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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 16-1

“Landmine Detection”
(«Обнаружение мин»)

Журнальные публикации

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"Infrared Imaging Detection of Water Permeation on Field Large-Scale Rock Relics"

Although thermal infrared (TIR) imaging technology has been successfully applied in the thermographic inspection of engineering defects and landmines, its use for detecting water permeation on field large-scale rock relics is new. Huashan Rock Painting, a world-famous field large-scale rock relic in Guangxi Province, China, was used as a case for TIR imaging detection of water permeation on field large-scale rock relics. This paper introduced detection methods, a key parameter, and a gradation model for TIR imaging. Three detection methods were specially designed and used in two experiments performed during the drought and rainy seasons, respectively. Thermographic features were comprehensively analyzed, and temperature variation curves of water-permeation places were quantitatively compared with those of places unaffected by water permeation. Water-permeation places can be precisely identified based on thermographic features and temperature variation curves. Physical interpretation was conducted based on the heat transfer equation and on the Stefan-Boltzmann law. The minimum temperature of solar irradiated water-permeation places was selected as the key parameter, and a -based model was established for water-permeation gradation. To strengthen the differences between water-permeation places and places unaffected by water permeation, TIR imaging should also be conducted during a sunny day after the rains, particularly during an intermittent sunny day after heavy rains in the rainy season. It is the best time for TIR-imaging-based water-permeation detection and gradation. [J1]

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

We used advanced ground-penetrating radar (GPR) inversion techniques for detecting landmines in laboratory conditions. The radar data were acquired with a calibrated vector network analyzer combined with an off-ground monostatic horn antenna, thereby setting up a stepped-frequency continuous-wave radar. Major antenna effects and interactions with the soil and targets were filtered out using frequency-dependent complex antenna transfer functions. The proposed strategy first exploits inversion approaches that are able to give an accurate characterization of the antenna-soil interaction and a reliable estimate of the soil permittivity. The outcomes of this first phase are at the basis of the application of a microwave tomographic approach based on the Born approximation to achieve the imaging of the subsurface. The algorithms were applied for imaging three landmines of different sizes and buried at different depths in sand. Although the radar system was off the ground, the results showed that it was possible to reconstruct all mines, including a shallow plastic mine as small as 5.6 cm in diameter. This last mine was invisible in the raw radar data, and the use of common GPR imaging techniques did not lead to satisfactory results. The proposed integrated method shows great promise for shallow subsurface imaging in a demining context, particularly because it automatically provides accurate information on the shallow soil dielectric permittivity. [J2]

"Seismic Source Quantitative Parameters Retrieval From InSAR Data and Neural Networks"

The basic idea of this paper relies on the concurrent exploitation of the capabilities of neural networks (NNs) and SAR interferometry (InSAR) for the characterization of a seismic source and the estimation of its geometric parameters. When a moderate-to-strong earthquake occurs, we can apply the InSAR technique to compute a differential interferogram. The earthquake is generated by an active seismogenic fault having its own specific geometry. The corresponding differential interferogram contains, in principle, information concerning the geometry of the seismic source that the earthquake comes from. To perform the inversion operation, a novel approach based on NNs is considered. This requires the generation of a statistically significant number of synthetic interferograms necessary for the network training phase. Each of them corresponds to a different combination of fault geometric parameters. After the training, the network is ready to perform, in real time, the inversion on new differential interferograms. This paper illustrates such a methodology and its validation on a set of experimental data. [J3]

"A Framework for Information-Based Sensor Management for the Detection of Static Targets"

A framework is presented for information-theoretic sensor management for the detection of static targets. The sensor manager searches for targets within a cell grid using a suite of sensor platforms. Each sensor platform may contain one or more sensing modalities, and each of these modalities has known probabilities of detection and false alarm and also has an associated cost of use. Additional information such as motion constraints on the sensors and the prior distribution of the targets in space is incorporated. The sensor manager then directs the movement of the sensors through the grid by maximizing the expected information gain that will be obtained with each new sensor observation. Key modeling questions are addressed, including the selection of an appropriate information measure and the joint or independent management of the sensors. Through a number of simulations, the performance of the sensor manager is compared to the performance of a blind sweep procedure, a random search procedure, and an alternative information-theoretic sensor manager. The intelligent sensor management procedure is demonstrated to achieve a superior performance compared to all of the other three techniques. A specific application area for which the sensor management problem is becoming more critical is landmine detection; thus, the performance of the sensor manager is also analyzed using real data from three different landmine detection sensing modalities, and the proposed sensor management technique is again demonstrated to be superior compared to more simplistic approaches. [J4]

"Mine Identification and Classification by Mobile Sensor Network Using Magnetic Anomaly"

In this paper, a new method is proposed to identify and classify the data obtained by the sensor network (SN) for the detection of mines. This method is used for the identification of antitank and antipersonnel mines and classification of buried objects within a target region. In this paper, a mobile SN is used to detect mines and some other objects buried and creating magnetic anomaly in and around the region where they are found, with the behavior of the individual sensors swarming onto the area under which a mine or any other object is buried. The process of collecting data by the SN and modeling it mathematically are explained in detail. The SN is modeled as a fictitious two-dimensional spatial impulse sampler. This paper is motivated by clearing the territories of mine fields to open them to agriculture. It is very important because, currently, in some countries, very fertile territories around the borders are covered by buried mines. The approach is basically based on magnetic anomaly measurements, which directly tackles the subregions corresponding to buried objects whether they represent objects that are separately located or occluded by other objects. It is based on a new developed method that is called "the back-most object detection and identification algorithm." This method is fully automatic, and there is no human intervention throughout the process. In this paper, classification of objects is based on their well-known shapes and dimensions. Therefore, there is no need for sophisticated learning algorithms to achieve classification. The experimental results are given both for detection and identification of a single mine and classification of a number of mines and any other objects that have a potential of giving false alarms in a target region. [J5]

