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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 41-1

“Radar Target in Clutter”
(«РЛ цель на фоне помеховых отражений»)

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"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. [J1]

"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. [J2]

"Performance Bounds and Angular Resolution Limit for the Moving Colocated MIMO Radar"

To identify a target, the moving noncoherent colocated multiple-input multiple-output (MIMO) radar system takes advantage of multiple antennas in transmission and reception which are close in space. In this paper, we study the estimation performance and the resolution limit for this scheme in which each array geometry is described by the sample-variance of the sensor distribution. So, our analysis encompasses any sensor distributions, including varying intersensors distances or/and lacunar (missing sensors) configuration. As in the space-time MIMO model considered here the radar is moving, the target Doppler frequency cannot be assumed invariant to the target position/angle. The first part of this paper derives and analyzes closed form (nonmatrix) expressions of the deterministic Cramer-Rao lower bound (CRB) for the direction and the velocity of a moving target contaminated by a structured noise (clutter echoes) and a background noise, including the cases of the clutter-free environment and the high signal-to-noise ratio (SNR) regime. The analysis of the proposed expressions of the CRB allows to better understand the characterization of the target. In particular, we prove the coupling

between the direction parameter and the velocity of the target is linear with the radar velocity. In the second part, we focus our study on the analytical (closed form) derivation and the analysis of the angular resolution limit (ARL). Based on the resolution of an equation involving the CRB, the ARL can be interpreted as the minimal separation to resolve two closely spaced targets. Consequently, the ARL is a key quantity to evaluate the performance of a radar system. We show that the ARL is in fact quasi-invariant to the movement of the MIMO radar. [J3]

"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. [J4]

"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. [J5]

"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. [J6]

"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. [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]

"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. [J9]

"Joint spatial registration and multi-target tracking using an extended probability hypothesis density filter"

An extended probability hypothesis density filter for translational measurement registration and multi-target tracking (MTT) is proposed. The number and states of the targets and the biases of the sensors are jointly estimated by this method without the data association. The sequential Monte Carlo method is used to implement the proposed algorithm considering non-linear and non-Gaussian conditions. Monte Carlo simulation results show that the proposed method (i) outperforms, although computationally a little more expensive than, the standard PHD filter which does not involve the process of spatial registration; (ii) outperforms the multi-sensor joint probabilistic data association (MSJPDA) filter which is also extended in this study for joint spatial registration and MTT when the clutter is relatively dense. [J10]

"Ground-based radar interferometer for tracking fast approaching targets"

This study describes the design and initial evaluation of a radar that detects and tracks a fast approaching target in a short-range application. In some radar applications, tracking durations less than 1 s and 3D tracking accuracy of a few tens of centimetres are required. To satisfy these requirements, a radar interferometer is proposed to simultaneously detect and track a target. A frequency-modulated continuous wave (FMCW) waveform is chosen and a method of separating clutter from a valid signal is developed to obtain very precise range information. In the tracking algorithm, a least squares (LS) filter is adopted because of its fast computing speed and good convergence characteristics to a steady state. This system is constructed using an open architecture approach, with a direct digital synthesiser, a field programmable gate array (FPGA) and a digital signal processor (DSP) as core components. The radar system was evaluated through real field testing. The test results showed that the proposed radar and tracking methods are able to estimate very accurate target positions in real field testing. [J11]

"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. [J12]

"Adaptive clutter suppression and resolving of velocity ambiguities for an experimental three-channel airborne synthetic aperture radar-ground moving target indication system"

This study investigates practical processing methods aiming at detecting ground moving targets and estimating their motion parameters for an experimental three-channel airborne synthetic aperture radar-ground moving target indication (SARGMTI) system. It focuses on two key points of GMTI processing: adaptive clutter suppression and resolving of velocity ambiguities. Different from the conventional clutter suppression based on SAR images or in range-Doppler domain of the entire-aperture pulses, the clutter cancellation is proposed to be performed in the Doppler domain of short-aperture pulses to avoid the superposition of clutter echoes from different ground patches in azimuth; meanwhile, the ground moving target signals are focused with the full aperture to maximise the signal-to-noise ratio. To resolve the velocity ambiguity, a joint strategy is proposed that combines the estimates of the along-track interferometric phases and the Doppler spectrum information of a ground moving target according to the Chinese remainder theorem. The implementations of the processing operations are verified with real data from the experimental three-channel airborne SAR-GMTI system. [J13]

"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. [J14]

"Strategy of doppler centroid estimation in synthetic aperture radar"

Doppler centroid is an important parameter in synthetic aperture radar (SAR) image processing. Owing to measurement uncertainties, many clutter-lock algorithms are proposed to estimate the Doppler centroid. One of the factors that affect the estimation is `chirp coupling` [linear FM signal is used as transmitting signal in SAR, and this makes echoes of targets from different range bins overlap with each other at the same range bin, which could be called `chirp coupling (CHCO)`]. In broadside or lowly squint mode SAR, CHCO is often ignored. However, with large squint angle, its influence on Doppler centroid estimation will increase and even affect the final image. The azimuth-frequency shift of echoes caused by CHCO is analysed and a method proposed to calculate the threshold angle which is used to judge its influence on Doppler centroid estimation. With the help of the threshold angle, a novel strategy of Doppler centroid estimation is proposed. After theoretic analyses, simulations and experimental results are provided to demonstrate the proposed strategy of Doppler centroid estimation. [J15]

"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. [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]

"Transitions in the polarimetric radar scattering properties of the sea surface"

The wide variability of sea surface conditions is reflected in a corresponding variability in sea clutter characteristics; moreover, these characteristics manifest a strong dependence on radar parameters such as frequency, waveform and polarisation. Ideally, radar systems should adapt their parameters to the prevailing sea conditions and viewing geometry so as to optimise performance. In practice this is seldom done, in large part because most radar systems have very limited capability to adapt, but also because the rules that might guide the adaptation process are not yet clearly established. Where an appreciable change in radar parameters or viewing geometry would yield only a slight change in clutter severity and a commensurately modest improvement in radar performance, there is little incentive to adapt. On the other hand, if there are sharp transitions in clutter properties as some radar parameter is varied, then exploitation of the transition may be highly advantageous. This study presents the results of a search for transitions in polarimetric X-band sea clutter, focusing on the dependence on scattering geometry. Experiments were conducted to study clutter variation with elevation angle and azimuth with respect to wind direction. The results demonstrate that transitions exist, that they can be surprisingly sharp, and that the consequences for target detectability may be significant. [J18]

"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. [J19]

"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. [J20]

"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. [J21]

"GMTI clutter cancellation using real non-ideal data"

The performance of displaced phase centre antenna (DPCA), adaptive DPCA (ADPCA) and joint domain localised space time adaptive processing (JDL-STAP) was examined when applied to data that were not gathered for ground moving target indication (GMTI) purposes, and using very few array elements. Three different methods to be applied at the pre-processing stage to match pulses from different spatial channels were compared. The ADPCA method was shown to be the most robust in the presence of signals leaked from other range cells while traditional DPCA proved to be the most effective at attenuating stationary targets in non-ideal conditions, providing that pre-processing, using a pulse shift and a ramp in phase, was applied to the data. Quantitative results are presented, which are drawn from real experiments using real airborne radar data and which provide a valuable insight into the tolerance of DPCA, ADPCA and STAP when put to use with few spatial channels on non-ideal data. The study shows that all three GMTI algorithms used with few antenna elements can successfully resolve moving targets from clutter in such data and discusses the limitations of each in suppressing unwanted stationary peaks. [J22]

"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. [J23]

"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. [J24]

"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. [J25]

"Toward the Development of Radar Scene Analyzer for Cognitive Radar"

In this paper, we propose a target signature search algorithm to address the radar scene analyzer in explicit terms for cognitive radar reception. A cognitive radar receiver encompasses two main blocks: the radar scene analyzer (RSA) and the Bayesian target tracker (BTT). The BTT needs to have prior knowledge of what it is looking for, such as terrain conditions, and the potential targets in that terrain. This information is provided by the RSA with the aid of other external resources. More formally, the statistical information about the environment and the target are central to the realization of the BTT. However, modeling the statistics of unknown target returns is a particularly challenging task. The objective of the proposed RSA structure is to tackle this challenge by extracting useful information about the target from the environment based on the texture modeling of sea clutter. Specifically, we formulate a weak target as an unknown input embedded in the sea surface, whose dynamics are closely coupled by those of the clutter. The mapping that governs the unknown system's dynamics is assumed to be smooth. The observables from the environment are then predicted one-step ahead with a bank of echo state networks (ESNs). The unknown target's signature is extracted from the ESN prediction error and then refined in two adaptive filtering stages. Performance of the resulting method is evaluated using the posterior Cramer-Rao lower bound (PCRB) on some controlled simulations. Finally, the intended application is presented on live recorded sea returns collected by the McMaster Intelligent PIXel Processing (IPIX) radar. Experiments show that the algorithm can accurately extract the target template from the environment. [J26]

"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. [J27]

"DataWare: Sea Clutter and Small Boat Radar Reflectivity Databases [JBest of the Web]"

In this issue, "Best of the Web" presents online radar reflectivity databases, which are free of charge to the international research community. Databases such as these are used for the characterization of interference (including noise, sea clutter and land clutter, among others) in radar systems, and the development of signal processing techniques that reduce the detrimental effects of this unwanted interference. The data can also be used for the development and evaluation of signal processing techniques aimed at detecting and tracking man-made objects by separating targets from interference based on Doppler and amplitude characteristics. These signal processing techniques include moving target indication (MTI), pulse-Doppler, space-time adaptive processing, track-before-detect (TkBD), and constant false alarm rate (CFAR) processing. [J28]

"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. [J29]

"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. [J30]

"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. [J31]

"Motion Parameter Estimation in the SAR System With Low PRF Sampling"

A novel approach to motion parameter estimation with low pulse repetition frequency (PRF) sampling based on compressed sensing (CS) theory is introduced. As is known to us, when PRF is less than the Doppler spectrum bandwidth, moving targets suffer both Doppler centroid frequency ambiguity and Doppler spectrum ambiguity. Under this condition, the traditional parameter estimation method in the Doppler domain is out of action. The key of this letter converts motion parameter estimation in the synthetic aperture radar system with low PRF sampling into solving an optimization equation based on CS theory. Because moving targets in the scene can be regarded as sparse signals after clutter cancellation, an optimization algorithm based on CS theory is proposed to reconstruct sparse signals and meanwhile estimate the along-track velocities and azimuth positions of moving targets. Considering the fact that range cell migration of moving targets is not subject to PRF limitations, Radon transform is adopted to obtain unambiguous across-track velocities and range positions. Results on simulation and real data are provided to show the effectiveness of this method. [J32]

"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. [J33]

"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. [J34]

"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. [J35]

"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. [J36]

"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. [J37]

"OFDM MIMO Radar With Mutual-Information Waveform Design for Low-Grazing Angle Tracking"

We propose an information theoretic waveform design algorithm for target tracking in a low-grazing angle (LGA) scenario. We incorporate realistic physical and statistical effects, such as Earth's curvature, vertical refractivity gradient of lower atmosphere, and compound-Gaussian characteristics of sea-clutter, into our model. We employ a co-located multiple-input-multiple-output (MIMO) radar configuration using wideband orthogonal frequency division multiplexing (OFDM) signalling scheme. The frequency diversity of OFDM provides richer information about the target as different scattering centers resonate at different frequencies. Additionally, we use polarization-sensitive transceivers to resolve the multipath signals with small separation angles. Thus, we track the scattering

coefficients of the target at different frequencies along with its position and velocity. We apply a sequential Monte Carlo method (particle filter) to track the target. Our tracker works in a closed-loop fashion with an integrated optimal waveform design technique based on mutual information (MI) criterion. We seek the optimal OFDM waveform at the current pulse duration to maximize the MI between the state and measurement vectors at the next pulse duration utilizing all the measurement history up to the current pulse. Our numerical examples demonstrate the importance of realistic physical modeling, effects of frequency diversity through OFDM MIMO configuration, and achieved performance improvements due to adaptive OFDM waveform design. [J38]

"Radar clutter-Editorial"

The performance of many radar systems is ultimately defined, and indeed limited, by their ability to detect, track and classify targets in the presence of backscatter from the targetГ‚Вїs environment, known as radar clutter. [J39]

