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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 8-1

“Radar Target Identification”
(«Идентификация РЛ целей»)

Журнальные публикации

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

The extinction pulse (E-Pulse) technique has been widely applied to problems involving radar target identification. In this paper a fast approximate target detection and recognition scheme based on the E-Pulse technique is proposed and applied to a subsurface target detection and recognition scenario. Previous studies have demonstrated that the target resonances for subsurface targets are closely related to the target resonances for a target within a homogenous environment. In the proposed method, the target resonance for the target in the homogenous medium will be used to construct the E-Pulse for target detection and recognition purposes. The details of the proposed method will be described in this paper. The obvious example of a target below a dielectric halfspace is the use of ground penetrating radar (GPR) for detecting and recognizing unexploded ordnance (UXO). However, instead of a GPR related scenario, a numerical example of a biomedically related problem, of a hip prosthesis model sited within a halfspace of homogenous human tissue model with realistic dielectric properties will be used to demonstrate the feasibilities of the proposed technique for target detection and recognition. The reasons for the choice of this particular example will also be explained in the paper. [J1]

"Ultra-wideband cognitive interrogator network: adaptive illumination with active sensors for target localisation"

The authors explore the potential application of cognitive interrogator network (COIN) in remote monitoring of mobile subjects in domestic environments, where the ultra-wideband radio frequency identification (UWB-RFID) technique is considered for accurate target localisation. The authors first present the COIN architecture in which the central base station (BS) continuously and intelligently customises the illumination modes of the distributed interrogators in response to the system's changing knowledge of the channel condition and subject movement. Subsequently, the analytical results of the locating probability and time-of-arrival (TOA) estimation uncertainty for a large-scale COIN with randomly distributed active sensors are derived based upon the implemented cognitive intelligence. As an important component to facilitate the adaptive illumination of the environment, the sequential-hypothesis-testing framework is proposed to estimate the tag antenna orientation. Finally, numerical examples are used to demonstrate the key effects of the proposed cognitive schemes on the system performance. [J2]

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

This paper studies the polarimetric-dispersion properties of urban targets and their evolution along time in terms of the geometrical configuration. The relations between target geometry and the scattering behavior have been defined through the analysis of large stacks of simulated images. Scattering maps and synthetic aperture radar (SAR) images have been synthesized with the numerical tool GRaphical Electromagnetic COmputing SAR for different qualitative models of two real buildings. Ground-based SAR (GB-SAR) data acquired in a subsidence measurement campaign has been used to assess the simulator's realism. These data have permitted the identification of the critical simulation parameters and their range of recommended values for realistic simulations. In the context of very high resolution images, the results derived from this study may be crucial for making progress in urban-image postprocessing. As the different resolution cells comprise few scattering centers showing a quasi-deterministic scattering behavior, nonprobabilistic models based on target's geometry seem more suited for scattering modeling. In these models, the geometry-scattering (GS) links precisely inferred from simulated images can be very important. In addition to change detection and land classification, GS models may help in improving the interpretation of subsidence results with differential interferometry. Certainly, new processing algorithms can be developed exploiting the available scattering data with more physical sense. In addition, they can take more advantage of the fine resolution and polarimetric capabilities of the new sensors, like TerraSAR-X or RADARSAT-2. [J3]

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

Imaging an avian target by inverse synthesis aperture radar (ISAR) is a novel and important technological approach of solving the problem of avian detection. However, the ISAR images of birds obtained with the conventional range-Doppler algorithm could be contaminated due to serious micro-Doppler effects, which are generated by the birds' flapping wings. In this letter, a novel imaging method of birds is proposed, which is simple to comprehend and operate, and avoids lots of complications and computation burdens. In the method, the moving status of bird is identified first via finding the variety of moving average values of the cross-correlation coefficient of the adjacent high-resolution range profiles. The usage of moving average values is attributed to the characters of the bird's flapping. The parts of respective flapping spectrogram can then be eliminated, and the parts of the residual spectrogram, i.e., the respective gliding spectrogram, can be connected to prepare for the cross-compression. In this letter, the minimum waveform entropy criterion and genetic algorithm are employed in the spectrogram connection to compensate the phase error. Finally, the feasibility and effectiveness of the methods are verified by simulation results. [J4]

"InSAR Coherence-Decomposition Analysis"

The phase coherence in synthetic aperture radar interferometry is often used in classification algorithms to detect possible temporal changes of the imaged terrain. However, in mountain areas, the interferometric coherence is also sensitive to the slight variations of the acquisition geometry. In this letter, we propose a very simple but effective method to separate the temporal decorrelation from the geometrical one. Assuming the imaged terrain can be modeled as a distributed target, the geometrical coherence can be estimated by exploiting a topographic model and the sensor acquisition parameters. The discrepancy between the geometrical coherence and the observed one can then be ascribed to temporal changes. Moreover, in presence of pointlike targets, the hypothesis of distributed terrain is no longer valid, and higher values of the observed coherence with respect to the synthetic geometrical one can be used to detect such targets. The proposed approach allows then in mountain areas the following conditions: (1) a simple and very fast rough estimation of the temporal coherence, and (2) the identification of pointlike targets using just two images. The method has been applied and tested in the Badong (China) site using European Remote Sensing satellite tandem data. [J5]

"Micro-Doppler Signature Extraction from Ballistic Target with Micro-Motions"

Precession and nutation of the warhead and the wobble of decoys are the typical micro-motions of ballistic targets, and micro-Doppler analysis is a new way to investigate micro-motions. Based on the difference of micro-motions between the warhead and decoys, micro-Doppler signatures might be extracted for radar target identification, which is seen as a good method and a technique of great potential. We build micro-motion models of a ballistic missile target, including precession, nutation, and wobble; develop a novel model of micro-Doppler modulations based on the proposed concept of the micro-motion matrix; derive the formulas of micro-Doppler induced by the three micro-motions; and verify them by simulation studies. In order to further approach the actual case, the effective point scatterer model and the occlusion effect are considered in micro-Doppler, and the simulated results are shown compared with ones under the fixed point scatterer model and without the occlusion effect. In addition the precession experiment is performed in a microwave chamber, and the measured result is in accordance with the simulated result and the computed result. [J6]

"Radar Target Recognition Based on Modified Characteristic Polarization States"

This paper proposes a radar target recognition algorithm based on a feature set extracted from the target characteristic polarization states (CPS) and evaluated at a set of target resonant frequencies in the frequency domain. The algorithm involves measuring the proximity between training (stored) prototypes and a test prototype. For this task, the algorithm implements the nearest neighbour (NN) algorithm at each resonance to give a vote, and then the majority resonance vote is used to identify the test target prototype. The approach begins by using the power optimization procedure of the Kennaugh power matrix at a set of resonant frequencies to derive a series of CPS (expressed in normalized Stokes vector form) together with their associated receiver power levels. Then, certain CPS are selected and weighted by their associated power levels to create the feature set. Finally, a Euclidean metric is used to determine the minimum k-NN distances between the training prototypes and a test prototype, and the target selected by the majority of the resonances is the identified target. The paper includes the identification performance for two symmetrical targets of similar electrical lengths. [J7]

"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. [J8]

"Resonance Behavior of Radar Targets With Aperture: Example of an Open Rectangular Cavity"

In the resonance region, the radar scattering response of any object can be modelled by natural poles with the formalism of the singularity expansion method. These natural poles are resonance parameters which provide useful information for the discrimination of radar targets as their general shape, characteristic dimensions and constitution. In the case of an open radar target, high-Q internal resonances and low-Q external resonances occur respectively inside the target and on its surface. Because internal resonances have a higher Q, they may have a higher total energy and can thus be used for target identification. In this paper, we choose to study the resonance behavior of a perfectly conducting rectangular cavity with a rectangular aperture. With this simple example, we intend to show how to distinguish between the two origins of these resonances: external resonances corresponding to traveling waves on the surface of the target and internal resonances corresponding to cavity waves. Indeed, this can be applied to characterize aircrafts, whose apertures (such as inlets, open ducts, air-intakes, cavities etc.) contribute significantly to the overall radar cross section. [J9]

"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. [J10]

"Special Issue on Remote Sensing of Building Interior"

The 15 papers in this special issue focus on remote sensing of building interior and can be categorized into: 1) system design and instrumentation; 2) advanced imaging techniques for elimination of glint from large flat wall structures; 3) radar polarimetry; 4) passive microwave radiometry; 5) advanced forward models based on high-frequency methods as well as full-wave solutions based on finite-difference time-domain technique for large-scale problems; and 6) detection and identification techniques of behind the wall stationary and moving concealed and unconcealed targets. [J11]

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

The identification of the physical nature of an object or target causing a ground-penetrating radar (GPR) anomaly, as well as the estimation of a target's dimensions and geometry, is rather challenging. To improve target identification, basic studies are still required, and they can be addressed primarily using a laboratory- or field-based physical model. The field model (test site) is usually expensive and difficult to build, but it provides data for controlled target properties and geometry from a natural environment that are essential for testing processing techniques. In this paper, we present the results from a field experiment where GPR data were collected on plastic and metallic pipes. The main objective is the comparison of the classical migration technique with a microwave tomography approach for reconstructing the geometrical target properties. The use of the microwave tomography approach will allow us to obtain more focused and stable images of the buried objects compared to the ones obtained using classical migration techniques. [J12]