"GRANMA: Gradient Angle Model Algorithm on Wideband EMI Data for Land-Mine Detection"

This letter presents a simple and fast algorithm to analyze wideband electromagnetic induction data for subsurface targets. A well-known four-parameter model is differentiated, resulting in a two-parameter model. A fast lookup table is used to find parameters as opposed to nonlinear optimization. The proposed approach provides a computationally faster way to reproduce the results of state-of-the-art methods. A detailed mathematical analysis of the model is given that describes the advantages and limitations of the proposed method. [J6]

"Acoustoseismic Method for Buried-Object Detection by Means of Surface-Acceleration Measurements and Audio Facilities"

An experimental setup for acoustoseismic detection of shallow buried objects is presented. The seismic (Rayleigh) waves were generated by exciting an acoustic airborne source by a series of sine-wave bursts, which were designed to cover a frequency range (100-1000 Hz) large enough to distinguish the vibrational characteristics of buried compliant objects. The signals were recorded by means of contact-acceleration microelectromechanical-system sensors moved above different buried objects (compliant and rigid). Signal acquisitions on only sandy soil revealed the natural variability of the outdoor test bed. This variability of soil parameters pointed out the difficulties of buried-object detection based on the amplitude thresholding of the signal spectrum. For this aim, the signals were processed in both time and frequency domains. An audio-channel output was devised to avail of the human hearing apparatus in distinguishing the buried objects according to spatial variations of the acceleration signals obtained by scanning the soil surface. [J7]

"Context-Dependent Multisensor Fusion and Its Application to Land Mine Detection"

We present a novel method for fusing the results of multiple land mine detection algorithms which use different

sensors, features, and different classification methods. The proposed multisensor/multialgorithm fusion method, which is called context-dependent fusion (CDF), is motivated by the fact that the relative performance of different sensors and algorithms can vary significantly depending on the mine type, geographical site, soil and weather conditions, and burial depth. CDF is a local approach that adapts the fusion method to different regions of the feature space. The training part of CDF has two components: context extraction and algorithm fusion. In context extraction, the features used by the different algorithms are combined and used to partition the feature space into groups of similar signatures, or contexts. The algorithm fusion component assigns a degree of worthiness to each detector in each context based on its relative performance within the context. To test a new alarm using CDF, each detection algorithm extracts its set of features and assigns a confidence value. Then, the features are used to identify the best context, and the degrees of worthiness of this context are used to fuse the individual confidence values. Results on large and diverse ground-penetrating radar and wideband electromagnetic data collections show that the proposed method can identify meaningful and coherent clusters and that different expert algorithms can be identified for the different contexts. Typically, the contexts correspond to groups of alarm signatures that share a subset of common features. Our extensive experiments have also indicated that CDF outperforms all individual detectors and the global fusion that uses the same method to assign aggregation weights. [J8]

"Globally Convergent Numerical Methods for Some Coefficient Inverse Problems"

How can we differentiate between an underground stone and a landmine? A class of new numerical methods aims to address this question using globally convergent-rather than locally convergent-algorithms for coefficient inverse problems. Numerical results model imaging of the spatially distributed dielectric permittivity function in an environment where antipersonnel landmines are embedded along with stones. [J9]

"Distributed Recovery from Network Partitioning in Movable Sensor/Actor Networks via Controlled Mobility"

Mobility has been introduced to sensor networks through the deployment of movable nodes. In movable wireless networks, network connectivity among the nodes is a crucial factor in order to relay data to the sink node, exchange data for collaboration, and perform data aggregation. However, such connectivity can be lost due to a failure of one or more nodes. Even a single node failure may partition the network, and thus, eventually reduce the quality and efficiency of the network operation. To handle this connectivity problem, we present PADRA to detect possible partitions, and then, restore the network connectivity through controlled relocation of movable nodes. The idea is to identify whether or not the failure of a node will cause partitioning in advance in a distributed manner. If a partitioning is to occur, PADRA designates a failure handler to initiate the connectivity restoration process. The overall goal in this process is to localize the scope of the recovery and minimize the overhead imposed on the nodes. We further extend PADRA to handle multiple node failures. The approach, namely, MDAPRA strives to provide a mutual exclusion mechanism in repositioning the nodes to restore connectivity. The effectiveness of the proposed approaches is validated through simulation experiments. [J10]

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

A different and useful approach is presented for detecting new events in a scene, such as the presence or absence of landmines or perhaps the movement of people, vehicles, or structures. The approach rests on the radar examination of an area several times, once, before there are targets present, and the other (or others) after. The change detection algorithm notices if there are any changes after the first view. In the present approach the prospective target is represented, not in terms of three complex elements of a scattering matrix, but in terms of phenomenologically-based Huynen parameters. Each element of the Huynen parameter set conveys a different type of physical and geometrical attribute about the scatterers, thus the potential for significant false-alarm mitigation is increased. We provide results of the application of this approach on fully polarimetric signatures of simulated pairs of buried cylindrical targets. These results indicate the following. 1) Huynen parameters are more effective for change detection than the scattering matrix elements because of their ability to generate higher unambiguous autocorrelation peaks and fewer dominating cross-correlation curves. 2) A large number of symmetries are observed in the plots of the Huynen parameters for both one and two buried cylinders. These symmetries may eventually lead to further classification insights. 3) By using standard Prony methods, relevant resonance frequencies are extracted from the parameter plots, from which the height of either one of the cylinders is estimated. 4) The diameter of either cylinder can also be obtained by a simple procedure based on ray-tracing and time delays. Numerical calculations substantiate all the above assertions. [J11]