"Outdoor Propagation Channel Modeling in Foliage Environment"

Foliage is a rich scattering environment that is slowly time varying. Most previous investigations in foliage models center on the statistical modeling of clutters and targets. Ideally, it would be desirable to characterize the nature of the propagation channel in foliage; however, it has not been investigated in detail up until now. This paper studies the problem of nonline-of-sight (NLOS) channel modeling based on extensive data collected using both narrowband and ultrawideband (UWB) radars. The modeling adopts the CLEAN algorithm, in which the channel-impulse response (CIR) is accomplished. It is observed that the multipath contributions arriving at the receiver are grouped into clusters. The arrival of clusters can be modeled as a Poisson process, whereas within each cluster, subsequent multipath contributions or rays also arrive according to a Poisson process. However, the arrival rate is quite different, along with the carrier frequency. It is also proposed that the amplitude of multipath channels can more accurately be characterized by a log-logistic distribution (LLD) other than commonly used clutter models such as the log-normal, the Weibull, or the Rayleigh fading model. The proposed foliage channel model is extendable to other outdoor environments. This is a great advantage for the specification and development of future wireless systems. [J40]

"Modified Kirchhoff Migration for UWB MIMO Array-Based Radar Imaging"

In this paper, the formulation of Kirchhoff migration is modified for multiple-input-multiple-output (MIMO) array-based radar imaging in both free-space and subsurface scenarios. By applying the Kirchhoff integral to the multistatic data acquisition, the integral expression for the MIMO imaging is explicitly derived. Inclusion of the Snell's law and the Fresnel's equations into the integral formulation further expends the migration technique to subsurface imaging. A modification of the technique for strongly offset targets is proposed as well. The developed migration techniques are able to perform imaging with arbitrary MIMO configurations, which allow further exploration of the benefits of various array topologies. The proposed algorithms are compared with conventional diffraction stack migration on free-space synthetic data and experimentally validated by ground-penetrating radar experiments in subsurface scenarios. The results show that the modified Kirchhoff migration is superior over the conventional diffraction stack migration in the aspects of resolution, side-lobe level, clutter rejection ratio, and the ability to reconstruct shapes of distributed targets. [J41]

"Noncoherent MIMO Radar for Location and Velocity Estimation: More Antennas Means Better Performance"

This paper presents an analysis of the joint estimation of target location and velocity using a multiple-input multiple-output (MIMO) radar employing noncoherent processing for a complex Gaussian extended target. A MIMO radar with Mtransmit and Nreceive antennas is considered. To provide insight, we focus on a simplified case first, assuming orthogonal waveforms, temporally and spatially white noise-plus-clutter, and independent reflection coefficients. Under these simplifying assumptions, the maximum-likelihood (ML) estimate is analyzed, and a theorem demonstrating the asymptotic consistency, large MN, of the ML estimate is provided. Numerical investigations, given later, indicate similar behavior for some reasonable cases violating the simplifying assumptions. In these initial investigations, we study unconstrained systems, in terms of complexity and energy, where each added transmit antenna employs a fixed energy so that the total transmitted energy is allowed to increase as we increase the number of transmit antennas. Following this, we also look at constrained systems, where the total system energy and complexity are fixed. To approximate systems of fixed complexity in an abstract way, we restrict the total number of antennas employed to be fixed. Here, we show numerical examples which indicate a preference for receive antennas, similar to MIMO communications, but where systems with multiple transmit antennas yield the smallest possible mean-square error (MSE). The joint Cramer-Rao bound (CRB) is calculated and the MSE of the ML estimate is analyzed. It is shown for some specific numerical

examples that the signal-to-clutter-plus-noise ratio (SCNR) threshold, indicating the SCNRs above which the MSE of the ML estimate is reasonably close to the CRB, can be lowered by increasing MN. The noncoherent MIMO radar ambiguity function (AF) is developed in two different ways and illustrated by examples. It is shown for some specif--ic examples that the size of the product MNcontrols the levels of the sidelobes of the AF. [J42]

"Multi-target tracking in clutter with sequential Monte Carlo methods"

For multi-target tracking (MTT) in the presence of clutters, both issues of state estimation and data association are crucial. This study tackles them jointly by Sequential Monte Carlo methods, a.k.a. particle filters. A number of novel particle algorithms are devised. The first one, which we term Monte-Carlo data association (MCDA), is a direct extension of the classical sequential importance resampling (SIR) algorithm. The second one is called maximum predictive particle filter (MPPF), in which the measurement combination with the maximum predictive likelihood is used to update the estimate of the multi-target's posterior. The third, called proportionally weighting particle filter (PWPF), weights all feasible measurement combinations according to their predictive likelihoods, and uses them proportionally in the importance sampling framework. We demonstrate the efficiency and superiority of our methods over conventional approaches through simulations. [J43]

"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. [J44]

"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. [J45]

"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. [J46]

"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. [J47]

"Estimating surface water flow speeds using time-frequency methods"

Synthetic aperture radar (SAR) image formation implicitly assumes that the backscattered returns arise from stationary isotropic targets. When objects move during the SAR integration time, signal anomalies appear that distort, displace and smear moving targets in the image. Although these anomalies degrade the image, they provide the information that allows analysis of the underlying target motion. Joint time-frequency analysis (JTFA) exploits these signal anomalies to estimate the motion of typical point targets. However, the weak, transient returns from water surface scatterers complicate standard JTFA estimates of water surface speeds. A time-frequency representation is applied based on the Capon-s spectral estimation technique that allows joint analysis of multiple azimuth lines, thereby increasing the signal-to-clutter ratio of weak scatterers. The authors compare the time-frequency estimate, employing single-phase-centre SAR data, to along-track interferometric SAR estimates of the same flow and show that both the methods produce comparable results. The authors derive the JTFA equations and estimate water surface speed for data collected at a specific imaging geometry. This study highlights the feasibility of using a single-phase-centre SAR system to determine the motion of slow moving distributed targets representative of water flow. [J48]

"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. [J49]

"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. [J50]

"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. [J51]

"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. [J52]

"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. [J53]

"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. [J54]

"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. [J55]

"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. [J56]

"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. [J57]

"Resolution Enhancement for Inversed Synthetic Aperture Radar Imaging Under Low SNR via Improved Compressive Sensing"

The theory of compressed sampling (CS) indicates that exact recovery of an unknown sparse signal can be achieved from very limited samples. For inversed synthetic aperture radar (ISAR), the image of a target is usually constructed by strong scattering centers whose number is much smaller than that of pixels of an image plane. This sparsity of the ISAR signal intrinsically paves a way to apply CS to the reconstruction of high-resolution ISAR imagery. CS-based high-resolution ISAR imaging with limited pulses is developed, and it performs well in the case of high signal-to-noise ratios. However, strong noise and clutter are usually inevitable in radar imaging, which challenges current high-resolution imaging approaches based on parametric modeling, including the CS-based approach. In this paper, we present an improved version of CS-based high-resolution imaging to overcome strong noise and clutter by combining coherent projectors and weighting with the CS optimization for ISAR image generation. Real data are used to test the robustness of the improved CS imaging compared with other current techniques. Experimental results show that the approach is capable of precise estimation of scattering centers and effective suppression of noise. [J58]

"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. [J59]

"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. [J60]

"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. [J61]

"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. [J62]

"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. [J63]

"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. [J64]

"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. [J65]

"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. [J66]

"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. [J67]

"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. [J68]

"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. [J69]

"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). [J70]

"Exploitation of Ship Scattering in Polarimetric SAR for an Improved Classification Under High Clutter Conditions"

This paper evaluates the potentialities of polarimetric ship scattering for basing classification methods that provide reasonable performance within cluttered scenes. Both simulated and airborne polarimetric synthetic aperture radar (SAR) images have been used to validate the conclusions of a previous phenomenological study. Numerical simulations have been carried out with GRECOSAR, a polarimetric interferometric SAR simulation tool that is able to process highly complex targets with a fast and accurate radar-cross-section prediction module. A representative set of scenarios has been defined, which includes various realistic ship models, sea states, and imaging geometries. In all of them, a two-scale sea surface model precisely accounting for sea-ship interaction and sea clutter has been added. The analysis of different images has shown that, with an adequate spatial resolution, ships may be characterized by a particular spatial arrangement and polarization state distribution of dominant scattering centers. This feature has allowed one to propose a new classification algorithm, which shows a promising behavior after various preliminary tests. In this paper, the performance of this technique is further evaluated with realistic clutter. The results show that robust classification is possible even in highly cluttered scenes if quad-pol imagery is available. On the contrary, in low clutter conditions, the usage of less

restrictive solutions, like circular dual-pol schemes, is feasible and may still get an acceptable performance. [J71]

"Through-the-Wall Imaging Using Differential SAR"

An algorithm for imaging of targets behind walls is proposed to reduce the wall reflection and enhance the signal-to-clutter ratio. The image formation is based on differential synthetic-aperture-radar image formation employing a continuous-wave radar system. In this approach, instead of using individual backscattered signals, the image is formed by employing the difference signals obtained by subtracting two successive signals along the track. This way, specular reflections are totally eliminated without the need for the knowledge of the wall parameters. This also affects the point target response which is corrected by an integration process. By using backscattered fields from small trihedral corner reflectors behind a poured concrete wall, measured over a frequency band of 1-2.5 GHz, the proposed method is demonstrated. [J72]

"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. [J73]

"Coherence-Improving Algorithm for Image Pairs of Bistatic SARs With Nonparallel Trajectories"

Ground moving target indication (GMTI) is one of the most important applications in a general bistatic synthetic aperture radar (SAR) system, where the transmitter and receiver move along nonparallel trajectories with different velocities. In order to improve the capability of clutter cancellation in bistatic SAR/GMTI processing, the coherence between two echoes collected by two receivers is investigated, and the full-coherence conditions are derived. A new coherence-improving algorithm for general bistatic SAR complex image pairs is proposed, which can be realized in the following steps: 2-D range azimuth prefiltering processing, relative geometric deformation correction, and image registration. An approximate implementation of 2-D prefiltering and the corresponding prefilter parameter analysis are also given. Last, two numerical experiment results are given to demonstrate the effectiveness of the proposed algorithm. [J74]

"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. [J75]

"Joint Transmitter and Receiver Polarization Optimization for Scattering Estimation in Clutter"

Controlling the polarization information in transmitted waveforms enables improving the performance of radar systems. We consider the design of optimal polarizations at both the radar transmitter and receiver for the estimation of target scattering embedded in clutter. The goal is to minimize the mean squared error of the scattering estimation subject to an average radar pulse power constraint. Under the condition that the target and clutter scattering covariance matrices are known a priori, we show that such a problem is equivalent to the optimal design of a radar sensing matrix that contains the polarization information. We formulate the optimal design as a nonlinear optimization problem and then recast it in a convex form and is thus efficiently solvable by semi-definite programming (SDP). We compare the sensing performance of the optimally selected polarization over conventional approaches. Our numerical results demonstrate that a significant amount of power gain is achieved in the target scattering estimation through such an optimal design. [J76]

"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. [J77]

"A Study on the Application of Time Modulated Antenna Arrays to Airborne Pulsed Doppler Radar"

The time modulated (TM) linear arrays with variable aperture sizes (VAS) are applied to the airborne pulsed Doppler (PD) radar system in this paper. The VAS arrays which have great flexibility in the control of the aperture excitations are employed to synthesize low/ultra-low sidelobe patterns in the PD radar system, and the optimized time sequences obtained via the differential evolution (DE) algorithm is used to minimize the average power loss due to the time modulation. Numerical simulation results of the signals transmitted and received by PD radar based on the VAS arrays show that the time modulation changed the waveforms of the signals in time domain but the received signals also contain the correct range and velocity information of the moving target. [J78]

"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. [J79]

"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. [J80]

"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. [J81]

"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. [J82]

"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. [J83]

"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. [J84]

"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. [J85]

"A Compressive Sensing Data Acquisition and Imaging Method for Stepped Frequency GPRs"