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

High resolution radars (HRRs) transmit a wideband signal to achieve a high range resolution. A target is considered as composed of multiple scatterers, which occupy or spread in multiple radar range cells with several scatterers in each cell. Therefore, the reflection of a target spreads in multiple range cells in the received signal, which contains more information of target than that obtained from low resolution radars. The target in high resolution radar systems is a range-spread target. The range-spreading or echo features of target are utilized for target detection and identification. The echoes of target are convolutions of transmitted signals with target range-scattering functions dependent on the gesture of target to the line of radar sight. A single echo is used in the conventional detection. It is difficult for target detection and identification in low signal-to-noise ratio (SNR) condition. In this paper, we propose a new range-spread target detection scheme exploiting the image features of cross time-frequency distribution (TFD) of a pair of adjacent received signals. After dechirping, the received signal reflected from target consists of multiple sinusoidal components due to its multiple scatterers when a linear frequency modulated (LFM) signal is transmitted from radar. Some regular image patterns or features of target appear in the cross TFD of two adjacent received signals, while the cross TFD of two independent Gaussian noises does not show such patterns. The cross TFD features are exploited in the proposed scheme. Three steps are composed in the proposed scheme. Firstly, a cross smoothed-pseudo Wigner-Ville distribution (CSPWVD) is made for two adjacent received signals to generate a two-dimensional (2-D) TF image. Then, some regular geometric patterns are detected and extracted from the image. At last, two features of the extracted geometric patterns are jointly utilized to detect target. The proposed algorithm is verified by using raw radar data.--It outperforms the conventional detection methods. [J13]

"Scaling Up Wide-Area-Search-Munition Teams"

Wide area search munitions (WASMs) are a cross between an unmanned aerial vehicle (UAV) and a munition. The first of these high-concept munitions, the low-cost autonomous attack system, was a miniature, autonomous WASM capable of broad-area search, identification, and destruction of a range of mobile ground targets. The LoCAAS used a small turbojet engine capable of powering the vehicle for up to 30 minutes and laser radar (ladar) with automatic target recognition to identify potential targets. The original LoCAAS was a fire-and-forget munition designed to operate independently. It flew preprogrammed search patterns until it located a target or ran out of fuel. [J14]

"High-Resolution Radar via Compressed Sensing"

A stylized compressed sensing radar is proposed in which the time-frequency plane is discretized into an N times N grid. Assuming the number of targets K is small (i.e., K Lt N2), then we can transmit a sufficiently ldquoincoherentrdquo pulse and employ the techniques of compressed sensing to reconstruct the target scene. A theoretical upper bound on the sparsity K is presented. Numerical simulations verify that even better performance can be achieved in practice. This novel-compressed sensing approach offers great potential for better resolution over classical radar. [J15]

"Application of Target Decomposition Theorems Over Snow-Covered Forested Areas"

This paper compares two well-known polarimetric decomposition theorems, Cloude-Pottier and Freeman-Durden, applied to L- and C-band Airborne Polarimetric Synthetic Aperture Radar (AIRSAR-POLSAR) data acquired during the Cold-Land Processes Field Experiments. Three field campaigns were carried out in February 2002, March 2002, and March 2003 over a snow-covered open terrain, a sparse coniferous forest, and a dense coniferous forest. The analysis evaluates the ability of the two target decomposition methods for the identification and understanding of the main scattering mechanisms. [J16]

"Phenomenological Vessel Scattering Study Based on Simulated Inverse SAR Imagery"

This paper presents a study on the origin of the dominating scattering mechanisms observed in polarimetric synthetic aperture radar (SAR) images of ships. The study has been made by using numerical simulations, which have been carried out with a radar cross section (RCS) prediction tool (GRaphical Electromagnetic COmputing) and a SAR simulator. Extensive series of simulations has been run for realistic 3-D geometrical models of ships with various sizes. Different radar parameters, aspect angles, and sea surface states have been considered in the scenario. Data analysis with coherent target decompositions has indicated characteristic polarimetric signatures for particular ships within a specific range of viewing angles. This happens at highly oblique incidences where the responses appear to be less sensitive to changes in the operating frequency and bearing angles. Under such conditions, ship scattering can be schematized by the distribution of a set of guide scatterers with high RCS. Their positions and polarimetric characteristics are quantitatively summarized in a new feature vector, which has been proposed to be the basis for classification algorithms. Key ideas about this vector are presented at the end of this paper, jointly with some examples related to three different ships. Recent

publications have shown that they can be successfully cast within a new unsupervised vessel classification scheme. [J17]

"RCS Analysis of a Configurable Mock-Up Cavity With Blade Motion Capability"

The scattering behavior and simulation of cavities are still being studied by several research groups. In this paper, a simplified jet-engine model has been manufactured and measured under different configurations, such as straight or curved blades, different fixed blades position, and free motion capability at adjustable speed. These measurements can be used to analyze the response of cavities as well as radar cross-section reference data for validating existing and future prediction codes. [J18]

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

The conventional range instantaneous Doppler (RID) algorithm is a well accepted inverse synthetic aperture radar (ISAR) imaging method for manoeuvring targets. In the RID imaging, the cross-range resolution depends on the instantaneous Doppler of scatterers at the imaging instant. For a high manoeuvring target, the instantaneous Doppler of scatterers may be small at some imaging instants and the satisfactory RID images may not be obtained. On the other hand, a large instantaneous chirp rate is often present for the same scatterer at the same instant for RID imaging. In order to obtain some additional information of a manoeuvring target, a novel ISAR imaging approach, referred to as the range instantaneous chirp (RIC), is proposed based on instantaneous chirp rate of scatterer to provide cross-range resolution. Using the proposed imaging algorithm, with the same received data of RID, a RIC image is generated at the same instant with a different `view`. Therefore the RIC image may provide some additional information that is not shown in the RID image. With both the RIC and RID images, a better target recognition and identification can be achieved for high-manoeuvring targets. The proposed RIC algorithm is verified by raw radar data. [J19]

"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. [J20]

"HRR Automatic Target Recognition from Superresolution Scattering Center Features"

The work presented here introduces a procedure for the automatic recognition of ground-based targets from high range resolution (HRR) profile sequences that may be obtained from a synthetic aperture radar (SAR) platform. The procedure incorporates an adaptive target mask and uses a superresolution algorithm to identify the cross-range positions of target scattering centers. These are used to generate a pseudoimage of the target whose low-order discrete cosine transform coefficients form the recognizer feature vector. Within the recognizer, the states of a hidden Markov model (HMM) are used to represent the target orientation and a Gaussian mixture model is used for the feature vector distribution. In a closed-set identification experiment, the misclassification rate for ten MSTAR targets was 2.8%. Also presented are results from open-set experiments and investigates the effect on recognizer performance of variations in feature vector dimension, azimuth aperture, and target variants. [J21]

"Helicopter Classification with a High Resolution LFMCW Radar"

Helicopter classification using a high resolution linear frequency modulated continuous wave (LFMCW) radar is addressed. A blade echo modelling for this radar system is derived, taking into account that the stop-and-go assumption is not longer applicable. The standard classification schemes based on the L/N-quotient and the evenness of the number of blades are easily reproduced in this high resolution context, although two main advantages are added: a high pulse repetition frequency (PRF) to acquire the Doppler bandwidth is no longer necessary, and the time for which we receive returned signal from the target may be maximized. On the other hand, a characteristic critical classification problem, for which the standard approaches do not properly work, is presented. Two classification schemes are proposed for this situation, the first one based on coherent matched masks and the second one based on incoherent masks where a robustness parameter has also been defined. Identification probabilities as a function of the signal-to-noise ratio (SNR) are obtained in order to characterize the performance of both techniques. Real data validate both the derived model and the proposed classification

algorithms. [J22]

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

Through-the-wall imaging techniques with ultrawideband (UWB) radars are promising candidates for non-destructive testing and reliable human detection, especially in disaster areas, where victims are buried under collapsed walls. These applications require high-resolution target imaging to identify the object shape, such as a human body. We have already proposed a high-quality 3-dimensional (3-D) imaging algorithm in the form of envelope that is aimed at near field sensing for non-contact measurement or target identification for robots. Envelope achieves real-time accurate 3-D imaging with group mapping from multiple observed ranges to target points, and offers a reliable image even in noisy situations. However, this method does not maintain its quality for through-the-wall imaging because an observed range shift due to wall penetration causes a serious distortion in the image. This paper presents a high-resolution 3-D imaging algorithm by modifying the original envelope, and which gives a more accurate object shape behind a wall. Furthermore, to enhance the resolution of the estimated images, this method is combined with a direct waveform compensation method, known as spectrum offset correction. Numerical simulations and an experiment verify that our proposed method achieves high-resolution 3-D imaging for through-the-wall radar applications. [J23]

"Waveform design in signal-dependent interference and application to target recognition with multiple transmissions"

The authors present illumination waveforms matched to stochastic targets in the presence of signal-dependent interference. The waveforms are formed by SNR and mutual information (MI) optimisation. We also use these waveforms in cognitive radar (CR) target identification application. In this application, the radar system attempts to identify a deterministic or random target using multiple transmissions. These transmissions are adaptively modified in response to previously received echoes. In addition, the authors present a new multi-band application of the CR platform. [J24]

"Maritime border control multisensor system"