"Experimental demonstration of high-resolution ultra-wideband impulse radar based on electrical-optical hybrid pulse generation"

A high-resolution ultra-wideband (UWB) impulse radar has been developed in order to realise high-resolution object imaging in a ground-penetrating radar (GPR) for landmine detection. The UWB impulse radar is based on an electrical-optical hybrid pulse generation scheme such that a clean, short pulse train with small, short ringing can be generated. The generated UWB impulse train has a pulse duration of approximately 200-ps and a repetition rate of less than 1-GHz. Its estimated equivalent isotropically radiated power was well matched with a spectral mask for GPRs, as defined by the Federal Communications Commission of the USA. From an experimental demonstration, it was observed that the developed high-resolution UWB impulse radar was able to resolve a relative positional change of an object with a resolution of less than 10-mm, resulting in accurate imaging of a complex three-dimensional object. [J12]

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

In this paper, first, a new range-estimation technique using time reversal (TR) for ground-penetrating-radar (GPR) applications is presented. The estimator is referred to as the TR/GPR range estimator. The motivation for this paper comes from the need of accurately estimating the location of underground objects such as landmines or unexploded ordinance for safe clearance. Second, the Cramer-Rao lower bound (CRLB) for the performance of the TR/GPR range estimator is derived and compared with the CRLB for the conventional matched filter (MF). The CRLB analysis shows that the TR/GPR range estimator has the potential to achieve higher accuracy in estimating the location of the target than that of the conventional MF estimator. Third, the proposed TR/GPR estimator is tested using finite-difference time-domain simulations, where the surface-based reflection GPR is modeled using an electromagnetic transverse-magnetic (TM) mode formulation. In our simulations, the TR/GPR estimator outperforms the conventional MF approach by up to 5-dB reduction in mean square error at signal-to-noise ratios ranging from -20 to 20 dB for dry-soil environments. [J13]

"Integrated High-Fidelity Geoscience Simulations for Enhanced Terrain-Related Target Detection"

A loosely coupled suite of physics-based geotechnical, geospatial, hydrogeologic, and thermal simulations are integrated into a virtual testing facility aimed at resolving terrain-related warfighter problems. This article describes the key aspects of the research conducted by the US Institute for Maneuverability and Terrain Physics Simulation and provides two examples of the virtual testing facility applied to subsurface threat detection. [J14]

"Applications of Grid Pattern Matching to the Detection of Buried Landmines"

Whereas overhead infrared imagery shows promise for detecting buried landmines, detection algorithms must deal with the daunting challenge of distinguishing between landmines and clutter objects which frequently possess similar spatial and spectral characteristics to landmines. However, groups of clutter features are rarely related spatially in the same way that groups of mines are related. For this reason, the recognition of minefield patterns in overhead landmine imagery can be useful to the detection of mines in minefields. In this paper, we present a simple method for detecting grid patterns in imagery, discuss means by which the method may be extended to a more general category of patterns, provide a method for the automated prediction of the locations of undetected mines based upon the observed pattern, and finally we discuss applications. Examples are provided using longwave infrared hyperspectral imagery. [J15]

"Development of a Coded Aperture X-Ray Backscatter Imager for Explosive Device Detection"

Defence R&D Canada has an active research and development program on detection of explosive devices using nuclear methods. One system under development is a coded aperture-based X-ray backscatter imaging detector designed to provide sufficient speed, contrast and spatial resolution to detect antipersonnel landmines and improvised explosive devices. The successful development of a hand-held imaging detector requires, among other things, a light-weight, ruggedized detector with low power requirements, supplying high spatial resolution. The University of California, San Diego-designed HEXIS detector provides a modern, large area, high-temperature CZT imaging surface, robustly packaged in a light-weight housing with sound mechanical properties. Based on the potential for the HEXIS detector to be incorporated as the detection element of a hand-held imaging detector, the authors initiated a collaborative effort to demonstrate the capability of a coded aperture-based X-ray backscatter imaging detector. This paper will discuss the landmine and IED detection problem and review the coded aperture technique. Results from initial proof-of-principle experiments will then be reported. [J16]

"Evolution's war on design-[Jelectronics biotech]"

The way that DNA stores information intrigues Professor Ron Weiss of Princeton University. A computer scientist by training, he told scientists at a Royal Society of Chemistry seminar on synthetic biology last autumn: "Twelve years ago, I became fascinated by the notion that we might be able to program cells with the ease with which

we program computers." [J17]

"Detection and Discrimination of Land Mines in Ground-Penetrating Radar Based on Edge Histogram Descriptors and a Possibilistic -Nearest Neighbor Classifier"

This paper describes an algorithm for land mine detection using sensor data generated by a ground-penetrating radar (GPR) system that uses edge histogram descriptors for feature extraction and a possibilistic K-nearest neighbors (K-NNs) rule for confidence assignment. The algorithm demonstrated the best performance among several high-performance algorithms in extensive testing on a large real-world datasets associated with the difficult problem of land mine detection. The superior performance of the algorithm is attributed to the use of the possibilistic K-NN algorithm, thereby providing important evidence supporting the use of possibilistic methods in real-world applications. The GPR produces a 3-D array of intensity values, representing a volume below the surface of the ground. First, a computationally inexpensive prescreening algorithm for anomaly detection is used to focus attention and identify candidate signatures that resemble mines. The identified regions of interest are processed further by a feature extraction algorithm to capture their salient features. We use translation-invariant features that are based on the local edge distribution of the 3-D GPR signatures. Specifically, each 3-D signature is divided into subsignatures, and the local edge distribution for each subsignature is represented by a histogram. Next, the training signatures are clustered to identify prototypes. The main idea is to identify few prototypes that can capture the variations of the signatures within each class. These variations could be due to different mine types, different soil conditions, different weather conditions, etc. Fuzzy memberships are assigned to these representatives to capture their degree of sharing among the mines and false alarm classes. Finally, a possibilistic K-NN-based rule is used to assign a confidence value to distinguish true detections from false alarms. The proposed algorithm is implemented and integrated within a complete-- land mine prototype system. It is trained, field-tested, evaluated, and compared using a large-scale cross-validation experiment that uses a diverse dataset acquired from four outdoor test sites at different geographic locations. This collection covers over 41 807 m2of ground and includes 1593 mine encounters. [J18]