A novel data acquisition and imaging method is presented for stepped-frequency continuous-wave ground penetrating radars (SFCW GPRs). It is shown that if the target space is sparse, i.e., a small number of point like targets, it is enough to make measurements at only a small number of random frequencies to construct an image of the target space by solving a convex optimization problem which enforces sparsity through lscr1minimization. This measurement strategy greatly reduces the data acquisition time at the expense of higher computational costs. Imaging results for both simulated and experimental GPR data exhibit less clutter than the standard migration methods and are robust to noise and random spatial sampling. The images also have increased resolution where closely spaced targets that cannot be resolved by the standard migration methods can be resolved by the proposed method. [J86]

"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. [J87]

"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. [J88]

"Two-dimensional pulse-to-pulse canceller of ground clutter in airborne radar"

It is well known that in the airborne radar, the location of the ground clutter spectrum in the angle-Doppler space is dependent mainly on the platform velocity and radar parameters. The authors propose a two-dimensional pulse-to-pulse canceller (TDPC) that can make full use of such prior information. The more detailed formulations of the ground clutter model and the signal model are given in a matrix-vector form. The least-squares-typical cost function associated with the filter coefficient matrix of the TDPC is established on the basis of the ground clutter model and the signal model. Like the classical displaced phase centre antenna (DPCA) processing, the proposed TDPC is also a spatial-temporal suppressor of ground clutter and can decrease the ground clutter signals, even though the DPCA condition is not satisfied. The proposed TDPC can also be used as an efficient pre-filtering tool before the conventional moving target indication (MTI) processing and the classical adaptive processing. Moreover, if only the TDPC plus the conventional MTI is used, it takes less computational time than the adaptive canceller. Experimental results show that the proposed TDPC has the satisfactory ground clutter suppression capability by using both simulated data and measured data. [J89]

"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. [J90]

"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. [J91]

"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. [J92]

"A Velocity Estimation Algorithm of Moving Targets using Single Antenna SAR"

A new algorithm is proposed for velocity estimation of moving targets in single antenna synthetic aperture radar (SAR). Based on the fact that different velocity vectors cause different geometrical figures of the two-dimensional (2-D) signature in the range-Doppler (RD) domain, this algorithm estimates the azimuth and range velocities by a 2-D search such that the range cell migration correction (RCMC) and the second range compression (SRC) are correctly performed. It is shown that, using the proposed algorithm, the Doppler ambiguity problem can be avoided and satisfactory accurate velocity estimation can be obtained in high signal-to-clutter ratio (SCR) scenarios. [J93]

"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. [J94]

"Speaker selection and tracking in a cluttered environment with audio and visual information"

Presented in this paper is a data association method using audio and visual data which localizes targets in a cluttered environment and detects who is speaking to a robot. A particle filter is applied to efficiently select the optimal association between the target and the measurements. State variables are composed of target positions and speaking states. To update the speaking state, we first evaluate the incoming sound signal based on cross-correlation and then calculate a likelihood from the audio information. The visual measurement is used to find an optimal association between the target and the observed objects. The number of targets that the robot should interact with is updated from the existence probabilities and associations. Experimental data were collected beforehand and simulated on a computer to verify the performance of the proposed method applied to the speaker selection problem in a cluttered environment. The algorithm was also implemented in a robotic system to demonstrate reliable interactions between the robot and speaking targets. [J95]

"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. [J96]

"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. [J97]

"Classification of primary radar tracks using gaussian mixture models"

Classification of primary surveillance radar tracks as either aircraft or non-aircraft is critical to a number of emerging applications, including airspace situational awareness and collision avoidance. Substantial research has focused on target classification of pre-processed radar surveillance data. Unfortunately, many non-aircraft tracks still pass through the clutter-reduction processing built into the aviation surveillance radars used by the federal aviation administration. This paper demonstrates an approach to radar track classification that uses only post-processed position reports and does not require features that are typically only available during the pre-processing stage. Gaussian mixture models learned from recorded data are shown to perform well without the use of features that have been traditionally used for target classification, such as radar cross-section measurements. [J98]

"Efficient and Enhanced Multi-Target Tracking with Doppler Measurements"

In many radar and sonar tracking systems, the target state typically includes target position and velocity components that are estimated from a time sequence of target position and Doppler measurements. The use of measured Doppler information directly in the target trajectory estimation leads to a nonlinear filter implementation such as the extended Kalman filter (EKF), particle filter etc. We investigate a method for including Doppler measurements as part of the data association process and then assess the benefits of this approach. It is well understood that data association performance can dominate the total performance of a tracker that is designed to track targets in the presence of clutter. In this case, the Doppler component of the measurements may be used in combination with the target position measurement as an additional discriminant of measurement origin. We have developed a simple but efficient Doppler data association (DDA) method which utilises both position and Doppler measurements for single and multi-target tracking. If the Doppler measurements are not used in trajectory state estimation, then the nonlinear filters for the incorporation of Doppler measurements are not required, however a significant improvement in tracking performance is still observed. The proposed DDA method is demonstrated using both the linear multi-target integrated probabilistic data association algorithm (LMIPDA) and the linear multi-target integrated track splitting algorithm (LMITS) in an active sonar underwater multi-target tracking scenario. [J99]

"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. [J100]

"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. [J101]

"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. [J102]

"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. [J103]

"Extraction of mixed-order multicomponent ship target signals from broadened sea clutter in bistatic shipborne surface wave radar"

A dynamic geometry model was built to describe the Doppler-broadening characteristics of the first-order Bragg lines for bistatic shipborne surface wave radar. They are time-varying because the Doppler frequency shifts of sea echoes are simultaneously modulated by the velocity components projected from the unavoidably different motions of both platforms, which is more complex than its counterpart in the monostatic mode. The geometrical relation is used to obtain the received signal model: strong first-order sea clutter interferences and submerged ship targets with constant and non-constant speeds are considered as mixed-order multicomponent polynomial-phase signals (mc-PPSs) and both second-order sea clutter continuum and atmospheric noise as additive noise. Then, a scheme based on the product high-order ambiguity function is proposed to extract the targets; it is a recursive procedure in which the first-order sea clutter is removed by an existing time-space cascaded filtering method. Monte Carlo simulations show the validity and efficiency of the proposed scheme. [J104]

"Approximate Cramer-Rao bound on Doppler error in correlation-processing relatively narrowband noise radar"

Limitations on accuracy of Doppler estimation in continuous-wave noise radar with correlation processing are studied. Second-order properties of output of the correlation receiver are evaluated and an approximate Cramer-

Rao bound on errors of Doppler measurement is derived. The accuracy of Doppler measurements is found to be affected by the following factors: power spectral density of noise signal, frequency response of the low-pass filter in correlator, observation time, velocity of the target and signal to noise ratio. It is shown that the random nature of the transmitted signal induces additional fluctuations at the output of correlator which limit the accuracy even in the infinite signal to noise case. Qualitative extension of the results to a case covering multiple targets and clutter is made. It is argued that the performance will decrease and that increasing transmitted power may not provide significant improvement when clutter is present. [J105]

"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. [J106]

"Non-adaptive multiple-input, multiple-output radar techniques for reducing clutter"

Multiple-input, multiple-output (MIMO) radars enhance performance by transmitting and receiving coded waveforms from multiple locations. This paper describes MIMO techniques that can be used to improve radar performance, especially in airborne ground moving target indicator (GMTI) applications. The authors begin by showing how MIMO techniques can lower airborne radar clutter to noise ratios (CNRs). This results in smaller losses when observing stationary or low-velocity targets. Next, the authors consider the implementation of MIMO radar modes using electronically scanned arrays (ESAs). Specifically, the authors show how MIMO techniques, applied to subarray-based ESAs, can cause high grating lobes and/or reduced search rates. To address this problem, the authors describe new space/time waveform coding techniques that can be used to improve performance. Two space/time waveform encoding approaches are proposed: (i) an overlapped virtual transmit subarray approach, and (ii) a beamspace MIMO approach. A third approach, involving conventional MIMO waveforms and irregular subarrays, is also briefly considered. [J107]

"High Range Resolution Profiles as Motion-Invariant Features for Moving Ground Targets Identification in SAR-Based Automatic Target Recognition"

A quantitative model analysis is presented to justify the extraction of high range resolution (HRR) profiles from synthetic aperture radar (SAR) images as motion-invariant features for identifying moving ground targets. A comparative study is conducted to assess the effectiveness in the identification process between using HRR profiles and SAR images as target signatures. The results indicate that HRR profiles are just as viable as SAR image for identification. Furthermore, a score-level multi-look fusion identification method has been investigated. It is found that a correct accurate identification rate of greater than 99 percent, a low false alarm rate, and a high level of identification confidence can be achieved, providing very robust performance. [J108]

"Multiple-input multiple-output over-thehorizon radar: experimental results"

Results from an experiment that applied one class of multiple-input multiple-output (MIMO) waveform techniques to over-the-horizon radar (OTHR) are reported. The experiment objective was to demonstrate that adaptive transmitter beamforming could be used in an appropriately design radar to reject spatially discrete Doppler-spread clutter. In the particular MIMO radar architecture that the authors call non-causal transmit beamforming, conventional or adaptive transmitter beamforming occurs following waveform transmission, propagation, scatter from targets and clutter sources, return propagation and finally signal reception. In the case reported herein spatially discrete clutter was successfully rejected to the noise floor of the radar return with rejection in excess of 35 dB achieved using common adaptive algorithms and straightforward training data selection. As part of the rejection algorithm the transmitted waveform direction-of-departure (DOD) from the transmitter array to the target was estimated and used as the preserved steer direction in the adaptive beamformer. The DOD estimates agree well with the geometrically determined true values. The demonstration of non-causal transmit beamforming suggests that it will be possible to create multiple simultaneous adaptive range-dependent transmitter beams with an appropriately designed OTHR. This has several applications including for the mitigation of Doppler-

spread clutter. [J109]

"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. [J110]

"Demonstration of a Network of Simultaneously Operating Digital Noise Radars [JMeasurements Corner]"

Search and rescue following a natural disaster is a difficult problem, exacerbated by the cluttered environment obscuring human victims. It is well known that UHF radar-frequency radiation can penetrate the types of materials typically found in these situations with relatively little loss. This paper discusses the development of a network of digital noise radars, designed to operate in that frequency range to locate and track human movement through walls and rubble. Each individual noise radar works by cross correlating the received signal with a replica of the transmit signal. A high correlation indicates the range to the target. This noise radar design makes use of the software radar concept by converting the analog transmitted and received signals to digital signals. With the signals in digital form, the cross-correlation process can be accomplished in software. A network of three digital noise radars was developed. The three radars operated simultaneously in the same frequency range, without interference, to triangulate the (x, y) position of a target within a room. The results showed that the network of radars was capable of locating and tracking a human through an obscuring wall. [J111]

"Ground Moving Target Indication Using an InSAR System With a Hybrid Baseline"

In this letter, a two-channel airborne experimental interferometric synthetic aperture radar (InSAR) designed for terrain height estimation is exploited to acquire the ability of ground moving target indication (GMTI). Due to the hybrid baseline of this system, the interferometric phase changes with the target motion as well as the terrain height. The fluctuation of the interferometric phase worsens the performance of the clutter suppression and the radial velocity estimation. In order to resolve this problem, a GMTI method with three steps is proposed. After two steps are used to eliminate the local flat-Earth phase and the cross-track interferometric phase of the scene, respectively, an adaptive filtering method is used to suppress the stationary clutter with the benefit of calibrating the sensor responses. A conventional constant false alarm rate detector is then used to indicate the moving targets. The validity of the proposed method is demonstrated with real data collected using an experimental airborne InSAR system. [J112]

"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. [J113]

"Estimation of Radial Velocity of Moving Targets by Along-Track Interferometric SAR Systems"

Along-track interferometric synthetic aperture radar (AT-InSAR) can be used to estimate the radial velocity of ground moving targets, starting from interferometric phase measures. The estimation obtained from a single-

phase interferogram suffers from ambiguities. To solve these problems, multichannel AT-InSAR systems are required. In this letter, we analyze the radial velocity maximum-likelihood estimation accuracy with respect to AT-InSAR system parameters, such as velocity values and different clutter and thermal noise levels. We consider two different models for the target response: a deterministic model and a zero-mean Gaussian model. The presented results show that AT-InSAR systems exhibit better estimation accuracies for low-velocity values (slow targets). [J114]

"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. [J115]

"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. [J116]

"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. [J117]

"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. [J118]

"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. [J119]