This focuses on the classification task performed into a multi-sensor system for the coastal surveillance. The system is composed of two platforms of sensors: a land-based platform equipped with a land based radar, an Automatic Identification System (AIS) and an infrared camera (IR); an airborne platform carrying an airborne radar that can operate in a spotlight Synthetic Aperture Radar (SAR) mode, a video camera, and a second IR camera. The tasks performed by the system are the detection, tracking, identification, and classification of multiple targets, the evaluation of their threat level, and the selection of an intervention on them. The classification algorithm implemented inside the system exploits an analytical approach based on the confusion matrix (CM) of the imaging sensors that belong to the system. Some measures of effectiveness (MoE) of the system are evaluated, considering both cases where an ideal error-free classification process and a non-ideal classification process are performed. [J25]

"Scattered EM Field Responses of Canonical Scatterers Illuminated by an Impulse-Radiating Antenna (IRA)"

This paper investigates the possibility of using the impulse-radiating antenna (IRA) as both a transmitter and receiver of electromagnetic energy for the purpose of target identification. Of specific interest is estimating the induced open-circuit voltage at the IRA's source terminals, when it is illuminated by the scattered EM field from simple conducting bodies excited by an incident field from the same IRA acting as a transmitter. In this study, several different canonical scatters are considered, including thin wires, spheres, conducting boxes, and an infinite conducting plate. For a 7 kV pulse excitation of the IRA, received peak transient voltages at the antenna ranged from a few volts to about 400 volts, depending on the scatterer. [J26]

"Sampling Procedures for Resonance Based Radar Target Identification"

The performance of radar target identification using the natural E-Pulse technique is significantly degraded if the sampling rates of the target response and the E-Pulse filter are ignored. In this work, improved sampling procedures over that previously reported by Antony and Shuley (Electron. Lett., vol. 40) in 2004 are proposed. Numerical results demonstrate that the proposed procedures significantly improve the target identification performance. [J27]

"A Robust State Space Model for the Characterization of Extended Returns in Radar Target

Signatures"

Analysis of radar scattering from targets with curved boundaries, such as objects comprising cylindrical and conical shapes, is important to many aerospace applications. The radar return is composed of a well-characterized physical optics response in the illuminated region where the transmitter and receiver are not shadowed by the object, and a combination of modal responses (e.g., creeping waves and edge-diffracted fields) in the shadow region. The modal responses have longer down-range than scattering centers located on the object, and therefore, produce extended (or off-body) returns in ISAR images, which are not well-understood. However, these returns are strongly dependent on local features of the object, and thus contain valuable information with regard to the target's geometrical and physical composition. Multiple reflections from illuminated facets, as well as multiply diffracted waves, can also add coherently in the direction of the receiver and produce such returns. This paper applies a robust, coherent-processing system identification technique, originally developed for radar sensor fusion, to estimate amplitude and phase of the scatterers that characterize extended returns in the target signature. Examples are presented that highlight the extraction of creeping waves using measured data on a cone-sphere. [J28]

"Physical Models for Polarimetric SAR Analysis"

Polarimetric signatures can be used to support target identification in the context of synthetic aperture radar (SAR). In this paper, we derive analytic expressions for the polarimetric signatures in the SAR image domain, for a class of localized scatters that may be found in a composite target. Specifically, we consider a convex surface, curved and straight edges, and a dihedral. For each of these subscatterers, we use asymptotic techniques to construct analytic expressions for the polarimetric images as a function of the target's geometry and orientation relative to the SAR scan, then extract Huynen's polarimetric parameters, and finally discuss the subscatterer identification in the composite image domain. [J29]

"Through-Wall Imaging With a 3-D UWB SAR Algorithm"

Ultra-wideband (UWB) radar systems become more and more important for material penetrating and imaging applications. Many conventional UWB signal processing algorithms for image generation are commonly based on migrations techniques which are not optimal in terms of object identification capability and calculation time. Thus, a surface reconstructing imaging algorithm has been implemented and verified by real radar data. It offers two crucial advantages with respect to the conventional algorithms: an extensive reduction of the calculation time and the ability to identify targets by the shape of the object. Several examples are given demonstrating the efficiency of this approach. It is based on a preselection of the received C-scan yielding the quasi-wavefronts of the object. [J30]

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

Although techniques for resolution enhancement in single-aspect radar imaging have made rapid progress in recent years, it does not necessarily imply that such enhanced images will improve target identification or recognition. However, when multiple looks of the same target from different aspects are obtained, the available knowledge increases, allowing more useful target information to be extracted. Physics-based image fusion techniques can be developed by processing the raw data collected from multiple inverse synthetic aperture radar sensors, even if these individual images are at different resolutions. We derive an appropriate data fusion rule to generate a composite image containing enhanced target shape characteristics for improved target recognition. The rule maps multiple data sets collected by multiple radars with different system parameters on to the same spatial-frequency space. The composite image can be reconstructed using the inverse 2-D Fourier transform over the separated multiple integration areas. An algorithm called the Matrix Fourier Transform is proposed to realize such a complicated integral. This algorithm can be regarded as an exact interpolation such that there is no information loss caused by data fusion. The rotation centers need to be carefully selected to properly register the multiple images before performing the fusion. A comparison of the image attribute rating curve between the fused image and the spatially averaged images quantifies the improvement in the detected target features. The technique shows considerable improvement over a simple spatial averaging algorithm and thereby enhances target recognition. [J31]

"A Multiagent Swarming System for Distributed Automatic Target Recognition Using Unmanned Aerial Vehicles"

Over the past few years, automatic target recognition (ATR) has emerged as an essential image analysis tool to identify objects from temporally and spatially disjoint possibly noisy image data. For many current applications, ATR is performed by unmanned aerial vehicles (UAVs) that fly within a reconnaissance area to collect image data through sensors and upload the data to a central ground control station for analyzing and identifying

potential targets. The centralized approach to ATR introduces several problems, including scalability with the number of UAVs, network delays in communicating with the central location, and the susceptibility of the system to malicious attacks on the central location. These challenges can be addressed by using a distributed system for performing ATR. In this paper, we describe a multiagent-based prototype system that uses swarming techniques inspired from insect colonies to perform ATR using UAVs in a distributed manner within simulated scenarios. We assume that UAVs are constrained in the resources available onboard and in their capabilities for performing ATR due to payload limitations. Our focus in this paper is on the coordination aspects between UAVs to efficiently decide how they are to act by using a swarming mechanism. We describe algorithms for the different operations performed by the UAVs in the system and for different swarming strategies, which are embedded within software agents located on the UAVs. We provide empirical simulations of our system within a simulated area of interest to determine its behavior in different scenarios with varying operational constraints. Our experimental results indicate that swarming strategies for distributed ATR perform favorably compared with centralized ATR strategies. [J32]

"Real-time motion compensation, image formation and image enhancement of moving targets in ISAR and SAR using S-methodbased approach"

The commonly used technique for inverse synthetic aperture radar (ISAR)/synthetic aperture radar signal analysis is a two-dimensional Fourier transform (FT), which results in an image of the target's reflectivity mapped onto a range and cross-range plane. However, in cases where the line-of-sight projections of the target's point velocities change or there is uncompensated movement within the coherent integration time, the FT produces blurred images. For target recognition applications, mainly those in military surveillance and reconnaissance operations, a blurred ISAR image has to be refocused quickly so that it can be used for real-time target identification. Two standard techniques used for improvement of blurred ISAR images are motion compensation and the use of quadratic time-frequency representations. Both are computationally intensive. The authors present an effective quadratic time-frequency representation, the S-method. This approach performs better than the Fourier transform method by drastically improving images of fast manoeuvring targets and by increasing the SNR in both low and high noise environments. These advantages are a result of the S-method's ability to automatically compensate for quadratic and all even higher-order phase terms. Thus, targets with constant acceleration will undergo full motion compensation and their point scatterers will each be localised. It should be noted that the source of the quadratic term can come not only from acceleration, but also from non-uniform rotational motion and the cosine term in wide-angle imaging. The method is also computationally simple, requiring only slight modifications to the existing FT-based algorithm. The effectiveness of the S-method is demonstrated through application to simulated and experimental data sets. [J33]

"Micro-Doppler analysis of wheels and pedestrians in ISAR imaging"

In radar imaging, it is well known that relative motion or deformations of parts of illuminated objects induce additional features in the Doppler frequency spectrum. These features are called micro-Doppler effect and appear as sidebands around the central Doppler frequency. They can provide valuable information about the structure of the moving parts and may be used for identification purposes. Previous papers have mostly focused on 1D micro-Doppler analysis. The authors propose to emphasise the analysis of such `non-stationary targets` using a 2D imaging space, using both the micro-Doppler and a high-range resolution analysis. As in 2D-ISAR imaging, range separation enables to better discriminate the various effects caused by the time-varying reflectors. The study is focused on two different common examples: rotating wheels and human motion. With the help of micro-Doppler signature, information on the geometrical features of wheels (position, orientation) and on the gait of pedestrians can be extracted. Examples will be shown with simulated and experimental data. [J34]

"Maritime border control computer simulation"

This work describes a computer simulator for an integrated command and control (C2) multi-sensor system acting in a maritime border control scenario. The analyzed system is composed of two platforms of multiple sensors: a land-based platform, equipped with a Vessel Traffic System (VTS) radar, an Infrared camera (IR), and an Automatic Identification System (AIS); an airborne platform, carrying an Airborne Early Warning Radar (AEWR) and an IR camera. The mission of the system is the detection, tracking, and identification of multiple naval targets inside a sea region, their threat level evaluation, and the selection of an intervention against possible threat targets, in order to inspect their nature. The Measures of Effectiveness (MoE) of the integrated system are evaluated, i.e., the system performance during the detection, the threat evaluation process, and the intervention. [J35]