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

Ground-penetrating radar (GPR) is recognized as a promising sensor for detecting buried landmines. In this case, the GPR antenna(s) must be elevated above the ground. However, this requirement results in heavy surface clutter. It is therefore necessary to overcome the effect. A commonly used procedure of time gating and background averaging cannot suit to small shallow nonmetallic landmine beneath a rough ground surface. In this letter, we proposed techniques to enhance the target signal through common midpoint (CMP) antenna array and data processing techniques, including velocity spectrum and CMP multifold stacking. The method has been tested using experiment data over a rough ground under which small plastic antipersonnel landmines is shallowly buried. The result shows the signal-to-clutter ratio was dramatically improved. [J19]

"A Comparison of Fast Inorganic Scintillators for Thermal Neutron Analysis Landmine Detection"

The Improved Landmine Detector System, a militarily fielded, teleoperated vehicle-mounted multi-sensor landmine detector, uses a thermal neutron analysis (TNA) detector to confirm the presence of a mine by detecting the bulk nitrogen in its explosives. To improve the nitrogen sensitivity or measurement times of the TNA detector, higher gamma ray rates will be required. The chief bottleneck to achieving the maximum possible performance from the present TNA or future versions is the relatively slow fluorescent decay time of the NaI(Tl) scintillators which are currently used. An experimental investigation was undertaken to compare a number of modern, fast inorganic scintillators to NaI(Tl) with respect to parameters relevant to TNA landmine detection, including efficiency, energy resolution, linearity, available size and cost. This paper presents results in the context of the high-rate, high-gamma-energy environments expected in such a TNA application. Large (7.62 cm times 7.62 cm) LaBr3:Ce scintillators, and to a lesser degree LaCl3:Ce, were found to stand-out as as the principal candidates for the detector upgrade to the TNA confirmation system. Their properties also make them ideal candidates for fast neutron analysis and associated particle imaging bulk explosives detectors. [J20]

"Research and Development of the Humanitarian Landmine Detection System by a Compact Fusion Neutron Source"

A 5 year task is described on the research and development of the advanced humanitarian landmine detection system by using a compact discharge-type fusion neutron source called IECF (Inertial-Electrostatic Confinement fusion) device and 3 dual sensors made of BGO and NaI. With 107D-D neutrons/s stably produced in steady-state mode, H-2.2 MeV, N-5.3, 10.8 MeV, gamma rays from (n, gamma) reaction with nitrogen atoms in the explosives are measured for two kinds of explosives (TNT, RDX), under the conditions of three different buried depths, and soil moistures. Final detection probabilities for arid soil are found to be 100 % in the present tests,

i.e., depths not exceeding 15 cm, moisture content of 18.5 % or less, and 20-minute measurements. The neutron backscattering method is found also excellent. [J21]

"Mine Classification With Imbalanced Data"

In many remote-sensing classification problems, the number of targets (e.g., mines) present is very small compared with the number of clutter objects. Traditional classification approaches usually ignore this class imbalance, causing performance to suffer accordingly. In contrast, the recently developed infinitely imbalanced logistic regression (IILR) algorithm explicitly addresses class imbalance in its formulation. We describe this algorithm and give the details necessary to employ it for remote-sensing data sets that are characterized by class imbalance. The method is applied to the problem of mine classification on three real measured data sets. Specifically, classification performance using the IILR algorithm is shown to exceed that of a standard logistic regression approach on two land-mine data sets collected with a ground-penetrating radar and on one underwater-mine data set collected with a sidescan sonar. [J22]

"Free-Space Imaging Beyond the Diffraction Limit Using a Veselago-Pendry Transmission-Line Metamaterial Superlens"

Focusing using conventional lenses relies on the collection and interference of propagating waves, but discounts the evanescent waves that decay rapidly from the source. Since these evanescent waves contain the finest spatial details of the source, the image suffers a loss of resolution and is referred to as ldquodiffraction-limited.rdquo Superlensing is the ability to create an image with fine features beyond the diffraction limit, and can be achieved with a ldquoVeselago-Pendryrdquo lens made from a metamaterial. Such a Veselago-Pendry superlens for imaging in free space must be stringently designed to restore both propagating and evanescent waves, but meeting these design conditions (isotropic n= epsivr= mur= -1) has proven difficult and has made its realization elusive. We demonstrate free-space imaging with a resolution over three times better than the diffraction limit at microwave frequencies using a Veselago-Pendry metamaterial superlens based on the negative-refractive-index transmission-line (NRI-TL) approach, which affords precise control over its properties and is also less susceptible to losses than other approaches. A microwave superlens can be particularly useful for illumination and discrimination of closely spaced buried objects over practical distances by way of back-scattering, e.g., in tumour or landmine detection, or for targeted irradiation over electrically small regions in tomography/hyperthermia applications. [J23]

"A Novel Scanning Land Mine Detector Based on the Technique of Neutron Back Scattering Imaging"

The neutron back-scattering (NBS) technique is a well established method to find hydrogen in objects. It can be applied in land mine detection taking advantage of the fact that land mines are abundant in hydrogen. The NBS technique is suitable for land mine scanning e.g., seeking for land mines with a moving detector system, because of the high speed of operation. Scan speeds up to 800 mm/s are reported here depending on the intensity of the neutron source, the mine size and the depth at which the mine is buried. [J24]