"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. [J120]

"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. [J121]

"Adaptive Polarized Waveform Design for Target Tracking Based on Sequential Bayesian Inference"

In this paper, we develop an adaptive waveform design method for target tracking under a framework of sequential Bayesian inference. We employ polarization diversity to improve the tracking accuracy of a target in the presence of clutter. We use an array of electromagnetic (EM) vector sensors to fully exploit the polarization information of the reflected signal. We apply a sequential Monte Carlo method to track the target parameters, including target position, velocity, and scattering coefficients. This method has the advantage of being able to handle nonlinear and non-Gaussian state and measurement models. The measurements are the output of the sensor array; hence, the information about both the target and its environment is incorporated in the tracking process. We design a new criterion for selecting the optimal waveform one-step ahead based on a recursion of the posterior Cramer-Rao bound. We also derive an algorithm using Monte Carlo integration to compute this criterion and a suboptimal method that reduces the computation cost. Numerical examples demonstrate both the performance of the proposed tracking method and the advantage of the adaptive waveform design scheme. [J122]

"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. [J123]

"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. [J124]

"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. [J125]

"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. [J126]

"Ground Moving Target Indication With Tandem Satellite Constellations"

Ground moving target indication (GMTI) from space by existing dual-channel radar systems such as TerraSAR-X and RADARSAT-2 has been shown to perform only insufficiently with respect to the relocation error of targets to their true ground position. Only two parallel receiver channels are too little to suppress the severe ground clutter and to estimate the target's parameters. Although this deficiency may partly be alleviated through antenna aperture switching, the resulting positioning accuracy is still not adequate for effective traffic monitoring purposes. Satisfactory results are only achievable with extended apertures, primarily with satellite constellations. This letter presents a statistical analysis of the performance of different concepts for cooperating back-to-back flying satellite systems. Particularly in anticipation of TanDEM-X, which will form the first operational GMTI-capable coherent synthetic aperture radar constellation after its launch in 2009. [J127]

"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. [J128]

"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. [J129]

"Doppler Keystone Transform: An Approach Suitable for Parallel Implementation of SAR Moving Target Imaging"

In this letter, a synthetic aperture radar (SAR) data reformatting approach named Doppler keystone transform (DKT) is proposed to correct the range migration of a moving target. By using the DKT, the SAR imaging program, i.e., the 2-D matched filtering, can be transformed into separate 1-D operations along range or azimuth direction, and therefore, the DKT is suitable for the parallel implementation of SAR imaging of the moving target. Our simulations show that by combining the DKT and the Doppler phase compensation methods, the moving target can be well imaged in high signal-clutter-ratio case. [J130]

"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. [J131]

"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. [J132]

"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. [J133]

"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. [J134]

"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. [J135]

"A Low-Power High-Sensitivity X-Band Rail SAR Imaging System [JMeasurement's Corner]"

Wideband radar imaging with range gating and high sensitivity can be achieved with the use of low-cost commercially available narrowband IF filters. Such filters reduce the effective receiver noise bandwidth of the radar system. This allows for high sensitivity, comparable to that of single-sideband radio receivers, while at the same time acquiring de-chirped wide-band received waveforms. A carefully developed radar architecture, based on the use of these IF filters, is shown in this paper. This radar architecture is then implemented in an X-band linear rail synthetic-aperture-radar (SAR) imaging system. The X- band rail SAR is a linear FM-chirped radar, which chirps from approximately 7.5 GHz to 12.5 GHz. The radar front end is mounted onto an eight-foot-long linear rail. The transmitted power is adjustable to 10dBm or less. It will be shown that objects as small as groups of pushpins in free space can be imaged using transmitted power as low as 10 nW. These results are compared to previous direct-conversion X-band FMCW rail SAR work. A high-sensitivity X-band rail SAR such as this could be useful for measuring low-radar-cross-section (RCS) targets. This radar could be used in high clutter environments that require a range gate. This low-power X-band rail SAR could be useful for operation in restricted transmission areas, where maximum radiated power is severely limited. Other applications include any that require low transmitter power, such as automotive radar. [J136]

"Advances in bistatic radar (Willis, N.J. and Griffiths, H.D., Eds.; 2007) [JBook Review]"

The editors have collected a comprehensive set of monographs that provide insight into the more recent history of bistatic radar design and implementation. This volume combines improved details of the environment along with novel system applications. Each chapter is authored by radar experts who had the vision and motivation to tackle a daunting development problem, and share their view of the successes and remaining implementation challenges. The book is divided into two parts: Bistatic/Multistatic Systems and Bistatic Clutter and Signal Processing. The book is an essential addition to the modern radar engineer's library. [J137]

"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. [J138]

"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. [J139]

"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. [J140]

"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. [J141]

"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. [J142]

"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. [J143]

"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. [J144]

"A mean track approach applied to the multidimensional assignment problem"

The primary contribution of this paper is the introduction of a new preprocessing method to eliminate unlikely observation-to-track pairs with medium size target-measurement spacings before filter gating is carried out. The proposed method follows a track-oriented approach, with the different track hypotheses being contained in target trees. A mean track is computed for each target tree to capture as much variability as possible from the track hypotheses which are in the tree. Each newly received measurement is first gated with the mean track; only if the outcome of the test is positive, the measurement is gated with all the track hypotheses in the tree. The

experimental results support the theoretical claims in the paper and show that a significant reduction in the number of observation-to-tracking pairing tests is achieved. [J145]

"Models and Algorithms for Tracking of Maneuvering Objects Using Variable Rate Particle Filters"

Standard algorithms in tracking and other state-space models assume identical and synchronous sampling rates for the state and measurement processes. However, real trajectories of objects are typically characterized by prolonged smooth sections, with sharp, but infrequent, changes. Thus, a more parsimonious representation of a target trajectory may be obtained by direct modeling of maneuver times in the state process, independently from the observation times. This is achieved by assuming the state arrival times to follow a random process, typically specified as Markovian, so that state points may be allocated along the trajectory according to the degree of variation observed. The resulting variable dimension state inference problem is solved by developing an efficient variable rate particle filtering algorithm to recursively update the posterior distribution of the state sequence as new data becomes available. The methodology is quite general and can be applied across many models where dynamic model uncertainty occurs on-line. Specific models are proposed for the dynamics of a moving object under internal forcing, expressed in terms of the intrinsic dynamics of the object. The performance of the algorithms with these dynamical models is demonstrated on several challenging maneuvering target tracking problems in clutter. [J146]

"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 [J147]

"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. [J148]

"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 [J149]

"Dynamic Configuration of Time-Varying Waveforms for Agile Sensing and Tracking in Clutter"

The advent of waveform-agile sensors has enabled the design of tracking systems where the transmitted waveform is changed on-the-fly in response to the tracker's requirements. This approach can provide performance improvements over individual optimization of the sensor waveform or the tracking algorithm. In this paper, we consider joint sensor configuration and tracking for the problem of tracking a single target in the presence of clutter using range and range-rate measurements obtained by waveform-agile, active sensors in a narrowband environment. We propose an algorithm to select and configure linear and nonlinear frequency-modulated waveforms to minimize the predicted mean square error (MSE) in the target state estimate; the MSE is predicted using the Cramer-Rao lower bound on the measurement error in conjunction with the unscented

transform. We further extend our algorithm to match wideband environments, and we demonstrate the algorithm performance through a Monte Carlo simulation of a radar tracking example. [J150]

"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. [J151]

"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. [J152]

"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. [J153]

"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. [J154]

"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. [J155]

"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. [J156]

"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. [J157]

"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. [J158]

"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. [J159]

"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. [J160]

"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. [J161]

"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. [J162]

"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. [J163]

"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 [J164]

"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 [J165]

"Statistical Analysis of High-Resolution SAR Ground Clutter Data"

This paper deals with the problem of modeling high-resolution synthetic aperture radar clutter data from different vegetated areas. We analyzed moving and stationary target recognition (MSTAR) data sets focusing on histograms, moments, and covariance of clutter amplitude, texture, and speckle. The most celebrated statistical models are tested on real data of grass field or wood and trees to validate the goodness of fit of the compound Gaussian model in different scenarios. The results demonstrate that for grass fields, the compound Gaussian model provides a good data fitting. This is not the case for woods images where the speckle is not more Gaussian distributed. Covariance analysis and concluding remarks complete this paper [J166]

"A Keystone Transform Without Interpolation for SAR Ground Moving-Target Imaging"

Synthetic aperture radar (SAR) image formation for a ground moving target necessitates the compensation of the unknown target trajectory. The keystone transform has been employed to remove the linear component of the range migration for the moving target, where interpolation is required. In this letter, a realization of the keystone transform avoiding interpolation is presented. The kernel of this transform, i.e., the range-frequency-dependent azimuth time rescaling, is implemented using only complex multiplications and fast Fourier transforms based on the scaling principle, which has been successfully applied in the equalization of the space-variant range cell migration in SAR processing. In addition, the moving target is coarsely focused according to the SAR geometry and the platform velocity while exploiting the scaling principle. This preliminary focusing is helpful in the isolation of the moving target from ground clutter, so as to facilitate a more refined processing with respect to each mover. SAR raw data combined with simulated echoes of moving targets are utilized to validate the presented approach [J167]

"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 [J168]

"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 [J169]

"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 [J170]

"Tracking of multiple maneuvering targets using multiscan JPDA and IMM filtering"

The paper considers the problem of tracking multiple maneuvering targets in the presence of clutter using switching multiple target motion models. A novel suboptimal filtering algorithm is developed by applying the basic interacting multiple model (IMM) approach and the joint probabilistic data association (JPDA) technique. Unlike the standard single-scan JPDA approach, the authors exploit a multiscan joint probabilistic data association (mscan-JPDA) approach to solve the data association problem. The algorithm is illustrated via a simulation example involving tracking of four maneuvering targets and a multiscan data window of length two [J171]

"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 [J172]

"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 [J173]

"Random Noise Radar/Sodar With Ultrawideband Waveforms"

Random noise waveforms with ultrawide bandwidth improve the range resolution and reduces the probability of intercept in radar/sodar. As a result of the nonperiodic waveform, the range ambiguity is removed as well. By transmitting a sine signal that is phase or frequency modulated by random noise, autocorrelation functions with improved side lobe suppression in range can be formed. There are great similarities in the signal-processing algorithms applied in noise radar and sodar. The much slower propagation velocity of sound compared to light reduces the signal bandwidth but increases the time of measurement, however. In both sodar and radar, the range resolution is determined by the wavelength band occupied by the transmitted waveform, while the velocity resolution is controlled by the ratio of wavelength and time of measurement. The slower sound velocity also enhances the range/Doppler ambiguity problem in sodar when periodic waveforms are applied. This ambiguity could be suppressed if nonperiodic waveforms are introduced, such as random noise. In this paper, fundamental similarities and differences on system level between sodar and radar are first discussed, and signal-processing algorithms applied in random noise radar/sodar are reviewed. In particular, the noise floor of the ambiguity function and its relationship to spectrum width and time of measurement are analyzed, including improved side lobe suppression using mismatched filtering. The signal-processing algorithms were tested on raw data from sodar measurements on moving targets, buildings, vegetation, and water surfaces. An adaptive filter algorithm for suppression of the increased noise floor from dominant reflectors was derived and successfully applied to both

sodar and stepped frequency radar data [J174]

"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. [J175]

"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. [J176]

"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. [J177]

"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. [J178]

"Performance improvement for constellation SAR using signal processing techniques"

A new concept of spaceborne synthetic aperture radar (SAR) implementation has recently been proposed-the constellation of small spaceborne SAR systems. In this implementation, several formation-flying small satellites cooperate to perform multiple space missions. We investigate the possibility to produce high-resolution wide-area SAR images and fine ground moving-target indicator (GMTI) performance with constellation of small spaceborne SAR systems. In particular, we focus on the problems introduced by this particular SAR system, such as Doppler ambiguities, high sparseness of the satellite array, and array element errors. A space-time adaptive processing (STAP) approach combined with conventional SAR imaging algorithms is proposed which can solve these problems to some extent. The main idea of the approach is to use a STAP-based method to properly overcome the aliasing effect caused by the lower pulse-repetition frequency (PRF) and thereby retrieve the unambiguous

azimuth wide (full) spectrum signals from the received echoes. Following this operation, conventional SAR data processing tools can be applied to focus the SAR images fully. The proposed approach can simultaneously achieve both high-resolution SAR mapping of wide ground scenes and GMTI with high efficiency. To obtain array element errors, an array auto-calibration technique is proposed to estimate them based on the angular and Doppler ambiguity analysis of the clutter echo. The optimizing of satellite formations is also analyzed, and a platform velocity/PRF criterion for array configurations is presented. An approach is given to make it possible that almost any given sparse array configuration can satisfy the criterion by slightly adjusting the PRF. Simulated results are presented to verify the effectiveness of the proposed approaches. [J179]