"Adaptive chaotic maps for identification of complex targets"

Identification of complex targets in radar or sonar is a difficult problem. The author shows how the parameters of a simple chaotic map may be optimised to increase the cross correlation of a transmitted signal with the reflection from one target while decreasing the cross correlation with another target. The targets consist of simple arrays of point scatterers. The author shows that the optimisation process produces a chaotic signal with a power spectrum that maximises the ratio of the cross correlation with one target to the cross correlation with a different target, however the author also shows that the specific time ordering of the chaotic signal is also important in determining the cross correlation. The performance of the chaotic signal is better than a random signal with the same power spectrum. The author also shows an example of applying these methods to targets that are more complex. [J36]

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

Inverse synthetic aperture radar (ISAR) is a non-cooperative target recognition technique that has been investigated for target identification by the combat identification (ID) community for the past decade. Recently, ISAR imaging of moving targets has been an area of vigorous research. ISAR imaging is an effective way to acquire high resolution images of targets of interest at long range and as such is an irreplaceable tool in the task of non-cooperative target recognition. Its applications include detection, imaging, and classification of ships and aircraft with airborne, maritime, and land-based radar systems. Being radar-based, this imaging technique can be employed in all weather and day/night conditions. [J37]

"Motion compensation in ISAR imaging using the registration-restoration-fusion approach"

The distortion in the inverse synthetic aperture radar (ISAR) image of a target is a result of small time-varying perturbed motion experienced by the target during the image integration period and is attributed to a phase modulation effect of the radar return from the target. Large distortion in ISAR images of a moving target has been investigated and demonstrated under controlled experiments and simulation. Results from the analysis suggest that severe distortion is attributed to the phase modulation effect where a time-varying Doppler frequency provides the smearing mechanism. For applications of target identification, the registration-restoration-fusion method has been developed to refocus the distorted ISAR images. This method has been applied to both the experimental and simulated ISAR data. Results demonstrate that the registration-restoration-fusion motion compensation approach can improve the distorted ISAR image better than what can be achieved by conventional Fourier transform methods. This study also adds insight into the distortion mechanisms that affect the ISAR images of a target in motion. [J38]

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

Ion mobility spectroscopy (IMS) is a technology that is ideally suited for the detection of very low levels of analyte due to its extreme sensitivity and ability to speciate. Detection of common military and industrial explosives using IMS is an ideal application, since IMS can be tailored to be sensitive to compounds that form negative ions such as nitrate-laden explosives. However, realization of a miniaturized IMS-based detection system for explosives has been hampered by limitations in resolution of miniaturized IMS tubes and by the need to preconcentrate explosive samples and then rapidly desorb them creating a transient chemical concentration. We have demonstrated a new gating and data processing technique that takes advantage of pulse compression approaches developed for modern radar systems for decreasing granularity in target identification. We will show that closely spaced peaks can be isolated by adding discriminating codes to the gating signal. We will then employ matched filtering for the received ion current signal greatly improving instrument performance. This scheme is most advantageous to small geometry IMS drift cells that suffer from lack of resolution due to their small size but would improve sensitivity and peak location uncertainty in any geometry IMS tube. Specifically, we have demonstrated a 13 fold increase in signal-to-noise ratio and have effectively decreased the uncertainty in the location of the signal peak by a factor of 4.4 using a 13-bit Barker coding pattern to operate our IMS gating. [J39]

"Detection of Depth Changes of a Metallic Target Buried in a Frequency-Dependent Lossy Halfspace Using the E-Pulse Technique"

The extinction pulse (E-pulse) technique has been widely applied to the problem of free-space radar target identification. In this paper, the possibility of applying the same E-pulse technique to a subsurface target recognition scheme is investigated. In particular, the detection of depth changes of a metallic target is considered with numerical examples that determine the depth of a hip prosthesis model buried inside representative human tissue. [J40]

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

This paper addresses the problem of radar waveform design for target identification and classification. Both the ordinary radar with a single transmitter and receiver and the recently proposed multiple-input multiple-output (MIMO) radar are considered. A random target impulse response is used to model the scattering characteristics of the extended (nonpoint) target, and two radar waveform design problems with constraints on waveform power have been investigated. The first one is to design waveforms that maximize the conditional mutual information (MI) between the random target impulse response and the reflected waveforms given the knowledge of transmitted waveforms. The second one is to find transmitted waveforms that minimize the mean-square error (MSE) in estimating the target impulse response. Our analysis indicates that under the same total power constraint, these two criteria lead to the same solution for a matrix which specifies the essential part of the optimum waveform design. The solution employs water-filling to allocate the limited power appropriately. We also present an asymptotic formulation which requires less knowledge of the statistical model of the target [J41]

"Minimax Robust MIMO Radar Waveform Design"

We consider the problem of minimax robust waveform design for multiple-input multiple-output (MIMO) radar based on mutual information (MI) and minimum mean-square error (MMSE) estimation for target identification and classification. Recognizing that a single, precise characterization of target power spectral density (PSD) is rare in practice, we assume the PSD lies in an uncertainty class of spectra bounded by known upper and lower bounds, which markedly relaxes the required target a priori knowledge. Based on this band model, we develop minimax robust waveforms for MIMO radar under both MMSE and MI criteria. These robust waveforms bound the worst-case performance at an acceptable limit, and also could insure performance will be sufficiently good for any PSD in the uncertainty class. Our findings also indicate that the MI and MMSE criteria lead to different minimax robust waveform solutions, which is in contrast to the case of the perfectly known target PSD [J42]

"Radar-Target Identification via Exponential Extinction-Pulse Synthesis"

New contributions to noncooperative radar-target discrimination using only the scattered response of conductive objects are presented in this paper. The technique studied is the extinction-pulse (E-pulse), which makes use of natural resonances as discrimination features. The E-pulse expansion using complex exponential functions as basis functions is proposed, obtaining new E-pulses with characteristics completely different from those in the literature. Specifically, a weighting factor is added to modulate the exponential frequency, providing E-pulses with better discrimination capability. Numerical results achieved in the discrimination between thin straight wires of different lengths show that the proposed exponential E-pulses improve the discrimination results with respect to other types of E-pulses in the literature. [J43]

"Syntactic Modeling and Signal Processing of Multifunction Radars: A Stochastic Context-Free Grammar Approach"

Multifunction radars (MFRs) are sophisticated sensors with complex dynamical modes that are widely used in surveillance and tracking. This paper demonstrates that stochastic context-free grammars (SCFGs) are adequate models for capturing the essential features of the MFR dynamics. Specifically, MFRs are modeled as systems that ldquospeakrdquo a language that is characterized by an SCFG. The paper shows that such a grammar is modulated by a Markov chain representing radar's policy of operation. The paper also demonstrates how some well-known statistical signal processing techniques can be applied to MFR signal processing using these stochstic syntactic models. We derive two statistical estimation approaches for MFR signal processing-a maximum likelihood sequence estimator to estimate radar's policies of operation, and a maximum likelihood parameter estimator to infer the radar parameter values. Two layers of signal processing are introduced in this paper. The first layer is concerned with the estimation of MFR's policies of operation. It involves signal processing in the CFG domain. The second layer is concerned with identification of tasks the radar is engaged in. It involves signal processing in the finite-state domain. Both of these signal processing techniques are important elements of a bigger radar signal processing problem that is often encountered in electronic warfare applications-the problem of the estimation of the level of threat that a radar poses to each individual target at any point in time. [J44]

"Single-Pass Polarimetric SAR Interferometry for Vessel Classification"

This paper presents a novel method for vessel classification based on single-pass polarimetric synthetic aperture radar (SAR) interferometry. It has been developed according to recent ship scattering studies that show that the polarimetric response of many types of vessels can be described by trihedral- and dihedral-like mechanisms.