"A Nonlinear Iterative Reconstruction and Analysis Approach to Shape-Based Approximate Electromagnetic Tomography"

A nonlinear Helmholtz-equation-modeled electromagnetic tomographic reconstruction problem is solved for the object boundary and inhomogeneity parameters in a damped Tikhonov-regularized Gauss-Newton (DTRGN) solution framework. In this paper, the object is represented in a suitable global basis, whereas the boundary is expressed as the zero level set of a signed-distance function. For an explicit parameterized boundary-representation-based reconstruction scheme, analytical Jacobian and Hessian calculations are made to express the changes in scattered field values w.r.t. changes in the inhomogeneity parameters and the control points in a spline representation of the object boundary, via the use of a level-set representation of the object. Even though, in this paper, a homogeneous dielectric is considered and a spline representation has been used to represent the boundary, the formulation can be used for a general global basis representation of the inhomogeneity as well as arbitrary parameterizations of the boundary, and is generalizable to three dimensions. Reconstruction results are presented for test cases of landminelike dielectric objects embedded in the ground under noisy data conditions. To confirm convergence and, at times, to know which of the obtained iterates are closer to the actual unknown solution, using a perturbation theory framework, a local (Hessian-based) convergence analysis is applied to the DTRGN scheme for the reconstruction, yielding estimates of convergence rates in the residual and parameter spaces. [J25]

"Possibilistic Versus Belief Function Fusion for Antipersonnel Mine Detection"

Two approaches for combining humanitarian mine detection sensors are presented-one based on belief functions and the other one based on possibility theory. The approaches are described in parallel. First, different measures are extracted from the sensor data. Mass functions and possibility distributions are then derived from the measures based on prior information. After that, the combination of masses and the combination of possibility degrees are performed in two steps, on a separate sensor level and between the sensors. Combination operators are chosen to account for different characteristics of the sensors. The selection of the decision rules is discussed for both approaches. The proposed approaches are illustrated on a set of real mines and nondangerous objects, and promising results have been obtained. [J26]

"Vegetation Mapping for Landmine Detection Using Long-Wave Hyperspectral Imagery"

We develop a vegetation mapping method using long-wave hyperspectral imagery and apply it to landmine detection. The novel aspect of the method is that it makes use of emissivity skewness. The main purpose of vegetation detection for mine detection is to minimize false alarms. Vegetation, such as round bushes, may be mistaken as mines by mine detection algorithms, particularly in synthetic aperture radar (SAR) imagery. We employ an unsupervised vegetation detection algorithm that exploits statistics of emissivity spectra of vegetation in the long-wave infrared spectrum for identification. This information is incorporated into a Choquet integral-based fusion structure, which fuses detector outputs from hyperspectral imagery and SAR imagery. Vegetation mapping is shown to improve mine detection results over a variety of images and fusion models. [J27]

"Minimum Classification Error Training for Choquet Integrals With Applications to Landmine Detection"

A novel algorithm for discriminative training of Choquet-integral-based fusion operators is described. Fusion is performed by Choquet integration of classifier outputs with respect to fuzzy measures. The fusion operators are determined by the parameters of fuzzy measures. These parameters are found by minimizing a minimum classification error (MCE) objective function. The minimization is performed with respect to a special class of measures, the Sugeno lambda-measures. An analytic expression is derived for the gradient of the Choquet integral with respect to the Sugeno lambda-measure. The new algorithm is applied to a landmine detection problem, and compared to previous techniques. [J28]

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

Ground penetrating radar (GPR)-based discrimination of landmines from clutter is known to be challenging due to the wide variability of possible clutter (e.g., rocks, roots, and general soil heterogeneity). This paper discusses the use of GPR frequency-domain spectral features to improve the detection of weak-scattering plastic mines and to reduce the number of false alarms resulting from clutter. The motivation for this approach comes from the fact that landmine targets and clutter objects often have different shapes and/or composition, yielding different energy density spectrum (EDS) that may be exploited for their discrimination (this information is also present in time-domain data, but in the frequency domain we can remove a phase if desired and can reveal better spatial characteristics and therefore often achieve greater robustness). This paper first applies the finite-difference time-domain (FDTD) modeling technique to establish the theoretical foundation. The method to generate EDS from GPR measurements is then described. The consistency of the frequency-domain features is examined through two different GPRs that have different spatial sampling rates and frequency bandwidths. Experimental results from several test sites, based on GPR data collected over buried mines and emplaced buried clutter objects, corroborate the theoretical development and the effectiveness of the proposed spectral feature to increase the accuracy of landmine detection and discrimination. [J29]

"Electromagnetic Induction From Highly Permeable and Conductive Ellipsoids Under Arbitrary Excitation: Application to the Detection of Unexploded Ordnances"

The secondary field produced by 3-D highly permeable and conductive objects is computed in the electromagnetic induction regime, with the purpose of modeling unexploded ordnances (UXOs) and surrounding clutter. The analytical formulation is based on the ellipsoidal coordinate system that is able to model real 3-D geometries as opposed to bodies of revolutions like within a spheroidal approach. At the frequencies of interest (tens of hertz to hundreds of kilohertz), conduction currents in the soil are negligible, and the fields are computed in the magnetoquasistatic regime based on the Laplace equation. Inside the objects, where the wave equation governs the field distribution, the currents are assumed to have a small penetration depth, allowing for the analytical simplification of the field components, which become decoupled at the surface. This approximation, which is valid across the entire frequency spectrum because of the high permeability and conductivity, avoids the necessity of using ellipsoidal wave functions and results in a considerable saving of computational time.