"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. [J180]

"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. [J181]

"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. [J182]

"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. [J183]

"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. [J184]

"Minimum norm property for the sum of the adaptive weights for a direct data domain least squares algorithm"

In most adaptive algorithms, it is generally assumed that one knows the direction of arrival (DOA) of the signal of interest (SOI) through the steering vector of the array and the goal is to estimate its complex amplitude in the presence of jammer, clutter and noise. In space-time adaptive processing (STAP) the goal is to seek for a target located along a certain look direction and at a particular Doppler frequency through a given steering vector. Therefore, the accuracy of the computed results in either case is based on the reliability of this a priori assumption of the steering vector. It is possible that due to mechanical vibrations, calibration errors or atmospheric refractions of the incident electromagnetic waves, the assumed DOA may not be very accurate or that the assumed value of the Doppler frequency is not appropriate. In either of these cases, the adaptive algorithm treats the SOI as an interferer and nulls it out. This perennial problem of signal cancellation is an open problem for adaptive algorithms. In this paper It is shown that the proper steering vector occurs at the minimum of the sum of the norm of the adaptive weights and can be used as an indicator to refine the estimate of the DOA of the SOI in adaptive algorithms or both the DOA or/and the Doppler frequency in STAP. Examples are presented to illustrate that the secondary processing outlined in this paper, may provide a refined estimate for the true DOA or/and Doppler frequency for the SOI in the presence of interference, clutter and noise [J185]

"Low-angle reflectivity modeling of land clutter"

In this letter, a practical mean reflectivity model of radar land clutter (LC) for the complex system design of ground-based radars involved in low-angle targets on some typical terrains is studied using the inductive reasoning method. The functional relationships between the radar parameters and radar surface clutter backscattering are analyzed. Following the recent research work in the area of reflectivity modeling of LC in the literature, the least squares method is employed to estimate the model parameters. The model is validated using reliable practical data and shown to outperform other models in accuracy. [J186]

"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. [J187]

"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. [J188]

"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. [J189]

"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. [J190]

"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. [J191]

"CuTE: curb tracking and estimation"

The number of road accident related fatalities and damages are reduced substantially by improving road infrastructure and enacting and imposing laws. Further reduction is possible through embedding intelligence onto the vehicles for safe decision making. Road boundary information plays a major role in developing such intelligent vehicles. A prominent feature of roads in urban, semi-urban, and similar environments, is curbs on either side defining the road's boundary. In this brief, a novel methodology of tracking curbs is proposed. The problem of tracking a curb from a moving vehicle is formulated as tracking of a maneuvering target in clutter from a mobile platform using onboard sensors. A curb segment is presumed to be the maneuvering target, and is modeled as a nonlinear Markov switching process. The target's (curb's) orientation and location measurements are simultaneously obtained using a two-dimensional (2-D) scanning laser radar (LADAR) and a charge-coupled device (CCD) monocular camera, and are modeled as traditional base state observations. Camera images are also used to estimate the target's mode, which is modeled as a discrete-time point process. An effective curb tracking algorithm, known as Curb Tracking and Estimation (CuTE) using multiple modal sensor information is, thus, synthesized in an image enhanced interactive multiple model filtering framework. The use and fusion of camera vision and LADAR within this frame provide for efficient, effective, and robust tracking of curbs. Extensive experiments conducted in a campus road network demonstrate the viability, effectiveness, and robustness of the proposed method [J192]

"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 [J193]

"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 [J194]

"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 [J195]

"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 [J196]

"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 [J197]

"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 [J198]

"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 [J199]

"Doppler visibility of coherent ultrawideband random noise radar systems"

Random noise radar has recently been used in a variety of imaging and surveillance applications. These systems can be made phase coherent using the technique of heterodyne correlation. Phase coherence has been exploited to measure Doppler and thereby the velocity of moving targets. The Doppler visibility, i.e., the ability to extract Doppler information over the inherent clutter spectra, is constrained by system parameters, especially the phase noise generated by microwave components. Our paper proposes a new phase noise model for the heterodyne mixer as applicable for ultrawideband (UWB) random noise radar and for the local oscillator in the time domain. The Doppler spectra are simulated by including phase noise contamination effects and compared with our previous experimental results. A genetic algorithm (GA) optimization routine is applied to synthesize the effects of a variety of parameter combinations to derive a suitable empirical formula for estimating the Doppler visibility in dB. According to the phase noise analysis and the simulation results, the Doppler visibility of UWB random noise radar depends primarily on the following parameters: 1) the local oscillator (LO) drive level of the receiver heterodyne mixer, 2) the saturation current in the receiver heterodyne mixer, 3) the bandwidth of the transmit noise source, and 4) the target velocity. Other parameters such as the carrier frequency of the receiver LO and the loaded quality factor of the LO have a small effect over the range of applicability of the model and are therefore neglected in the model formulation. The Doppler visibility curves generated from this formula match the simulation results very well over the applicable parameter range within 1 dB. Our model may therefore be used to quickly estimate the Doppler visibility of random UWB noise radars for trade-off analysis [J200]

"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 [J201]

"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 [J202]

"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 [J203]

"Maximum Likelihood Estimation of Compound-Gaussian Clutter and Target Parameters"

Compound-Gaussian models are used in radar signal processing to describe heavy-tailed clutter distributions. The important problems in compound-Gaussian clutter modeling are choosing the texture distribution, and estimating its parameters. Many texture distributions have been studied, and their parameters are typically estimated using statistically suboptimal approaches. We develop maximum likelihood (ML) methods for jointly estimating the target and clutter parameters in compound-Gaussian clutter using radar array measurements. In particular, we estimate i) the complex target amplitudes, ii) a spatial and temporal covariance matrix of the speckle component, and iii) texture distribution parameters. Parameter-expanded expectation-maximization (PX-EM) algorithms are developed to compute the ML estimates of the unknown parameters. We also derived the Cramer-Rao bounds (CRBs) and related bounds for these parameters. We first derive general CRB expressions under an arbitrary texture model then simplify them for specific texture distributions. We consider the widely used gamma texture model, and propose an inverse-gamma texture model, leading to a complex multivariate t clutter distribution and closed-form expressions of the CRB. We study the performance of the proposed methods via numerical simulations [J204]

"Wideband Extended Range-Doppler Imaging and Waveform Design in the Presence of Clutter and Noise"

This paper presents a group-theoretic approach to address the wideband extended range-Doppler target imaging and design of clutter rejecting waveforms. An exact imaging method based on the inverse Fourier transform of the affine group is presented. A Wiener filter is designed in the affine group Fourier transform domain to minimize wideband clutter range-Doppler reflectivity. The Wiener filter is then used to form an operator to precondition transmitted waveforms to reject clutter. Alternatively, the imaging and clutter rejection methods are equivalently re-expressed to perform clutter suppression upon reception. These methods are coupled with noise suppression upon reception. Numerical simulations are performed to demonstrate the performance of the proposed approach. Our study shows that the framework introduced in this paper can address the joint design of receive and transmit processing, design of clutter rejecting waveforms, suppression of noise, and reduction of computational complexity in receive processing [J205]

"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 [J206]

"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 [J207]

"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 [J208]

"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 [J209]

"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. [J210]

"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. [J211]

"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. [J212]

"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. [J213]

"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. [J214]

"Networked sensor management and data rate control for tracking maneuvering targets"

This paper presents sensor and data rate control algorithms for tracking maneuvering targets. The manuevering target is modeled as a jump Markov linear system. We present novel extensions of the Interacting Multiple Model (IMM), Particle filter tracker, and Probabilistic Data Association (PDA) algorithms to handle sensor and data rate control. Numerical studies illustrate the performance of these sensor and data rate control algorithms. [J215]

"Radar: the evolution since World War II"

Modern radar design has benefited from the evolution of specialized digital processing, allowing high resolution ground mapping, target identification, and target tracking under many conditions. Air-to-air interception makes use of complex decision processes to select from many modes that depend on the clutter backgrounds and flight profiles. Today's multimode radars provide this information for each task while minimizing distractions. Fire control radars support a wide selection of weapons, including cannons and guided missiles. This is possible because of advanced digital processing. In the interval since WW II, radar design evolved from vacuum tubes to semiconductors and then to massively integrated circuits. Computers specialized for fast Fourier transforms (FFTs) have revolutionized radar data processing. System reliability has improved from a few hours to hundreds of hours. Effective built-in test informs ground maintenance personnel of problems for easy maintenance and low failure rates reduce or eliminate field maintenance benches at forward locations. Airborne surveillance radars, such as AW ACS Joint Stars have changed the nature of warfare. Commanders have virtually full view of enemy and friendly forces. Radars, in combination with other remote sensors, provide precise weapon delivery, reducing collateral damage and making all weapons more effective [J216]

"Numerical Simulation of the Doppler spectrum of a flying target above dynamic oceanic surface by using the FEM-DDM method"

To study the Doppler (DP) spectrum of a flying target above dynamic oceanic surface, a two-level quasi-stationary algorithm (TLQSA) of the finite element method (FEM) with domain decomposition (DDM) is developed. The DP spectrum of a fast-moving target requires small time-sampling rate. At most time steps, scattering from the flying target is solved by the FEM solution in only one subdomain. Meanwhile, the interactions between the target and rough sea surface in other subdomains are obtained by solving the global DDM coupling matrices. The slowly moving sea surface is evolved at a larger time step and the DP of oceanic clutter is obtained through all-subdomain FEM calculation. Numerical simulations of the DP spectrum from a target flying above dynamic oceanic surface with and without the presence of a ship-like object are obtained. The functional dependence of the DP spectrum in both the time and frequency domains upon sea surface wind speed, target altitude, observation angle, etc., are demonstrated and discussed. [J217]

"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. [J218]

"Evaluation of ionospheric sporadic-E clutter in an arctic environment for the assessment of high-frequency surface-wave radar surveillance"

This paper studies the Arctic ionospheric environment using ionosonde data and assesses the potential of high-frequency surface-wave radar (HFSWR) surveillance for surface vessels and low-altitute air targets. The evaluation is based on sporadic-E (Es) interference in the HFSWR signal. For surveillance problems up to 150 km, such as in the Northwest Passage through Canada's Arctic islands, the ionospheric Es clutter is the dominant clutter that may degrade the performance of the future HFSWR systems. The results show that Es occurs least often at Eureka in winter and at Resolute Bay in summer. Generally, Es occurs less often in the Arctic than at midlatitudes. Observations also suggest that the best time to perform HFSWR surveillance in the Arctic is between approximately 07:00-15:00 UT and 21:00-24:00 UT. During these hours, the number of days that Es interference occurs in a month and the range of frequencies (in the 4-7 MHz range) reflected are minimized compared to other times of the day. These observations suggest that the future HFSWR systems in the Northwest Passage should be designed to operate at higher radio frequencies. For example, a radio frequency higher than 7 MHz can be operated in order to minimize the Es interference during the hours of 07:00-15:00 UT and 21:00-24:00 UT. It is concluded that the Es interference in the HFSWR signal in the Arctic can be equal to or less than that at midlatitudes (e.g., off the east coast of Newfoundland). Furthermore, the overall performance of HFSWR will be better in the Arctic than at midlatitudes due to lower levels of interference of sea clutter and man-made-related noises combined with a much better level of HFSWR propagation. [J219]

"Velocity estimation of fast moving targets using a single SAR sensor"

