal amount of liquid nitrogen. Finally, initial tests of these soil modification techniques with a dielectric rod antenna ground penetrating radar are performed and demonstrate that the addition of liquid nitrogen to excessively wet soils can reduce loss and enhance target visibility [J701]

"A maximum-likelihood beamspace processor for improved search and track"

The authors describe a two-stage digital beamforming architecture for use in radar. The first stage uses digitized subarray voltages to form a number of highly overlapped adaptive beams. The beams are themselves adaptively weighted during the second stage. Maximum-likelihood processing is used in the second stage to estimate target amplitude and angle of arrival. It is shown that the new architecture supports improved search and track performance compared to traditional systems that use a single receive beam and monopulse processing to measure angle [J702]

"The multifaceted peter swerling"

First Page of the Article [J703]

"GLRT-based adaptive detection algorithms for range-spread targets"

We address adaptive detection of a range-spread target or targets embedded in Gaussian noise with unknown covariance matrix. To this end, we assume that cells (referred to in the following as secondary data) that are free of signal components are available. Those secondary data are supposed to possess either the same covariance matrix or the same structure of the covariance matrix of the cells under test. In this context, we design detectors relying on the generalized likelihood ratio test (GLRT) and on a two-step GLRT-based design procedure. Remarkably, both criteria lead to receivers ensuring the constant false alarm rate (CFAR) property with respect to the unknown quantities. A thorough performance assessment of the proposed detection strategies, together with the evaluation of their processing cost, highlights that the two-step design procedure is to be preferred with respect to the plain GLRT. In fact, the former leads to detectors that achieve satisfactory performance under

several situations of practical interest and are simpler to implement than those designed resorting to the latter [J704]

"Technique for target detection and ranging based on broadband LPI radars"

A processing technique for improving the ranging and detection capabilities of LPI radars and the measured performance of an experimental system are presented. The precision of the measured distance is very high even under low SNR conditions. The associated detection algorithm also exhibits good performance in noisy environments [J705]

""Statistics 101" for multisensor, multitarget data fusion"

This tutorial summarizes the motivations, concepts, techniques, and applications of finite-set statistics (FISST), a system-level, "top-down" direct generalization of ordinary single-sensor, single-target engineering statistics to the multisensor, multitarget realm. FISST provides powerful new conceptual and computational methods for dealing with multisensor, multitarget, and multi-evidence data fusion problems. The paper begins with a broad-brush overview of the basic concepts of FISST. It describes how conventional single-sensor, single-target formal Bayesian modeling is carefully extended to general data fusion problems. We examine a simple example: joint detection and tracking of a possibly non-existent maneuvering target in heavy clutter. The tutorial concludes with a commentary on certain criticisms of FISST. [J706]

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