Numerical results favorably compare with numerical and experimental data, which proves the usefulness of our method to model UXOs in clutter-contaminated soils. Finally, the optimization approach used to match our numerical predictions with experimental data demonstrates the possibility of remotely inferring the material properties of objects. [J30]

"A Generalized Likelihood Ratio Test for Detecting Land Mines Using Multispectral Images"

In this letter, we address the problem of detecting anomalies in multispectral images that are due to the presence of land mines. The proposed detection scheme follows from a generalized likelihood ratio test (GLRT) involving a mixture of certain probability density functions. More specifically, the GLRT is based on the assumption that the pixel values of a subblock within a single spectral-plane image can be modeled as a mixture of two Gaussian density functions (model distribution of background pixels) and a uniform density function (model distribution of anomalous pixels when they are present). We extend the single spectral-plane GLRT to the multiple spectral-plane case where the subblocks are from multispectral images. To assess the proposed GLRT, which we call the Gaussian-uniform GLRT (GU-GLRT) algorithm, we applied the GU-GLRT and popular RX algorithms to images from a real multispectral image sequence and used receiver operating characteristic (ROC) curves as the figure of merit. In the experiments that we conducted, the GU-GLRT outperformed the RX algorithm in the sense that the area under the ROC curve was greatest for the GU-GLRT algorithm. [J31]

"Infrared Thermography for Buried Landmine Detection: Inverse Problem Setting"

This paper deals with an inverse problem arising in infrared (IR) thermography for buried landmine detection. It is aimed at using a thermal model and measured IR images to detect the presence of buried objects and characterize them in terms of thermal and geometrical properties. The inverse problem is mathematically stated as an optimization one using the well-known least-square approach. The main difficulty in solving this problem comes from the fact that it is severely ill posed due to lack of information in measured data. A two-step algorithm is proposed for solving it. The performance of the algorithm is illustrated using some simulated and real experimental data. The sensitivity of the proposed algorithm to various factors is analyzed. A data processing chain including anomaly detection and characterization is also introduced and discussed. [J32]

"Particle Filtering Based Approach for Landmine Detection Using Ground Penetrating Radar"

In this paper, we present an online stochastic approach for landmine detection based on ground penetrating radar (GPR) signals using sequential Monte Carlo (SMC) methods. The processing applies to the two-dimensional B-scans or radargrams of 3-D GPR data measurements. The proposed state-space model is essentially derived from that of Zoubir etal., which relies on the Kalman filtering approach and a test statistic for landmine detection. In this paper, we propose the use of reversible jump Markov chain Monte Carlo in association with the SMC methods to enhance the efficiency and robustness of landmine detection. The proposed method, while exploring all possible model spaces, only expends expensive computations on those spaces that are more relevant. Computer simulations on real GPR measurements demonstrate the superior performance of the SMC method with our modified model. The proposed algorithm also considerably outperforms the Kalman filtering approach, and it is less sensitive to the common parameters used in both methods, as well as those specific to it. [J33]

"Feature Extraction and Discriminator Design for Landmine Detection on Double-Hump Signature in Ultrawideband SAR"

An air- or vehicleborne ultrawideband synthetic aperture radar (UWB SAR) has ground penetrating capability, which provides a sufficient approach to detect landmines over wide areas from a safe standoff distance. In this paper, a support vector machine (SVM) with hypersphere classification boundary, which is referred to as HyperSphere-SVM (HS-SVM), using a hidden Markov model (HMM) kernel on the feature vector extracted by a postfilter-based method is proposed for landmine detection. The postfilter-based method can extract the feature containing not only the amplitude but also the amplitude varying information of the double-hump signature of metallic and plastic landmines. Compared with simple kernels, e.g., the Gaussian kernel, the HMM kernel employs the state-transition information in the extracted feature into the discrimination procedure and, thus, can improve detection performance. The proposed postfilter-based feature extraction method and the HMM kernel HS-SVM are verified on the field data collected by a UWB SAR system in different scenarios. [J34]

"Multiple-Mode Selection of Walled-LTSA Array Elements for High-Resolution Imaging to Visualize Antipersonnel Plastic Landmines"

We propose a resolution improvement technique for a high-density array of walled linearly tapered slot antennas

(LTSAs) in ground-penetrating radar imaging. In the system, we use the walled-LTSA array in a near-field measurement configuration and select various pairs of transmitter and receiver antennas out of the array elements. We prepare four selection modes so that we can practically enhance the imaging resolution. We remove the direct-coupling effect and compensate the path-length fluctuation caused by element individuality and element selection. Experiments demonstrate that the technique realizes higher resolution image acquisition to yield a clearer segmentation of antipersonnel plastic landmines in combination with adaptive image processing, based on complex-amplitude texture, even on a wet laterite soil condition. [J35]

"Detection of Unexploded Ordnance via Efficient Semisupervised and Active Learning"

Semi supervised learning and active learning are considered for unexploded ordnance (UXO) detection. Semi supervised learning algorithms are designed using both labeled and unlabeled data, where here labeled data correspond to sensor signatures for which the identity of the buried item (UXO/non-UXO) is known; for unlabeled data, one only has access to the corresponding sensor data. Active learning is used to define which unlabeled signatures would be most informative to improve the classifier design if the associated label could be acquired (where for UXO sensing, the label is acquired by excavation). A graph-based semi supervised algorithm is applied, which employs the idea of a random Markov walk on a graph, thereby exploiting knowledge of the data manifold (where the manifold is defined by both the labeled and unlabeled data). The algorithm is used to infer labels for the unlabeled data, providing a probability that a given unlabeled signature corresponds to a buried UXO. An efficient active-learning procedure is developed for this algorithm, based on a mutual information measure. In this manner, one initially performs excavation with the purpose of acquiring labels to improve the classifier, and once this active-learning phase is completed, the resulting semi supervised classifier is then applied to the remaining unlabeled signatures to quantify the probability that each such item is a UXO. Example classification results are presented for an actual UXO site, based on electromagnetic induction and magnetometer data. Performance is assessed in comparison to other semi supervised approaches, as well as to supervised algorithms. [J36]