A new methodology is presented to retrieve slant-range velocity estimates of moving targets inducing Doppler-shifts beyond the Nyquist limit determined by the pulse repetition frequency (PRF). The proposed approach exploits the linear dependence (not subject to PRF limitations) of the Doppler-shift with respect to the slant-range velocity, at each wavelength. Basically, we propose an algorithm to compute the skew of the two-dimensional spectral signature of a moving target. Distinctive features of this algorithm are its ability to cope with strong range migration and its efficiency from the computational point of view. By combining the developed scheme to retrieve the slant-range velocity with a methodology proposed earlier to estimate the velocity vector magnitude, the full velocity vector is unambiguously retrieved without increasing the mission PRF. The method gives effective results even when the returned echoes of the moving targets and the static ground overlap completely, provided that the moving targets signatures are digitally spotlighted and the signal-to-clutter ratio (SCR) is, roughly, greater than 14 dB. The effectiveness of the method is illustrated with simulated and real data. As an example, slant-range velocities of moving objects with velocities between 6 and 12 times the Nyquist velocity are estimated with accuracy better than 3%. [J220]

"Multisensor tracking of a maneuvering target in clutter using IMMPDA filtering with simultaneous measurement update"

We present a (suboptimal) filtering algorithm for tracking a highly maneuvering target in a cluttered environment using multiple sensors. The filtering algorithm is developed by applying the basic interacting multiple model (IMM) approach and the probabilistic data association (PDA) technique to a two sensor (radar and infrared, for instance) problem for state estimation for the target. A simultaneous measurement update approach is followed where the raw sensor measurements are passed to a central processor and fed directly to the target tracker. A multisensor PDA filter is developed for parallel sensor processing for target tracking under clutter. A past approach using parallel sensor processing has ignored certain data association probabilities leading to an inaccurate implementation. Another existing approach applies only to nonmaneuvering targets. The algorithm is illustrated via a highly maneuvering target tracking simulation example where two sensors, a radar and an infrared sensor, are used. Compared with an existing IMM/PDA filtering algorithm with sequential sensor processing, the proposed algorithm achieves significant improvement in the accuracy of track estimation. [J221]

"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. [J222]

"Robust separation of background and target signals in radar cross section measurements"

Coherent measurements of radar cross-section on a target moving along the system line-of-sight in free space will trace a circle centered on the origin of the complex (I,Q) plane. The presence of additional complex background signals (including stationary clutter, target support, and averaged target-mount interactions), which do not depend on target position, will translate the origin of the circle to some complex point (I0,Q0). The presence of outliers (mostly due to radio-frequency interference) can introduce significant errors in the determination of the radius and center of the I-Q circle. We have implemented a combination of a robust and efficient least median square and an orthogonal-distance regression algorithm to eliminate or to reduce the influence of outliers, and then to separate the target and background signals. Concurrently, the influence of noise is also reduced. Thus, we can obtain both target-independent estimates of the background and a background-free estimates of the radar cross-sections of calibration artifacts. In measurements on low-observable targets, the subtraction of the background signal from the measurement and calibration significantly improves the measurement accuracy. This technique is especially useful for subwavelength translations at very and ultra-high-frequencies, where spectral techniques are not applicable because the available arc of data is limited. [J223]

"Dynamic Cramer-Rao bound for target tracking in clutter"

Recently, there have been several new results for an old topic, the Cramer-Rao lower bound (CRLB). Specifically, it has been shown that for a wide class of parameter estimation problems (e.g. for objects with deterministic dynamics) the matrix CRLB, with both measurement origin uncertainty (i.e., in the presence of false alarms or random clutter) and measurement noise, is simply that without measurement origin uncertainty times a scalar information reduction factor (IRF). Conversely, there has arisen a neat expression for the CRLB for state estimation of a stochastic dynamic nonlinear system (i.e., objects with a stochastic motion); but this is only valid without measurement origin uncertainty. The present paper can be considered a marriage of the two topics: the clever Riccati-like form from the latter is preserved, but it includes the IRF from the former. The effects of plant and observation dynamics on the CRLB are explored. Further, the CRLB is compared via simulation to two common target tracking algorithms, the probabilistic data association filter (PDAF) and the multiframe (N-D) assignment algorithm. [J224]

"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. [J225]

"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. [J226]

"Sequential Monte Carlo framework for extended object tracking"

The authors consider the problem of extended object tracking. An extended object is modelled as a set of point features in a target reference frame. The dynamics of the extended object are formulated in terms of the translation and rotation of the target reference frame relative to a fixed reference frame. This leads to realistic, yet simple, models for the object motion. It is assumed that the measurements of the point features are unlabelled, and contaminated with a high level of clutter, leading to measurement association uncertainty. Marginalising over all the association hypotheses may be computationally prohibitive for realistic numbers of point features and clutter measurements. The authors present an alternative approach within the context of particle filtering, where they augment the state with the unknown association hypothesis, and sample candidate values from an efficiently designed proposal distribution. This proposal elegantly captures the notion of a soft gating function. The performance of the algorithm is demonstrated on a challenging synthetic tracking problem, where the ground truth is known, in order to compare between different algorithms. [J227]

"Bayesian multiple target tracking in forward scan sonar images using the PHD filter"

A multiple target tracking algorithm for forward-looking sonar images is presented. The algorithm will track a variable number of targets estimating both the number of targets and their locations. Targets are tracked from range and bearing measurements by estimating the first-order statistical moment of the multitarget probability distribution called the probability hypothesis density (PHD). The recursive estimation of the PHD is much less computationally expensive than estimating the joint multitarget probability distribution. Results are presented showing a variable number of targets being tracked with targets entering and leaving the field of view. An initial implementation is shown to work on a simulated sonar trajectory and an example is shown working on real data with clutter. [J228]

"Spatial distribution model for tracking extended objects"

A Bayesian filter has been developed for tracking an extended object in clutter based on two simple axioms: (i) the numbers of received target and clutter measurements in a frame are Poisson distributed (so several measurements may originate from the target) and (ii) target extent is modelled by a spatial probability distribution and each target-related measurement is an independent 'random draw' from this spatial distribution (convolved with a sensor model). Diffuse spatial models of target extent are of particular interest. This model is especially suitable for a particle filter implementation, and examples are presented for a Gaussian mixture model and for a uniform stick target convolved with a Gaussian error. A rather restrictive special case that admits a solution in the form of a multiple hypothesis Kalman filter is also discussed and demonstrated. [J229]

"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). [J230]

"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. [J231]

"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. [J232]

"Automatic target classification of slow moving ground targets in clutter"

A new approach is proposed which will allow air-to-ground target classification of slow moving vehicles in clutter. A wideband space-time adaptive (STAP) filter architecture, based on subbanding, is developed and coupled with a one dimensional template-based minimum mean squared error (MMSE) classifier. The performance of this STAP/ATC (automatic target classification) algorithm is quantified using an extensive simulation. The level of residual clutter afforded by various filter configurations and the associated incremental improvement in ATC performance is quantified, revealing the potential for realizable hardware and software implementations to achieve acceptable ATC performance. [J233]

"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. [J234]

"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. [J235]

"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. [J236]

"Numerical simulation of bistatic scattering from a target at low altitude above rough sea surface under an EM-wave incidence at low grazing angle by using the finite element method"

To study bistatic scattering from a target at low altitude above two-dimensional (2-D) randomly rough sea surface under an electromagnetic (EM) wave incidence at low grazing angle (LGA), a numerical approach of the finite element method (FEM) is developed. The conformal perfectly matched layer (PML), as the truncation boundary of the FEM, is employed to reduce the reflection error of planar PML in conventional FEM. Numerical code of our FEM is examined by available solution of the FBM (forward backward iterative) method. Bistatic and back-scattering from composite model of a target above randomly rough sea surface generated by Monte Carlo realization, and functional dependence upon the sea surface wind speed, target altitude, incident and scattering angles etc. are numerically demonstrated and discussed. This study presents numerical description for the observation principle and physical insight associated with the coupling interactions of a complex volumetric target and randomly rough sea surface. [J237]

"Millimeter-Wave Radar Targets and Clutter [JBook Review]"

{no data available} [J238]

"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. [J239]

"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. [J240]

"Multiple hypothesis tracking for multiple target tracking"

Multiple hypothesis tracking (MHT) is generally accepted as the preferred method for solving the data

association problem in modern multiple target tracking (MTT) systems. This paper summarizes the motivations for MHT, the basic principles behind MHT and the alternative implementations in common use. It discusses the manner in which the multiple data association hypotheses formed by MHT can be combined with multiple filter models, such as used by the interacting multiple model (IMM) method. An overview of the studies that show the advantages of MHT over the conventional single hypothesis approach is given. Important current applications and areas of future research and development for MHT are discussed. [J241]

"A STAP overview"

This tutorial provides a brief overview of space-time adaptive processing (STAP) for radar applications. We discuss space-time signal diversity and various forms of the adaptive processor, including reduced-dimension and reduced-rank STAP approaches. Additionally, we describe the space-time properties of ground clutter and noise-jamming, as well as essential STAP performance metrics. We conclude this tutorial with an overview of some current STAP topics: space-based radar, bistatic STAP, knowledge-aided STAP, multi-channel synthetic aperture radar and non-sidelooking array configurations. [J242]

"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. [J243]

"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. [J244]

"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. [J245]

"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. [J246]

"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. [J247]

"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. [J248]

"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. [J249]

"Novel multiple phase centre reflector antenna for GMTI radar"

Adaptive cancellation of stationary clutter for a ground moving target indicator (GMTI) radar requires antenna sensing using multiple apertures. In essence, simultaneous independent observations of the target plus clutter are required. Conventionally, multiple antenna apertures can be achieved through the use of physically separated antennas, or antennas which can be controlled so that subsections are used to receive. Herein, the use of reflector antennas to effect multiple phase centres is described. Multiple feedhorns pointed laterally from the focal point of the reflector are first reviewed, with capabilities and limitations discussed. A new technique for achieving multiple phase centres with a reflector antenna is then introduced. This technique is based on the excitation and combination of TE and/or TM modes from a single antenna feedhorn. It is shown that, by proper combination of multiple TE modes from a single feedhorn, radiation patterns with separate phase centres can be produced from the same reflector. TE and TM modes can also be combined to effect the same, but this is omitted for brevity. The characteristics of the resulting radiation patterns are analysed with a view towards maximising the separation of the antenna phase centres while maintaining symmetry between the patterns and minimising the reduction in gain and constant phase beamwidth with respect to the reflector's conventional radiation pattern. [J250]

"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. [J251]

"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. [J252]

"Three-dimensional SAR imaging of a ground moving target using the InISAR technique"

In this paper, a three-dimensional (3-D) interferometric synthetic aperture radar (ISAR) imaging method for moving targets is presented. This imaging method is based on the ISAR principle and the simple observation that all scatterers on a moving target move in tandem. The angular motion parameters in the cross-range directions could be estimated using the overall range profile of the moving target. Registration of the respective complex images at the two (or more) interferometric antennas can then be achieved via compensating the respective echoes at the raw data level, thus avoiding phase-unwrapping processing and image-resampling processing as required by conventional methods. Finally, a 3-D image of the moving target can then be reconstructed from the 3-D spatial coordinates of these scatterers. Furthermore, the method works well even for a target moving in heavily cluttered environments. [J253]

"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. [J254]

"Azimuth positioning of moving targets in two-channel SAR by direction-of-arrival estimation"

Many present and future SAR systems that are also intended to measure and monitor moving objects on the ground will be restricted to only two parallel antenna apertures owing to the enormous costs involved for extra receiver channels. This is particularly true for space-based systems, such as RADARSAT-2 and TerraSAR-X. Classical techniques to simultaneously detect moving targets by rejecting the superimposed clutter and to estimate their correct locations subsequently via direction-of-arrival (DoA) estimates cannot be applied owing to the dual-receiver limitation. Proposed is an alternative method to retrieve clutter-suppressed target signals in the individual channels that allow the application of DoA-estimation and verifies its feasibility with measured airborne SAR data. [J255]

"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. [J256]

"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. [J257]

"Parametric autofocus of SAR imaging-inherent accuracy limitations and realization"

In synthetic aperture radar (SAR) imaging, low scene contrast may degrade the performance of most of the existing autofocus methods. In this paper, by dividing a slow-time signal into three isolated components, namely target, clutter, and noise, in SAR imaging, a novel parametric statistical model is proposed during the coherent processing interval. Based on the model, Cramer-Rao bounds (CRBs) of the estimation of unknown parameters are derived. It is shown that the CRBs of the target parameter estimation strongly depend on the background, i.e., clutter and noise, and the CRBs of the background parameter estimation may be obtained regardless of the target component. Motivated from this result and using the estimated background parameters, a novel effective parametric autofocus method is developed, which is applicable to any scene contrast. In addition, a preprojection is also introduced to simplify the subsequent parameter estimation. Finally, the proposed model and the novel method are illustrated by some real SAR data. [J258]