The adopted methodology is quite simple. The input interferometric data are decomposed in terms of the Pauli basis, and hence, one height image is derived for each simple mechanism. Then, the local maxima of these images are isolated, and a 3-D map of scatters is generated. The correlation of this map with the scattering distribution expected for a set of reference ships provides the final classification decision. The performance of the proposed method has been tested with the orbital SAR simulator developed at Universitat Politecnica de Catalunya. Different vessel models have been processed with a sensor configuration similar to the incoming TanDEM-X system. The analysis of diverse vessel bearings, vessel speeds, and sea states shows that the map of scatters matches reasonably the geometry of ships allowing a correct identification even for adverse environmental conditions. [J45]

"Template-Based Target Identification and Confusion Matrices [JAESS Tutorial IV]"

One-dimensional high-range-resolution (HRR) and two-dimensional range-Doppler-imaging (RDI) radar represent possible sensor technologies where template-based techniques can be applied to perform combat identification (CID). The majority of the research reported in these areas consists of empirical studies. This article provides a theoretical basis for understanding some of the fundamental trade-offs associated with these CID techniques, such as the following: What are the relative advantages of RDI over HRR radar or of finer versus coarser resolution in the HRR process? What is the relative advantage of coherent over noncoherent processing? How do target correlations, signal-to-noise ratio (SNR), and target scintillation affect the ability to identify targets? Because confusion matrices are often used to characterize the performance of CID systems, we provide analytical methods for calculating the entries in confusion matrices as a function of the issues cited above. These formulations provide analytical bases to guide system trade-off decisions. The organization of this paper is as follows. We begin with a short overview of HRR and RDI and then explore a number of ways to process the associated target templates that range from an ideal, theoretical approach to an approach that would be more feasible to implement within current-day radars. We first develop analytic template-based methodologies for constructing confusion matrix entries for nonscintillating targets for both coherent and noncoherent processing assumptions. The confusion matrix entries in these cases are conditional probabilities obtained from a simple rule: find the probability that among m (in general, correlated) random variables, each associated with a possible target, that any one is the largest. For the noncoherent case, the successful application of this rule requires the target template values to explicitly include the effects of thermal noise (noise-adjusted templates). We conclude by showing h--ow to calculate theoretically optimum results (e.g., using maximum likelihood techniques) for noncoherent processing of targets that exhibit uncorrelated Swerling 1 scintillation in ail resolution bins as a function of the SNR. This approach allows us to include overall target intensity (e.g., total radar cross section (RCS)) as a further factor in the target decision process. [J46]

"Feature-aided tracking with GMTI and HRR measurements via mixture density estimation"

Tracking ground moving targets with ground moving target indicator and high resolution range (HRR) measurements is becoming increasingly important for many military and civilian applications. We first propose a new HRR information exploitation method using the technique of mixture density estimation. With this technique, features extracted from HRR profiles include not only peak locations and magnitudes, but also the information regarding how energy spreads around peaks. Therefore it is expected to increase significantly the feature discrimination power. We then develop a feature-aided tracking (FAT) algorithm that combines HRR features with traditional kinematic measurements in a probabilistic way. The algorithm does not require any a priori knowledge of target identifications. Simulation results are presented for both the HRR feature extraction method and the FAT algorithm. [J47]

"Ground Target Recognition Using Rectangle Estimation"

We propose a ground target recognition method based on 3-D laser radar data. The method handles general 3-D scattered data. It is based on the fact that man-made objects of complex shape can be decomposed to a set of rectangles. The ground target recognition method consists of four steps; 3-D size and orientation estimation, target segmentation into parts of approximately rectangular shape, identification of segments that represent the target's functional/main parts, and target matching with CAD models. The core in this approach is rectangle estimation. The performance of the rectangle estimation method is evaluated statistically using Monte Carlo simulations. A case study on tank recognition is shown, where 3-D data from four fundamentally different types of laser radar systems are used. Although the approach is tested on rather few examples, we believe that the approach is promising [J48]

"Reformulating Reid's MHT method with generalised Murty K-best ranked linear assignment algorithm"

The authors reformulate Reid's multiple hypothesis tracking algorithm to exploit a K-best ranked linear assignment algorithm for data association. The reformulated algorithm is designed for real-time tracking of large numbers of closely spaced objects. A likelihood association matrix is constructed that, for each scan, for each cluster, for each cluster hypothesis, exactly and compactly encodes the complete set of Reid's data association hypotheses. The set of this matrix's feasible assignments with corresponding non-vanishing products is shown to map one-to-one respectively onto the set of Reid's data association hypotheses and their corresponding probabilities. The explicit structure of this matrix is a new result and leads to an explicit hypothesis counting formula. Replacement of the likelihood association matrix elements by their negative natural logs then transforms the data association matrix into a linear assignment problem matrix and recasts the problem of data association into efficiently finding sets of ranked assignments. Fast polynomial time Murty ranked assignment algorithms can thus replace Reid's original NP-hard exhaustive hypothesis identification, probability evaluation, and branch-and-prune methods and can rapidly determine the maximally likely data association hypothesis, the second most likely, etc. Results from two high fidelity surveillance sensor simulations show the validity of the proposed method. [J49]

"In This Issue-Technically"

For a successful enemy maneuver, their most important action is the ability to identify, locate, and track their correct target. High-resolution imaging sensors such as the inverse synthetic aperture radar perform this action in the most effective way and are especially useful against low radar cross-section targets. Once the correct target is acquired and identified, the decision to engage is made and the weapons are selected. Counter-targeting is the attempt to prevent (or degrade) the engage-and-launch-weapons decision by the enemy. This paper describes an all-digital image synthesizer technique capable of generating realistic false-target images for counter-targeting using modern digital radio frequency memory technology. Uses in counter-lock on for coherent seekers in the terminal mode are also discussed. Examples of the output false target image capability are presented. [J50]

"Radar Target Identification Using a “Banded” E-pulse Technique"

Resonance based radar target recognition using the extinction pulse (E-pulse) technique was first implemented in the mid 1980s. Various derivatives of the E-pulse technique itself as well as the associated problems of identification and differentiation have been reported throughout the literature. In this paper a modified version of the E-pulse, termed the "banded" E-pulse technique is introduced as an alternative tool for target identification [J51]

"Radar target identification using a likelihood ratio test and matching pursuit technique"

On the basis of likelihood ratio test (LRT) theory, a new method for radar target identification with matching pursuits, including the estimation method for target scattering response and the extraction technique for the reference atom dictionary to characterise the target scattering, is introduced. When compared with the generalised LRT (GLRT) target identification method, there is a very important contribution in our method that the whole scattering waveform, not only a few main poles, is used to identify targets without any prior parameterisation model hypothesis. Furthermore, the identification to candidate targets can be performed in an almost aspect-independent manner over a full aspect angle in white Gaussian noise through a finite size reference atom dictionary. Simulation results using scattered responses synthesised from weighted sums of some exponentially damped sinusoids and calculated scattering signatures of three thin wires through a time-domain electric field integral equation are presented to contrast the performance of our method to the GLRT and the best LRT target identification method as a function of signal-to-noise ratio [J52]

"Polarimetric Analysis of Radar Signature of a Manmade Structure"

Identification of manmade structures from radar images has always been a difficult task, especially for single-polarization radar. Fully polarimetric radar, however, can provide detailed information on scattering mechanisms that could enable the target or the structure to be identified. Complexity remains stemming from overlaps of single-bounce scattering, double-bounce scattering, and triple- and higher order bounce scattering from various components of a manmade structure, which makes physical interpretation a challenge. In this letter, an interesting example using polarimetric synthetic aperture radar (PolSAR) data of the Great Belt Bridge, Denmark, was presented to illustrate the capability of PolSAR in analyzing radar signatures. Polarimetric target decomposition is used to differentiate the multiple-bounce scatterings contained in the PolSAR images. Two C-band Danish EMISAR data takes, with the first obtained during the bridge's construction and the second after its completion, are used to extract the scattering characteristics of the bridge deck, bridge cables, and supporting structures [J53]

"High-Accuracy Urban DEM Using Permanent Scatterers"

The permanent scatterers (PS) technique is a powerful operational tool that exploits a long series of synthetic aperture radar data for monitoring ground deformations with millimeter accuracy on a high spatial density grid of pointwise targets. The technique has been applied successfully to a number of applications, from subsidence and volcano monitoring to slow-landslide detection. This paper aims to analyze and demonstrate the positioning capability of the PS technique applied to the generation of urban elevation maps. The problem of the univocal identification of the PS position (discarding pixel-dependent sidelobes, both far and near) is addressed, and an easy and efficient solution is proposed. The results obtained in the Milan site allow the appreciation of the very high quality of an urban digital elevation model retrieved with the PS technique. The ground level of the city is identified with submeter accuracy, and elevated targets, where present, reveal building profiles. The estimated city street level (ranging plusmn3m in 16times18 km2) is then compared to those obtained with the same technique using a descending parallel track and an ascending one. Furthermore, the estimated PS elevation with respect to the ground has been connected to temperature-dependent elongations of high structures [J54]

"Integration of optical and radar classifications for mapping pasture type in Western Australia"

In this study, independent classifications of Landsat Thematic Mapper imagery and Jet Propulsion Laboratory AirSAR were combined to create an integrated classification of pasture and other vegetation types for a study area in the agricultural zone of Western Australia. The resulting classification combines greenness and brightness information from optical data with structure and water content information from synthetic aperture radar (SAR). Field observations of vegetation type, botanical composition, ground cover percentage, wet and dry biomass, canopy height, and soil water content were collected at 34 sites representing a range of pastures, browse shrubs, and crops. An unsupervised version of the Complex Wishart classification procedure, based on preserving scattering characteristics from the Freeman and Durden backscatter decomposition, was applied to the C-, L-, and P-band polarimetric SAR data. The optical classification was carried out using a principle component analysis on the green, red, and near-infrared bands and clustering on the basis of a class centroid distance measure and knowledge of ground targets. These two classification results were then fused together. Assessment of a confusion matrix using the individual sites showed that identification of more uniform, dense, and structurally distinct canopies was better than that of more diverse, sparse, and structurally ambiguous canopies, as the former were better represented by the canopy height attribute used in the SAR classification component. The optical classification enabled correction of SAR misclassification of vegetation due to surface roughness and soil moisture effects, or similar backscatter responses from herbaceous or arboreal canopies. The results show that simplification of vegetation into groups based upon properties with sensitive responses in both the optical and SAR domains, and combination of separate SAR and optical classifications, has potential for improving classification of diverse and heterogeneous herbaceous and browse cover in grazing lands. However, collection of ground calibration data must be at an appropriate spatial scale and include canopy and surface measurements directly related to backscatter mechanisms and spectral sensitivity. [J55]