"Selecting a Discrimination Algorithm for Unexploded Ordnance Remediation"

We review the algorithms that have been used to discriminate between hazardous unexploded ordnance (UXO) and harmless clutter. Statistical classifiers use model parameters estimated from geophysical data to formulate a decision rule. This rule tries to discriminate between UXO and clutter using the available information. In contrast, library-based discrimination algorithms make decisions using a predefined library of signatures for expected UXO types. Given the variety of algorithms that are available for UXO discrimination, we describe two metrics for evaluating discrimination performance-the area under the receiver operating characteristic and the false-alarm rate. We propose a bootstrapping algorithm for estimating these metrics when limited data are available. Last, we demonstrate this approach on real electromagnetic and magnetic data sets. [J37]

"Numerical Modeling of Higher Order Magnetic Moments in UXO Discrimination"

The surface magnetic anomaly observed in unexploded ordnance (UXO) clearance is mainly dipolar, and consequently, the dipole is the only magnetic moment regularly recovered in UXO discrimination. The dipole moment contains information about the intensity of magnetization but lacks information about the shape of the target. In contrast, higher order moments, such as quadrupole and octupole, encode asymmetry properties of the magnetization distribution within the buried targets. In order to improve our understanding of magnetization distribution within UXO and non-UXO objects and to show its potential utility in UXO clearance, we present a numerical modeling study of UXO and related metallic objects. The tool for the modeling is a nonlinear integral equation describing magnetization within isolated compact objects of high susceptibility. A solution for magnetization distribution then allows us to compute the magnetic multipole moments of the object, analyze their relationships, and provide a depiction of the anomaly produced by different moments within the object. Our modeling results show the presence of significant higher order moments for more asymmetric objects, and the fields of these higher order moments are well above the noise level of magnetic gradient data. The contribution from higher order moments may provide a practical tool for improved UXO discrimination. [J38]

"Computation of Land Mine Signatures Using Domain Decomposition With Lagrange Multipliers"

Computation of land mine signatures, as recorded by metal detectors, requires much effort regarding the discretization of the detector coil and the much smaller metal part of the land mine. A domain decomposition method enables a finer discretization for certain areas. By using the Lagrange multipliers approach, the coarse and fine meshed domains are solved at the same time with only one system of equations. In this paper, this method is presented for the magneto-quasi-static application of a metal detector used as a mine searching device [J39]

"Finite-Difference Methods and Validity of a Thermal Model for Landmine Detection With Soil Property Estimation"

In this paper, we introduce and validate a 3-D linear thermal model for landmine detection. A finite-difference approximation of generalized solutions to the model is proposed, and its convergence properties are proved. An efficient numerical algorithm based on splitting methods is suggested for solving the discretized problem. Moreover, we introduce methods to estimate the (bare) soil and air-soil interface thermal properties. These parameters depend strongly on weather, environmental conditions, and soil type; their accuracy affects strongly the thermal modeling. The validity of the thermal model with the estimated soil properties is verified by comparing the simulations with data sets acquired in outdoor minefields [J40]

"Frequency Subband Processing and Feature Analysis of Forward-Looking Ground-Penetrating Radar Signals for Land-Mine Detection"

There has been significant amount of study on the use of ground-penetrating radar (GPR) for land-mine detection. This paper presents our analysis of GPR data collected at a U.S. Army test site using a new approach based on frequency subband processing. In this approach, from the radar data that have over 2.5 GHz of bandwidth, we compute separate radar images using the one wide (2 GHz) and four narrow (0.6 GHz) frequency subbands. The results indicate that signals for different frequency subbands are significantly different and give very different performance in land-mine detection. In addition, we also examine a number of features extracted from the GPR data, including magnitude and local-contrast features, ratio between copolarization and cross-polarization signals, and features obtained using polarimetric decomposition. Feature selection procedures are employed to find subsets of features that improve detection performance when combined. Results of land-mine detection, including performance on blind test lanes, are presented [J41]

"Information-Based Sensor Management in the Presence of Uncertainty"

Recognizing the uncertainty present in all real-world problems, this correspondence extends the mathematical framework of a previously presented information-based sensor manager to permit operation with uncertain sensor probabilities of detection and false alarm. Simulation results demonstrate the importance of proper uncertainty modeling for the attainment of robust sensor manager performance [J42]

"UWB short-range radar sensing-The architecture of a baseband, pseudo-noise UWB radar sensor"

The pioneers of radio science made their first trials of wireless information transmission and demonstrated localization of a steel vessel by radio waves more than 100 years ago. Back then, the world of radio frequencies was organized in a very simple way. The researchers could use any frequency band. There was no interference by others and no controlling government bodies. Since then, governmental authorities have established tight regulations that have split up the available frequency band into small partitions for exclusive use. This article discusses the architecture of a baseband, pseudo-noise UWB radar and gives some examples of applications [J43]

"Exploiting Spin Echo Decay in the Detection of Nuclear Quadrupole Resonance Signals"

Nuclear quadrupole resonance (NQR) is a radio-frequency technique that can be used to detect the presence of quadrupolar nuclei, such as the 14N nucleus prevalent in many explosives and narcotics. In a typical application, one observes trains of decaying NQR echoes, in which the decay is governed by the spin echo decay time(s) of the resonant line(s). In most detection algorithms, these echoes are simply summed to produce a single echo with a higher signal-to-noise ratio, ignoring the decaying echo structure of the signal. In this paper, after reviewing current NQR signal models, we propose a novel NQR data model of the full echo train and detail why and how these echo trains are produced. Furthermore, we refine two recently proposed approximative maximum-likelihood detectors that enable the algorithms to optimally exploit the proposed echo train model. Extensive numerical evaluations based on both simulated and measured NQR data indicate that the proposed detectors offer a significant improvement as compared to current state-of-the-art detectors [J44]