"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. [J259]

"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. [J260]

"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. [J261]

"Clutter map information for data association and track initialization"

This paper considers the problem of forming and maintaining tracks when measurements have both uncertain origin and are corrupted by additive sensor noise. The spatial clutter measurement density is assumed nonhomogeneous and known. The PPDA-MAP algorithm provides a set of recursive formulae for data association and probability of target existence, thus enabling automatic track initiation, track maintenance, and track termination. New values for initial probability of target existence for IPDA-type algorithm are also derived. Simulation results compare the performance of IPDA-MAP with IPDA, IMM-PDA, IMM-PDA-MAP, EB-PDA and EB-PDA-MAP in a heavy and nonuniform clutter situation. [J262]

"Multisensor resource deployment using posterior Cramer-Rao bounds"

The development of a general framework for the systematic management of multiple sensors in target tracking in the presence of clutter is described. The basis of the technique is to quantify, and subsequently control, the accuracy of target state estimation. The posterior Cramer-Rao lower bound (PCRLB) provides the means of achieving this aim by enabling us to determine a bound on the performance of all unbiased estimators of the unknown target state. The general approach is then to use optimization techniques to control the measurement process in order to achieve accurate target state estimation. We are concerned primarily with the deployment and utilization of limited sensor resources. We also allow for measurement origin uncertainty, with sensor measurements either target-generated or false alarms. An example in which the aim is to track a submarine by deploying a series of constant false-alarm rate passive sonobuoys is presented. We show that by making some standard assumptions, the effect of the measurement origin uncertainty can be expressed as a state-dependent information reduction factor which can be calculated off-line. This enables the Fisher information matrix (FIM) to be calculated quickly, allowing Cramer-Rao bounds to be utilized for real-time, dynamic sensor management. The sensor management framework is shown to determine deployment strategies that enable the target to be accurately localized, and at the same time efficiently utilize the limited sensor resources. [J263]

"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. [J264]

"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. [J265]

"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. [J266]

"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. [J267]

"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. [J268]

"Space-time autoregressive filtering for matched subspace STAP"

Practical space-time adaptive processing (STAP) implementations rely on reduced-dimension processing, using techniques such as principle components or partially adaptive filters. The dimension reduction not only decreases the computational load, it also reduces the sample support required for estimating the interference statistics. This results because the clutter covariance is implicitly assumed to possess a certain (nonparametric) structure. We demonstrate how imposing a parametric structure on the clutter and jamming can lead to a further reduction in both computation and secondary sample support. Our approach, referred to as space-time autoregressive (STAR) filtering, is applied in two steps: first, a structured subspace orthogonal to that in which the clutter and

interference reside is found, and second, a detector matched to this subspace is used to determine whether or not a target is present. Using a realistic simulated data set for circular array STAP, we demonstrate that this approach achieves significantly lower signal-to-interference plus noise ratio (SINR) loss with a computational load that is less than that required by other popular approaches. The STAR algorithm also yields excellent performance with very small secondary sample support, a feature that is particularly attractive for applications involving nonstationary clutter. [J269]

"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. [J270]

"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. [J271]

"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. [J272]

"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. [J273]

"Sequential importance sampling filtering for target tracking in image sequences"

We propose in this letter a new approach to direct target tracking in cluttered image sequences using sequential importance sampling (SIS). We use Gauss-Markov random field modeling to describe the clutter correlation and incorporate the clutter and target signature models into the design of the SIS tracking algorithm. We quantify the performance of the SIS tracker using a simulated image sequence generated from real infrared airborne radar data and compare it to the performance of a grid-based hidden Markov model tracker. Simulation results show good performance for the proposed algorithms in a scenario of very low target-to-clutter ratio. [J274]

"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. [J275]

"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. [J276]

"PDAF with multiple clutter regions and target models"

This paper presents the theory of a new multiple model probabilistic data association filter (PDAF). The analysis is generalized for the case of multiple nonuniform clutter regions within the measurement data that updates each model of the filter. To reduce the possibility of clutter measurements forming established tracks, the solution includes a model for a visible target. That is, a target that gives sensor measurements that satisfy one of the target models. Other features included in the algorithm are the selection of a fixed number of nearest measurements and the addition of signal amplitude to the target state vector. The nonuniform clutter model developed here is applicable to tracking signal amplitude. Performance of this algorithm is illustrated using experimentally recorded over-the-horizon radar (OTHR) data. [J277]

"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. [J278]

"Results of flight tests of a two-channel radar system with real-time MTI processing"

Space-time adaptive processing (STAP) in real-time is discussed for two applications: first, STAP can be used for suppressing clutter and jammers; moreover, clutter filter coefficients gained by STAP can be used for the purpose of the correct positioning of moving targets within SAR images. Results of this real-time STAP technique as well as the results of the moving-target repositioning technique are presented: the clutter-suppression quality

and the moving target repositioning accuracy are demonstrated with real SAR data and moving targets recorded during a measurement campaign. [J279]

"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. [J280]

"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. [J281]

"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. [J282]

"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. [J283]

"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. [J284]

"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 [J285]

"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. [J286]

"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. [J287]

"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 [J288]

"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 [J289]

"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. [J290]

"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. [J291]

"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. [J292]

"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 [J293]

"Median cascaded canceller for robust adaptive array processing"

A median cascaded canceller (MCC) is introduced as a robust multichannel adaptive array processor. Compared with sample matrix inversion (SMI) methods, it is shown to significantly reduce the deleterious effects of impulsive noise spikes (outliers) on convergence performance of metrics; such as (normalized) output residue power and signal to interference-plus-noise ratio (SINR). For the case of no outliers, the MCC convergence performance remains commensurate with SMI methods for several practical interference scenarios. It is shown that the MCC offers natural protection against desired signal (target) cancellation when weight training data contains strong target components. In addition, results are shown for a high-fidelity, simulated, barrage jamming and nonhomogenous clutter environment. Here the MCC is used in a space-time adaptive processing (STAP) configuration for airborne radar interference mitigation. Results indicate the MCC produces a marked SINR performance improvement over SMI methods. [J294]

"Texture and speckle statistics in polarimetric SAR synthesized images"

We investigate in this paper the one-point statistical properties of the backscattered power derived by polarization synthesis of polarimetric synthetic aperture radar (SAR) observations. In particular, we focus our attention on the normalized second moment of intensity and its dependency on the polarization state. For the analysis of this dependency, a novel graphical representation-an extension of the polarization response-is introduced: the polarimetric texture signature. The second moment of backscattered power characterizes statistically the variation of the radar signal due to speckle and the underlying radar cross section. The classical texture product model with a scalar radar reflectivity implies that the normalized second moment of intensity does not depend on the polarization state. However, such dependency is found in experimental observations, a fact that calls for further investigation of the phenomenon. Considering at first speckle statistics for homogeneous areas having no texture, it is demonstrated that correlation among the single-look speckle patterns, which are added on an intensity basis in a multilook operation, is responsible for a weak polarization dependency of the normalized second moment. Concerning the textural properties, a new model is proposed-the mixture model-where it is assumed that polarimetrically diverse scattering mechanisms contribute to the total return from an ensemble of resolution elements. Numerical simulations are used to reconstruct the texture signatures according

to the mixture model, starting from simple assumptions related to scattering processes from natural targets. It is found that the polarimetric texture signature can be an interesting discriminator of weak targets against clutter, when only polarimetric diversity and not radiometric diversity plays a role. The effects predicted by the theory are confirmed by experimental analysis of polarimetric data acquired by the Jet Propulsion Laboratory AIRSAR sensor. Finally a classification scheme based on the polarimetric texture signature is proposed. [J295]

"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 [J296]

"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 [J297]

"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 [J298]

"Development of a Digital Array Radar (DAR)"

Twenty-first century littoral and open-sea missions present US Navy (USN) shipboard-radar systems with the challenge of detecting small targets in severe clutter and against multiple sources of interference. In Fiscal Year 2000 (FY00), the Office of Naval Research (ONR) sponsored a program to develop an active array radar that includes a digital beamforming (DBF) architecture. The DBF radar system has the potential for improved time-energy management, improved signal-to-clutter (S/C) ratios, improved reliability and reduced life-cycle costs. This paper summarizes the latest developments of the program during FY00 [J299]

"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 [J300]

"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 [J301]

"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 [J302]

"Performance complexity study of several approaches to automatic target recognition from SAR images"

A framework which allows for the direct comparison of alternate approaches to automatic target recognition (ATR) from synthetic aperture radar (SAR) images is described and applied to variants of several ATR algorithms. This framework allows comparisons to be made on an even footing while minimizing the impact of implementation details and accounts for variation in image sizes, in angular resolution, and in the sizes of orientation windows used for training. Alternate approaches to ATR are characterized in terms of the best achievable performance as a function of the complexity of the model parameter database. Several approaches to ATR from SAR images are described and the performance achievable by each for a range of database complexities is studied and compared. These approaches are based on a likelihood test under a conditionally Gaussian model, log-magnitude least squared error, and quarter power least squared error. All approaches are evaluated for a wide range of parameterizations and the dependence on these parameters of both the resulting performance and the resulting database complexity is explored. Databases for all of the approaches are trained using identical sets of images and their performance is assessed under identical testing scenarios in terms of probability of correct classification, confusion matrices, and orientation estimation error. The results indicate that the conditionally Gaussian approach outperforms the other two approaches on average for both target recognition and orientation estimation, that accounting for radar power fluctuation improves performance for all three methods, and that the conditionally Gaussian approach normalized for power delivers average performance that is equal or superior to all other considered approaches [J303]

"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 [J304]

"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 [J305]

"Homodyned-K fluctuation model"

The statistics of the matched filter output are examined for the case of a nonfluctuating target in K-type clutter. The resulting "homodyned-K" backscatter model is a generalization of the classic Rayleigh-Rice model and has applications in radar, sonar, optics, and ultrasonic medical imaging. This paper presents exact and asymptotic equations for the probability density function, survival function, moments, and parameter estimation. The exact equations are expressed as infinite series. Also provided are proof of the series' convergence and guidance for their numerical computation. Examples illustrating the model's application to radar and sonar are presented using electromagnetic and acoustic backscatter data. [J306]

"SPRI: simulator of polarimetric radar images"

Simulator of polarimetric radar images (SPRI) consists of a suite of image processing programs for producing realistic millimeter-wave (MMW) radar images artificially on a workstation. The heart of the simulation approach is a polarimetric Rayleigh clutter simulator coupled to a clutter database. The simulator produces high resolution single-look polarimetric images. Hard targets can then be embedded into this clutter map, and the resultant image can be degraded in resolution, number of looks, polarization, etc. to match that which would be observed by a real sensor. Examples of simulated images, and comparisons of these simulations to actual images, are presented. The MMW Clutter Database is the most comprehensive to-date database of over 3500 Mueller matrices for many kinds of terrestrial clutter measured at 35 and 95 GHz, many of which are at incidence angles close to grazing. The database can be accessed via a World Wide Web flexible interface that enables data to be combined in new and unique ways specified by the user, and displayed in either tabular or graphical format. The structure and access procedure to the database are described [J307]

"Principal components, covariance matrix tapers, and the subspace leakage problem"

A new class of robust space-time adaptive beamforming techniques is introduced to address a broad range of subspace leakage phenomena that arise in many sensor array applications. When present, these leakage phenomena can significantly increase the effective rank of the dominant colored noise interference spectrum, thereby reducing the appeal of techniques that exploit low-rank dominant interference (such as principal components (PC) or diagonal loading) to reduce sample support (training) requirements. By combining the covariance matrix taper (CMT) approach with either PC or diagonal loading, the minimal sample support properties of these techniques can be preserved [J308]

"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 [J309]

"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 [J310]

"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 [J311]

"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 [J312]

"Measured and predicted synthetic aperture radar target comparison"