"A Classification Approach Based on SVM for Electromagnetic Subsurface Sensing"

In clearing terrains contaminated or potentially contaminated by landmines and/or unexploded ordnances (UXOs), a quick wide-area surveillance is often required. Nevertheless, the identification of dangerous areas (instead of the detection of each subsurface object) can be enough for some scenarios/applications, allowing a suitable level of security in a cost-saving way. In such a framework, this paper describes a probabilistic approach for the definition of risk maps. Starting from the measurement of the scattered electromagnetic field, the probability of occurrence of dangerous targets in an investigated subsurface area is determined through a suitably defined classifier based on a support vector machine. To assess the effectiveness of the proposed approach and to evaluate its robustness, selected numerical results related to a two-dimensional geometry are presented. [J56]

"Multifunction millimeter-wave systems for armored vehicle application"

There is an emerging need for millimeter-wave capabilities on military vehicles; in order to make such capabilities more affordable, we have been experimenting with the notion of combining multiple functions into a single device. The functions to be performed simultaneously include: 1) active protection (AP) radar for point defense against antitank threats; 2) surveillance radar for airborne and ground targets; 3) trunking radio for mobile ad hoc networking at a high data rate (>100 Mb/s); and 4) combat identification (ID). Due to a unique combination of characteristics, millimeter-wave radios, radars, and other sensors are attractive for military vehicle use. These characteristics include: 1) smaller profile/footprint of the high-gain antennas; 2) adequate weather penetration; 3) antijam, low probability of intercept, low probability of detection; and 4) wide bandwidth. For the combination of applications identified, this need is best met via a system operating near the 35-GHz atmospheric

transmission window. Current mobile millimeter-wave ground-based systems (AP radar, wide-band communication, and combat ID) utilize highly directional steerable beams. Mechanical beam steering is usually done, resulting in restricted beam agility. Nevertheless, mechanical beam-steering performance is acceptable for AP radar and combat ID systems (but not for Joint Tactical Radio networked communications). A true multifunction system, however, requires beam-steering speeds that far exceed capabilities of even the best mechanical technologies. This is due to the need to support either networking or simultaneous multifunctions via time-shared beam steering. Thus, a true multifunction system must steer its beam anywhere in the upper hemisphere in less than 1 ms. Phased arrays are the obvious solution to these needs. Unfortunately, past phased-array technologies were unaffordable for Army vehicle application-hence, the multiplicity of systems. However, a new trend in development of affordable phased-array Ka-band antennas enables development of affordable Ka-band multifunction systems. [J57]

"A smart radar absorber based on the phase-switched screen"

Although conventional (i.e., passive) radar absorbers are widely used for modifying the radar cross-section (RCS) of current military platforms, such absorbers may not have adequate performance to satisfy future requirements. Active absorbers, however, offer the potential to overcome the so-called Rozanov performance limit and to enable additional smart functionality such as monitoring damage, adaptive control of RCS or target appearance, identification-friend-or-foe, and absorb-while-scan. This paper outlines the concept and basic properties of a novel type of active radar absorber, the so-called phase-switched screen (PSS). The basic PSS topology is then modified so as to enable it to operate as a smart radar absorber when used together with an external sensor and feedback control loop. System implementation issues and the optimum choice of design parameters for a range of operational scenarios are discussed, and theoretical predictions are supported by measured performance data. [J58]

"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 [J59]

"Identification of multiaspect radar signals based on the feature space trajectory concept"

Identification of radar targets has often been based on information gathered from only a single relative aspect between the radar and target. However, identification performances can be significantly improved, provided that radar signals at multiple aspects are simultaneously used to identify radar targets. In this paper, we investigate performances of various approaches to identification using multiaspect radar signals. In addition, some novel techniques based on the feature space trajectory concept are introduced to further enhance the identification performance of the conventional methods. All of these approaches are demonstrated using radar cross section (RCS) data of various aircraft models measured at compact range. Results show that the proposed methods via the FST concept can provide the most promising identification accuracy. [J60]

"Target identification using belief functions and implication rules"

Presented here is the theoretical basis of data fusion for the purpose of target identification using the belief function theory. The key feature is that we allow the knowledge sources to supply their information in the form of uncertain implication rules. How these rules can be elegantly handled within the framework of the belief function theory is described. A small scale, practical example for target identification is worked through in detail to clarify the theory for future users. [J61]

"Convolutional models for buried target characterization with ground penetrating Radar"

Identification of buried antipersonnel landmines with ground penetrating radar (GPR) establishes a need for

application-specific scattering models and associated estimation algorithms relating the measured scattered field to target characteristics such as size, material composition and burial depth. To this end, starting from integral representations of the scattered field, we derive frequency- and time-domain convolutional models for the GPR response of buried dielectric and metal mine-like targets, including simple analytical expressions for the target transfer function/impulse response. The main steps in the derivation are the linearization of the scattering problem by either the Born or the Physical Optics approximation, the application of a new far-field backscattering representation of the half-space Green's tensor, and the introduction of point source/receiver models for the GPR antennas and the receiver chain. Using three-dimensional finite-difference time-domain (FDTD) and measured data examples, we illustrate the validity of the convolutional models and how they can be used to characterize buried targets. For the characterization, we make use of a deconvolution algorithm, termed "subset selection deconvolution", which uses our target impulse response approximations as a priori information on the form of the impulse response to be estimated. The results demonstrate the possibility to determine target size and depth from the estimated impulse response with millimeter accuracy under laboratory conditions, both of which are valuable information for landmine identification. [J62]

"Decades of improvements in re-entry ballistic vehicle tracking"

This paper deals with a missile defense challenge, which has been studied extensively for decades and still remains a topic of active research, the tracking of a ballistic vehicle in its re-entry phase. With Anti-Ballistic Missile or Anti-Tactical-Ballistic Missile goals, most of missile defenses need to track re-entry vehicles with a view to locating them precisely and allowing low altitude interception. The re-entry vehicle leaves a quiet exoatmospheric phase and a quasi-Keplerian motion to an endo-atmospheric phase with large aerodynamic loads and a sudden deceleration. The motion is then obviously nonlinear and furthermore both the extent and the evolution of the drag are difficult to predict. Since the sixties, while more and more efficient sensors, such as sophisticated phased-array radars, were developed, the associated data processing techniques have been improved, taking advantage of computer performance increases. Although re-entry vehicle tracking is undoubtedly a non-linear filtering problem, it was firstly solved by rustic linear filters with fixed weight and an assumed drag table. Then, Kalman filters were exploited. Uncoupled and polynomial for a while, they are now fully coupled and really non-linear. They are called Extended Kalman filters, are based on the linearization about the estimated state and are the current efficient and classic solution to non-linear filtering. Moreover, they perform drag estimation which may be useful to the identification capabilities of the missile defense. In the future, even more sophisticated techniques, such as the promising and fashionable particle filtering, are likely to be developed in re-entry vehicle tracking. [J63]

"An ultrawide-band microwave radar sensor for nondestructive evaluation of pavement subsurface"

A new ultrawide-band (UWB) microwave radar sensor operating from 0.6 to 5.6 GHz has been developed using microwave integrated circuits for pavement subsurface characterization. UWB antennas operating from 0.5-10-GHz have been designed and tested for use in the sensor. A new simple, yet effective, accurate procedure was also developed to compensate for the common amplitude deviations and nonlinear phase errors produced by the inherent imperfection of the system. The developed compensation method is applicable to other systems and effectively reduces the potential masking of adjacent targets as well as facilitating and increasing the accuracy for target identification of the sensor. The sensor has been used to assess a pavement sample with less than 0.1 in of error in the pavement's layer thickness. The developed system represents the first UWB stepped-frequency radar sensor completely realized using microwave integrated circuits over the frequency range of 0.6-5.6 GHz for subsurface sensing applications. [J64]

"Pattern recognition of multiple signals from ground penetrating radar for metal and plastic objects"

The author describes methods for pattern recognition of multiple time signals of embedded targets in water or soil. The received time signals are investigated using characteristic features of metal and plastic pipes in water for better detection of plastic and for soil with noisy signals. The classification of time signals is done by statistical signal parameters, ARMAX, Prony modelling, a new difference vector method of the model transfer function H(z) in the coefficient vector feature space, principal component analysis (PCA), and the classification (more than the estimation or identification) of radar targets via complex frequencies (CNR-complex natural resonances) of these multiple time signals. [J65]

"Consequence of incorrect sampling procedures in resonance-based radar target identification"

Radar target identification based on complex natural resonances is sometimes achieved by convolving a linear time-domain filter with a received target signature. The filter is constructed from measured or pre-calculated target resonances. The performance of the target identification procedure is degraded if the difference between

the sampling rates of the target signature and the filter is ignored. The problem is investigated for the natural extinction pulse technique (E-pulse) for the case of identifying stick models of aircraft. [J66]

"Role of polarisation in automatic target recognition using resonance descriptions"

The role of polarisation in late time complex resonance based target identification is investigated numerically for the case of an L-shaped wire. While repeated extraction of the resonances for varying polarisation allows for better signal-to-noise immunity, it is also found that there are preferred polarisations for each complex resonance. The first few of these polarisations are extracted for the sample target. [J67]

"Non-cooperative target recognition in the frequency domain"