The DARPA Image Understanding program publicly released measured and predicted synthetic aperture radar (SAR) targets were compared by means of correlation. The training set consisted of three classes (BMP-2, T-72, and BTR-70) at 17 deg depression and 233 azimuths. The test set consisting of seven different serial-numbered targets at 15 deg depression was tested at 196 azimuths. After segmentation and normalization, each test image was correlated with all the training images to generate correlation and classification statistics. Measured correlation scores were higher and more consistent for same serial number training than variant training. The average in-class (0.837) and between-class (0.734) means for measured correlations were higher than both the average in-class (0.707) and between-class (0.675) means for predicted correlations; however, the corresponding variances for in-class (0.056) and between-class (0.048) predicted correlations were higher than in-class (0.026) and between-class (0.036) measured variances. The measured training data declared the target correctly almost 100% of the time; the T-72 and BTR-70 model-predicted data declared the target correctly 80% of the time. The correlation scores varied approximately sinusoidally with aspect. Correlation plots between a single orientation target and the entire training sets showed that a target was highly correlated at both the correct aspect angle and the correct angle rotated 180 deg [J313]

"A new method to separate ground clutter and atmospheric reflections in the case of similar Doppler velocities"

This paper introduces a new ground clutter suppression technique which preserves weather echoes. This clutter suppression method uses both statistical and polarimetric properties of the target and clutter. This technique is intended for use in atmospheric studies for weather echoes the spectral properties of which do not differ much from those of ground clutter. This technique can be applied both to the total signal or to its separate Doppler frequency components [J314]

"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 [J315]

"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 [J316]

"Spiky sea clutter at high range resolutions and very low grazing angles"

X-band (9.5-10.0 GHz) backscatter at near grazing incidence (0.2 deg) from the sea off the coast of Kauai, Hawaii, was measured with a radar characterized by a high spatial resolution in range (0.3 m) and a high temporal resolution (2000 Hz pulse repetition frequency (PRF)). Extensive amounts (over 20 min per measurement) of vertically and horizontally polarized sea clutter data were taken with upwind (UP) and crosswind (CR) transmit geometries during the collection campaign. Specific but representative examples of the clutter were statistically and phenomenologically analyzed over time scales varying from long (200 s), to intermediate (5 s), to short (50 ms), and over range swaths varying from full (160 m), to partial (30 m), to a single range cell (0.3 m). All analyses and results presented here are noncoherent, involving only the clutter amplitudes. Each type of clutter exhibited the characteristic spiky behavior which has come to be expected from microwave sea backscatter observed at low grazing angles and high range resolutions, while showing, between themselves, marked transmit geometry and polarization dependent contrasts, with the horizontally polarized clutter, measured with an UP transmit geometry, being especially notable for its frequently occurring, significant high frequency spectral content. Within the same clutter type, differences were observed in the probability distributions of radar cross sections (RCS) of spatially and temporally extended spiking events [J317]

"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). [J318]

"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. [J319]

"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. [J320]

"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. [J321]

"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. [J322]

"Angular mean and variance for selected two-source radar-target combinations"

Angle tracking of the desired target in the presence of interference is a common radar problem. It can occur when the desired target is competing with a jammer, clutter, or multipath. Angle statistics can vary significantly for a tracking radar depending upon the nature of this interference. The angular mean and variance are presented for three different statistical two-target types for single and multiple measurements. Previously derived values are presented for completeness in conjunction with derivations not found in the open literature. The signal-to-noise ratio is assumed to be large so that the effects of receiver noise may be neglected. [J323]

"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. [J324]

"Gating techniques for maneuvering target tracking in clutter"

Gating techniques for maneuvering target tracking using an IMM-PDA filter are considered in this paper. Existing gating techniques, namely, centralized gating and model based gating are reviewed and new gating techniques, called model probability weighted gating and two-stage model probability weighted gating, are proposed. A benchmark trajectory and a random scenario are considered for performance evaluation of the gating techniques in terms of RMS errors, percentage of track loss and computational load. [J325]

"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. [J326]

"Minimal sample support space-time adaptive processing with fast subspace techniques"

The authors investigate finite data support for subspace or projection methods for STAP which are robust against strong clutter returns. A theoretical analysis of the eigenvector projection technique is presented that provides insight into the problem of determining the optimum choice of the projected clutter subspace and matched filter adjustments (with respect to target Doppler frequency). An estimator of the optimum subspace dimension, which is significantly smaller than clutter rank, as a function of the number of samples is presented. This result, combined with a previously proposed near-optimal eigenvector-free projection techniques with minimal sample support, reduce the computational burden so drastically that even fully adaptive optimum STAP with large degrees of freedom may become practical for real-time applications. [J327]

"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. [J328]

"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. [J329]

"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. [J330]

"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. [J331]

"Low altitude target model for radar simulation"

A simulation model of antenna array signals from a low altitude target is considered. Explicit expressions for statistical and spectral characteristics of the scattered signals are obtained in the Kirchhoff approximation. The model permits to evaluate the efficiency of different techniques of low altitude target tracking. It benefits the comprehension of the influence of multipath propagation on tracking radars [J332]

"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 [J333]

"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. [J334]

"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. [J335]

"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 [J336]

"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. [J337]

"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. [J338]

"Focused synthetic aperture radar processing of ice-sounder data collected over the Greenland ice sheet"

The authors developed a synthetic aperture radar (SAR) processing algorithm for airborne/spaceborne ice-sounding radar systems and applied it to data collected in Greenland. By using focused SAR (phase-corrected coherent averaging), they improved along-track resolution by a factor of four and provided a 6-dB processing gain over unfocused SAR (coherent averaging without phase correction) based on a point-target analysis for a Greenland ice-sounding data set. Also, They demonstrated that the focused-SAR processing reduced clutter and enabled them to identify bedrock-interface returns buried in clutter. Using focused-SAR technique, they processed data collected over a key 360-km-long portion of the 2000-m contour line of southwest Greenland. To the best of their knowledge, these are the first high-quality radar ice thickness measurements over this key location. Moreover, these ice-thickness measurements have been used for improving mass-balance estimates of the Greenland ice sheet [J339]

"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 [J340]

"New data association method for automotive radar tracking"

An improved multi-target data association method for automotive radar is presented. The new approach is

formulated using the association probabilities of the joint probabilistic data association (JPDA) filter. An optimal track-to-measurement data association is accomplished using the decision logic algorithm. Simulation results in heavily cluttered conditions show that the tracking accuracy of the proposed method is about 19% better than that of the JPDA filter [J341]

"Predicting an upper bound on SAR ATR performance"

We present a method for predicting a tight upper bound on performance of a vote-based approach for automatic target recognition (ATR) in synthetic aperture radar (SAR) images. In such an approach, each model target is represented by a set of SAR views, and both model and data views are represented by locations of scattering centers. The proposed method considers data distortion factors such as uncertainty, occlusion, and clutter, as well as model factors such as structural similarity. Firstly, we calculate a measure of the similarity between a given model view and each view in the model set, as a function of the relative transformation between them. Secondly we select a subset of possible erroneous hypotheses that correspond to peaks in similarity functions obtained in the first step. Thirdly, we determine an upper bound on the probability of correct recognition by computing the probability that every selected hypothesis gets less votes than those for the model view under consideration. The proposed method is validated using MSTAR public SAR data, which are obtained under different depression angles, configurations, and articulations [J342]

"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 [J343]

"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 [J344]

"Multiple moving target feature extraction for airborne HRR radar"

This study considers the clutter suppression and feature extraction of multiple moving targets for airborne high range resolution (HRR) phased array radar. To avoid the range migration problems that occur in the HRR radar data, we divide each HRR profile into nonoverlapping low range resolution segments. No information is lost due to the division and hence no loss of resolution occurs. We show how to use a vector auto-regressive filtering technique to suppress the clutter. Then a relaxation-based parameter estimation algorithm is presented for multiple moving target feature extraction. Numerical results are given to demonstrate the effectiveness of the algorithm [J345]

"Analysis of multiplicative speckle models for template-based SAR ATR"

It has been noted that signal aperture radar (SAR) imagery of clutter exhibits Rayleigh multiplicative noise due to speckle. We use a database of MSTAR target chips to verify that the noise is multiplicative rather than additive for all regions in the chip. Then, by examining histograms corresponding to the noise residuals, we show that a Weibull distribution that is almost Rayleigh best fits the data. However, when we restrict the analysis over the target region, the log-normal and Rayleigh models fit the noise equally as well. This can be attributed to scattering mechanisms that are unstable over five degrees of aspect angle [J346]

"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 [J347]

"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 [J348]

"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 [J349]

"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 [J350]

"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 [J351]

"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 [J352]

"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 [J353]

"Fundamentals of multisite radar systems: multistatic radars and multiradar systems [JBook Review]"

First Page of the Article [J354]

"Simulator for advanced fighter radar EPM development"

In order to develop electronic protection measures (EPM) for airborne intercept radars, it is necessary to fully understand the often complex effects of different types of electronic countermeasure (ECM) techniques on the radar operation. To aid in this effort, a software-based high-fidelity simulator called SAFIRE has been developed. SAFIRE models target clutter and ECM signal returns on a pulse-by-pulse basis for arbitrarily long scenario durations. Conventional air-to-air processing modes that are typically used in airborne intercept radars for search and track functions are also modelled. The capabilities of SAFIRE are described, with particular emphasis on the ECM model. The ECM model is based on a modern coherent jammer which uses digital radio frequency memory (DRFM) technology to generate false targets and “smart” noise for sophisticated ECM techniques. Sample results from SAFIRE are presented to illustrate its utility in analysing the effects of such ECM techniques on the radar processing. Benchmark timing results for SAFIRE code execution are also provided, which indicate that for many jamming scenarios of interest, the code execution is only about five times slower than real time. This is a significant feature since the scenario durations that are required for these studies are often relatively long [J355]

"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 [J356]

"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 [J357]

"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 [J358]

"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 [J359]

"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 [J360]

"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 [J361]

"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 [J362]

"Extraction of moving ground targets by a bistatic ultra-wideband SAR"

The use of a bistatic antenna configuration for ground moving target indication in an ultra-wideband and widebeam synthetic aperture radar system is discussed. To suppress the strong clutter signal the radar channels have a strict requirement on equality. In a bistatic system they are not equal, and the author investigates how to compensate for the bistatic configuration. Bistatic effects on clutter scattering cannot be compensated, and an attempt is therefore made to estimate the bistatic scattering influence of the ground moving target indication. The bistatic to monostatic synthetic aperture inversion in a wide antenna beam is derived in both the time and the frequency domain. The mismatch between the radar channels will cause clutter leakage. The pulse compressed impulse response leakage is determined both for the time and frequency domains [J363]

"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 [J364]

"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 [J365]

"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 [J366]

"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 [J367]

"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 [J368]

"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 [J369]

"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 [J370]

"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 [J371]

"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 [J372]

"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 [J373]

"An automatic identification of clutter and anomalous propagation in polarization-diversity weather radar data using neural networks"

Radar polarization measurements have mostly been used to improve rainfall estimation and hydrometeor characterization. The authors extend the use of such measurements to the problem of ground clutter recognition, including the case when this problem is associated with anomalous propagation of the electromagnetic wave. They present a methodology used for recognizing both clutter and meteorological targets. The methodology is based on the knowledge of the scattering properties of the targets, as provided by the polarization measurements and the use of the neural network approach that performs the classification. The results show that if circular polarization is used, the circular depolarization ratio and the degree of polarization are good discriminators of clutter and nonclutter. They have used data from the Alberta polarization diversity radar to build an automatic decision process using a feedforward neural network. After they trained the neural network, they tested the classifier for two common clutter situations: when there is an electromagnetic wave anomalous propagation and when targets from rain are mixed with the clutter close to the radar [J374]

"FPGA-based adaptive tracking estimation computer"

We describe an FPGA-based adaptive tracking estimation computer (FATEC) for a multiple target tracking (MTT) radar system. Its design is centered around a small processor core customized according to the requirements of tracking application, to run the main control program and provide software flexibility, with a number of tracking algorithms (models) implemented in hardware-type functional units, in order to meet the timing requirements of the application. The FATEC approach provides combination of software flexibility, hardware efficiency, and functional adaptivity of implementation of application-specific computers for the other applications of a similar type, enabling various partitioning options between the software and the hardware parts of the solution [J375]

""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. [J376]

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