Non-cooperative target recognition is investigated in the frequency domain using measured in-flight aircraft data. It is found that the frequency domain target signatures are distinct for different aircraft types and at different aspects. As a result, target identification in the frequency domain is just as viable as using conventional high-range resolution profiles in the range domain. In addition, there are many advantages of working in the frequency domain; many of the problems encountered in the range domain can be avoided. This leads to a much simpler task in performing target recognition. [J68]

"An asymptotically unbiased E-pulse-based scheme for radar target discrimination"

This communication proposes an E-pulse-based scheme for radar target discrimination that provides asymptotically correct results for any level of additive white noise contaminating the radar signal. After multiple sampling of the signal dispersed by the target, it is analytically shown that the cross correlation between the output signals of the E-pulse designed for the standard target, corresponding to two different sampling periods, is asymptotically, regardless of the amount of contaminating noise. The results obtained by simulation have allowed us to propose a discrimination criterion that produces better results than the original E-pulse technique at very low signal-to-noise ratio (SNR) levels. [J69]

"Invariant-based probabilistic target tracking and identification with GMTI/HRR measurements"

An invariant-based algorithm is presented for ground moving-target tracking and identification using ground moving-target indicator and high-resolution range measurements. The algorithm effectively exploits coupled information between target kinematics and identification spaces by introducing the concept of local and global motion. A geometrical invariant constraint based on the target rigidity principle is built into target kinematics and measurement models, which facilitate joint information exploitation. An interacting multiple template algorithm is developed to tightly work with a traditional tracker for joint tracking and identification. Besides providing target kinematics behaviour and identity information, the algorithm is capable of reconstructing the prominent physical structure of a moving target. [J70]

"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. [J71]

"On the use of permanent symmetric scatterers for ship characterization"

The symmetric scattering characterization method (SSCM) has been recently introduced for high-resolution characterization of certain targets under coherent conditions. SSCM is based on the Poincarer' sphere representation, which supports a high-resolution decomposition of symmetric target scattering, as well as assessment and validation of the backscatter coherence. In this paper, the SSCM is investigated for ship characterization using Convair-580 polarimetric synthetic aperture radar (SAR) data. It is shown that the target Poincarer' parameters permit identification of dominant scatterers with a significant symmetric scattering component. The polarization orientation angle of these quasi-symmetric scatterers is used to derive an estimate of the ship's pitch angle, under certain conditions. The effect of SAR system focus setting errors and Doppler centroid mistracking on the SSCM performance is investigated. It is shown that the SSCM is sensitive to the

system focus setting and Doppler centroid shift. The first-order effects of these errors can be removed prior to the application of the SSCM method. [J72]

"Plane-wave synthesis by an antenna-array and RCS determination: theoretical approach and numerical simulations"

Radar cross-section (RCS) measurements of a target performed in an anechoic chamber with the conventional one antenna calibration technique may yield erroneous results at frequencies lower than those for which the chamber has been initially designed, essentially because the absorbers become ineffective and the field emitted by the antenna no longer satisfies the plane-wave (PW) condition on the target. A possible way to circumvent these difficulties is to use a phased antenna-array that synthesizes a PW in a bounded domain, usually called the quiet zone (QZ). In this paper, we propose a calibration technique that allows an accurate reconstruction of the RCS of a target located in the near-field of the array, even when electrically conducting walls are present. A theoretical study of the problem at hand is presented that allows one to specify clearly the hypotheses that are being made and to identify the parameters that govern the accuracy of the RCS reconstruction. When the target-array, antenna-antenna, and target-walls-target interactions are neglected, it is demonstrated that this calibration technique synthesizes a PW in QZ if the calibration object is a line source (two-dimensional) or an infinitesimal dipole (three-dimensional). Three-dimensional full-wave numerical simulations, that take all the previously mentioned interactions into account, illustrate the efficiency of this technique when the array and conducting walls are a few wavelengths apart from the target. [J73]

"Three-band biorthogonal interpolating complex wavelets with stopband suppression via lifting scheme"

Wavelet research has primarily focused on real-valued wavelet bases. However, the complex filterbanks provide much convenience for complex signal processing. For example, in radar and sonar signal processing, the complex signals from the I/Q receiver can be efficiently processed with complex filterbanks rather than real filterbanks. Specifically, the positive and negative Doppler frequencies imply different physical content in the moving target detector (MTD) and moving target identification (MTI); therefore, it is significant to design complex multiband filterbanks that can partition positive and negative frequencies into different subbands. We design two novel families of three-band biorthogonal interpolating complex filterbanks and wavelets by using the three-band lifting scheme. Unlike the traditional three-band filterbanks, the novel complex filterbank is composed of three channels, including the lowpass channel, the positive highpass channel whose passband distributes in the positive frequency region, and the negative highpass channel in the negative frequency region. Such a filterbank/wavelet naturally provides the ability to extract positive frequency components and negative frequency components from complex signals. Moreover, a novel set of design constraints are introduced to manipulate the stopband characteristic of highpass filters and are referred to as stopband suppression, which strengthens the traditional constraints of vanishing moments. Finally, a numerical method is given to further lower stopband sidelobes. [J74]

"Acoustic and electromagnetic wave interaction: estimation of Doppler spectrum from an acoustically vibrated metallic circular cylinder"

The idea of using acoustically induced Doppler spectra as a means of target detection and identification is introduced. An analytical solution for the calculation of the bistatic scattered Doppler spectrum from an acoustically excited, vibrating, metallic, circular cylinder is presented. First, the electromagnetic scattering solution of a slightly deformed circular cylinder is obtained using a perturbation method. Then, assuming the vibration frequency is much smaller than the frequency of the incident electromagnetic wave, a closed form expression for the time-frequency response of the bistatic scattered field is obtained which can be used directly for estimating the Doppler spectrum. The acoustic scattering solution for an incident acoustic plane wave upon a solid elastic cylinder is applied to give the displacement of the cylinder surface as a function of time. Results indicate that the scattered Doppler frequencies correspond to the mechanical vibration frequencies of the cylinder, and the sidelobe Doppler spectrum level is, to the first order, linearly proportional to the degree of deformation and is a function of bistatic angle. Moreover, the deformation in the cylinder, and thus the Doppler sidelobe level, only becomes sizeable near frequencies of normal modes of free vibration in the cylinder. Utilizing the information in the scattered Doppler spectrum could provide an effective means of buried object identification, where acoustic waves are used to excite the mechanical resonances of a buried object. [J75]

"Analysis of SAR images by multidimensional wavelet transform"

The description and development are described of a multidimensional continuous wavelet transform for synthetic aperture radar (SAR) image analysis, especially for the analysis of 'dispersive' reflectors located on a ground

illuminated by a SAR. The usual imaging process makes the assumption that the reflectors are isotropic (i.e. that they behave the same way regardless of the angle from which they are viewed) and white (they have the same properties within the emitted frequency bandwidth). New imaging capacities (offering large bandwidth, low band and large angular excursions of analysis, for example) make these assumptions obsolete. The goal is to present methods based on the multidimensional continuous wavelet transform which highlight these effects for target recognition or identification. Some examples of this analysis are given by processing real data collected in X-band by the RAMSES airborne SAR facilities at ONERA [J76]

"Enhanced recognition in hybrid systems"

Identifying the mode of operation of a hybrid system while simultaneously tracking the state is difficult without a direct modal measurement. Even with such a measurement, subtle biases have been observed in applications. It is shown here that for one estimation algorithm, modal identification can be improved with a simple adjustment in the measurement update [J77]

"New approach to target identification by use of a robust algorithm for optimal matching of wideband radar signal to target"

Using an array of coupled oscillators, a novel broadband radar signalling scheme is introduced. It is shown that the collective output of the oscillator array is a flexible signal that can be matched to a target at a specific aspect. Also, a new robust algorithm based on eigenvectors of the correlation matrix is introduced, by which the generated signal can be matched to the target over a limited range of aspects. This capability is important, because radars are unable to estimate the aspect of a real target precisely. In this new approach to radar target identification, after estimation of the approximate aspect of an unknown target, a variety of waveforms matched to different potential targets are synthesised and transmitted to the target in turn. The maximum peak power of the backscattered signals will then specify the identity of the target. Computer simulations have shown that this technique is robust to both additive noise and aspect angle uncertainty [J78]

"UWB radars in medicine"

Applied research on biomedical applications of UWB radar is targeted to the identification of the possible new devices made possible by the technology, to the design and development of those devices, and to the clinical testing of the systems obtained. Applications can be divided into two main sectors according to the frequency range used. For the conventional UWB radar microwave region: cardiac biomechanics assessment; chest movements assessment OSA (obstructive sleep apnoea) monitors; soft-tissue biomechanics research; heart imaging ("Holter type" echocardiography); chest imaging. Together with systems for: cardiac monitoring; respiratory monitoring; SIDS (sudden infant death syndrome) monitor; vocal tract studying. If an IR laser diode is used as the antenna, a more common radar is obtained (actually a hybrid between a narrow band and a wide band radar) which emits a short packet of electromagnetic waves whose echoes are sampled using conventional UWB receiver equipped with a PIN photodiode. Possibilities include: non-invasive biochemical study of soft tissues, non-invasive study of metabolic processes, and IR spectral imaging [J79]

"Dominant scatterer identification testing with an integrated X-band radar system"

Radar return data from airborne jet aircraft were collected and analyzed to determine the presence of consistent, dominant radar returns of point scatterers on aircraft simulating landing conditions. These measurements were performed by integrating two separate X-band radars into one system with the ability to simultaneously track and image aircraft. Selected processed data from both radar systems were analyzed and are presented for the airborne jet aircraft [J80]

"A simple model for SAR azimuth speckle, focusing, and interferometric decorrelation"

The phenomenon of speckle in synthetic aperture radar (SAR) images is well known as a characteristic grainy appearance of radar images. Speckle is frequently a significant obstacle to visual interpretations of radar data or target identification. In addition, it is usually the dominant noise source in SAR interferometry, since it is responsible for image decorrelation that degrades interferometric fringes, places severe constraints on orbits, and limits the accuracy of height measurements. This communication deals with the geometric sources of speckle. This conventional picture is extended to the case of vertically separated scatterers, and the formulation that results is applied to the structurally similar topics of azimuth focusing, interferometric decorrelation from defocusing, and atmospheric phase delays. [J81]

"Characterization of target symmetric scattering using polarimetric SARs"

Cameron's coherent target decomposition (CTD) theory and the classification method that Cameron developed for operational use of his CTD are reconsidered. It is shown that Cameron's classification leads to a coarse scattering segmentation because of the large class dispersion that corresponds to a synthetic aperture radar (SAR) system with about ±8-dB channel imbalance. The application of Cameron's method within known SAR radiometric calibration requirements limits the utility of the classification. In addition, Cameron's classification is applied under the implicit assumption on the coherence nature of target scattering, and this might yield erroneous results within areas of noncoherent scattering. A new method, named the symmetric scattering characterization method (SSCM), is introduced to better exploit the information provided by the largest target symmetric scattering component in the context of coherent scattering. The Poincarer' sphere is used as the basis for a more complete representation of symmetric scattering than Cameron's unit disk, thus enabling the SSCM to generate better segmentation of target symmetric scattering with much higher resolution. In order to limit the application of the SSCM to targets of coherent scattering, new methods are developed for assessment and validation of the coherent nature of point and extended target scattering. [J82]

"Joint tracking and identification algorithms for multisensor data"

The paper describes an algorithm to jointly form a track and assign an identity flag to a target on the basis of measurements provided by a suite of sensors: surveillance radar, high resolution radar and electronic support measures. The algorithm is built around Bayes' inference and Kalman filters with the interacting multiple model. The improved performance in the track formation and identity estimation, which accrues by the joint tracking and identification algorithm, is evaluated by Monte Carlo simulation and compared to the performance of filters that process the data provided by each single sensor. The joint tracking and identification algorithm plays an important role in modern surveillance systems with non-cooperative target recognition capabilities. [J83]

"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. [J84]

"Identification of ground targets from sequential high-range-resolution radar signatures"

An approach to identifying targets from sequential high-range-resolution (HRR) radar signatures is presented. In particular, a hidden Markov model (HMM) is employed to characterize the sequential information contained in multiaspect HRR target signatures. Features from each of the HRR waveforms are extracted via the RELAX algorithm. The statistical models used for the HMM states are formulated for application to RELAX features, and the expectation-maximization (EM) training algorithm is augmented appropriately. Example classification results are presented for the ten-target MSTAR data set. [J85]

"Radar target identification using one-dimensional scattering centres"

Identification concerning different types of radar targets can be achieved by using various radar signatures, such as one-dimensional (1-D) range profiles, 2-D radar images, and 1-D or 2-D scattering centres on a target. To solve the target identification problem, the authors utilise 1-D scattering centres, which correspond to the highest peaks in the 1-D range profile. The proposed approach obtains scale and translational-invariant features based on the central moments from the distribution of the 1-D scattering centres on the target; these 1-D scattering centres can be extracted from various techniques such as the inverse fast Fourier transform (IFFT), fast root-multiple signal classification (fast root-MUSIC), total least squares-Prony (TLS-Prony), generalised eigenvalues utilising signal subspace eigenvectors (GEESE), and the matrix-pencil (MP) algorithm. The information redundancy contained in these features, as well as their dimensions, are further reduced via the Karhunen-Loeve transform, followed by adequate scaling of the computed central moments. The resulting small dimensional and redundancy-free feature vectors are classified using the Bayes classifier. Finally, this new strategy for radar target identification is demonstrated with data measured in the compact range facility, and the above five different techniques for 1-D scattering centre extraction are compared and investigated in the context of target identification [J86]

"FOPEN SAR imaging using UWB step-frequency and random noise waveforms"

The detection and identification of targets obscured by foliage have been topics of great interest. Several synthetic aperture radar (SAR) experiments have demonstrated promising images of terrain and man-made objects obscured by dense foliage, by using either linear frequency modulation (LFM) or step-frequency

waveforms. We present here the methodology and results of a comparative study on foliage penetration (FOPEN) SAR imaging using ultrawideband (UWB) step-frequency and random noise waveforms. A statistical-physical foliage transmission model is developed for simulation applications. The foliage obscuring pattern is analyzed by means of the technique of paired echoes. The results of the comparative study demonstrates the ability of a UHF band UWB random noise radar to be used as a FOPEN SAR. Advantages of the random noise radar system include covert detection and immunity to radio frequency interference (RFI) [J87]

"Performance analysis of a GLRT automated target discrimination scheme"

The use of a generalized likelihood ratio test (GLRT) based on the late-time scattered return for target discrimination was recently presented by J.E. Mooney et al. (see ibid., vol.46, p.1817-23, Dec. 1998). The performance of the GLRT was demonstrated by direct simulation with scattering data from a target library consisting of several thin-wire targets. In this paper, a numerical procedure for analytically evaluating the performance of the GLRT is presented. At the heart of this procedure is the computation of the probability density of the GLRT decision statistic. Unlike previous works that rely solely on some simulation examples to demonstrate performance, our accurate analytical results provide strong evidence of the effectiveness of the GLRT method. The resulting analysis yields a measure of the discrimination capability of the GLRT. This measure, which is referred to as the probability of correct identification, is computed as a function of signal-to-noise ratio (SNR) using the theoretical scattering data from several thin-wire targets. These results are compared to the direct simulation results presented by Mooney et al. to demonstrate the accuracy of the analysis [J88]

"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 [J89]

"Recognizing occluded objects in SAR images"

Recognizing occluded vehicle targets in synthetic aperture radar (SAR) images is addressed. Recognition algorithms, based on local features, are presented that successfully recognize highly occluded objects in both XPATCH synthetic SAR signatures and real SAR images of actual vehicles from the MSTAR data. Extensive experimental results are presented for a basic recognition algorithm, using SAR scattering center relative locations as features with the XPATCH data and for an improved algorithm, using scatterer locations and magnitudes with the real SAR targets in the MSTAR data. The results show the effect of occlusion on recognition performance in terms of probability of correct identification, receiver operating characteristic curves, and confusion matrices [J90]

"Spaceborne along-track SAR interferometry: performance analysis and mission scenarios"

A system study of a spaceborne along-track synthetic aperture radar (SAR) interferometer is presented. This sensor has been successfully experienced for detecting moving targets by using only airborne installations. Several key issues must be addressed when spaceborne configurations are envisaged. To this end, a quantitative evaluation of system performance and measurement accuracy has been conducted. First, the identification of possible space configurations has been accomplished. In particular, the two antennas can operate on a single satellite or they can be carried along appropriate trajectories by two spacecrafts. Then, an error budget of radial velocity measurement accuracy has been performed. Finally, two possible mission scenarios are dealt in details, and numerical results are reported [J91]

"A technique for the identification and localization of SAR targets using encoding transponders"

Targets in SAR images can be tagged for unambiguous identification and localization by equipping them with transponders that encode the signal received from the SAR before it is retransmitted. The encoding technique described below requires no modification of the SAR. The SAR data can be processed to image the

transponders with the background suppressed. The transponder response is suppressed in a conventionally processed SAR image. The encoding technique enables the transponder signal to be automatically detected in the SAR data [J92]

"Pole estimation for arbitrarily-shaped dielectric targets using genetic algorithm-based resonance annihilation technique"

The use of a genetic algorithm-based resonance annihilation technique to extract the interior poles of an arbitrarily shaped dielectric object with the ultimate purpose of target identification is proposed. The technique is demonstrated for a dielectric sphere with a very good agreement between the exact and extracted pole values [J93]

"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 [J94]

"Enhanced target detection and identification via optimised radar transmission pulse shape"

The optimisation of the transmission radar pulse shape to maximise either target detection or identity discrimination between the T-72 and M1 main battle tanks is investigated. Significant performance improvements in target detection and identification are obtained using such matched illumination transmission waveforms over that of standard chirped pulses [J95]

"Three-dimensional interferometric ISAR imaging for target scattering diagnosis and modeling"

Two-dimensional (2-D) inverse synthetic aperture radar (ISAR) imaging has been widely used in target scattering diagnosis, modeling and target identification. A major shortcoming is that a 2-D ISAR image cannot provide information on the relative altitude of each scattering center on the target. In this paper, we present an interferometric inverse synthetic aperture radar (IF-ISAR) image processing technique for three-dimensional (3-D) target altitude image formation. The 2-D ISAR images are obtained from the signature data acquired as a function of frequency and azimuthal angle. A 3-D IF-ISAR altitude image can then be derived from two 2-D images reconstructed from the measurements by antennas at different altitudes. 3-D altitude image formation examples from both indoor and outdoor test range data are demonstrated on complex radar targets [J96]

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