"Optimal Maneuvering of Seismic Sensors for Localization of Subsurface Targets"

We consider the problem of detecting and locating subsurface objects by using a maneuvering array that receives scattered seismic surface waves. We demonstrate an adaptive system that moves an array of receivers according to an optimal positioning algorithm that is based on the theory of optimal experiments. The goal is to minimize the number of distinct measurements (array movements) needed to localize objects such as buried

landmines. The adaptive localization algorithm has been tested using data collected in a laboratory facility. The performance of the algorithm is exhibited for cases with one or two targets and in the presence of common types of clutter such as rocks in the soil. Results are also shown for a case where the propagation properties of the medium vary spatially. In these tests, the landmines were located using three or four array movements. It is envisioned that future systems could incorporate this new method into a portable mobile mine-location system [J45]

"Filtering Soil Surface and Antenna Effects From GPR Data to Enhance Landmine Detection"

The detection of antipersonnel landmines using ground-penetrating radar (GPR) is particularly hindered by the predominant soil surface and antenna reflections. In this paper, we propose a novel approach to filter out these effects from 2-D off-ground monostatic GPR data by adapting and combining the radar antenna subsurface model of Lambot with phase-shift migration. First, the antenna multiple reflections originating from the antenna itself and from the interaction between the antenna and the ground are removed using linear transfer functions. Second, a simulated Green's function accounting for the surface reflection is subtracted. The Green's function is derived from the estimated soil surface dielectric permittivity using full-wave inversion of the radar signal for a measurement taken in a local landmine-free area. Third, off-ground phase-shift migration is performed on the 2-D data to filter the effect of the antenna radiation pattern. We validate the approach in laboratory conditions for four differently detectable landmines embedded in a sandy soil. Compared to traditional background subtraction, this new filtering method permits a better differentiation of the landmine and estimation of its depth and geometrical properties. This is particularly beneficial for the detection of landmines in low-contrast conditions [J46]

"Mobility Limited Flip-Based Sensor Networks Deployment"

An important phase of sensor networks operation is deployment of sensors in the field of interest. Critical goals during sensor networks deployment include coverage, connectivity, load balancing, etc. A class of work has recently appeared, where mobility in sensors is leveraged to meet deployment objectives. In this paper, we study deployment of sensor networks using mobile sensors. The distinguishing feature of our work is that the sensors in our model have limited mobilities. More specifically, the mobility in the sensors we consider is restricted to a flip, where the distance of the flip is bounded. We call such sensors as flip-based sensors. Given an initial deployment of flip-based sensors in a field, our problem is to determine a movement plan for the sensors in order to maximize the sensor network coverage and minimize the number of flips. We propose a minimum-cost maximum-flow-based solution to this problem. We prove that our solution optimizes both the coverage and the number of flips. We also study the sensitivity of coverage and the number of flips to flip distance under different initial deployment distributions of sensors. We observe that increased flip distance achieves better coverage and reduces the number of flips required per unit increase in coverage. However, such improvements are constrained by initial deployment distributions of sensors due to the limitations on sensor mobility [J47]

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

Ground-penetrating radar (GPR) is capable to detect plastic antipersonnel landmines as well as other subsurface targets. In order to reduce false alarms, an option of automatic landmine discrimination from neutral minelike targets would be very useful. This paper presents a possibility for such discrimination and analyzes it experimentally. The authors investigate time-frequency features of an ultrawideband (UWB) target response for the discrimination between buried landmines and other objects. The discrimination method includes the extraction of an early-time target impulse response, its time-frequency transformation, and the extraction of time-frequency features based on a singular value decomposition of the transformed image. In order to take into account the changes in the UWB target signals, the experimental conditions are completely controlled to focus on the behavior of the target's response with respect to its depth and the horizontal position of the GPR above it. The dependence of the features on the GPR bandwidth is analyzed as well. The Mahalanobis distance is used as a criterion for optimal discrimination. The obtained results define the best features and conditions when the landmine discrimination is successful. For comparison, the discriminant power of the proposed features has been tested on a dataset, acquired during a field campaign in Angola [J48]

"Subsurface Sensing of Buried Objects Under a Randomly Rough Surface Using Scattered Electromagnetic Field Data"

This paper proposes a new inverse method for microwave-based subsurface sensing of lossy dielectric objects embedded in a dispersive lossy ground with an unknown rough surface. An iterative inversion algorithm is employed to reconstruct the geometry and dielectric properties of the half-space ground as well as that of the buried object. B-splines are used to model the shape of the object as well as the height of the rough surface. In

both cases, the control points for the spline function represent the unknowns to be recovered. A single-pole rational transfer function is used to capture the dispersive nature of the background. Here, the coefficients in the numerator and denominator are the unknowns. The approach presented in this paper is based on the state-of-the-art semianalytic mode matching forward model, which is a fast and efficient algorithm to determine the scattered electromagnetic fields. Numerical experiments involving two-dimensional geometries and TM incident plane waves demonstrate the accuracy and reliability of this inverse method [J49]

"Optimizing the Area Under a Receiver Operating Characteristic Curve With Application to Landmine Detection"

A common approach to training neural network classifiers in a supervised learning setting is to minimize the mean-square error (mse) between the network output for each labeled training sample and some desired output. In the context of landmine detection and discrimination, although the performance of an algorithm is correlated with the mse, it is ultimately evaluated by using receiver operating characteristic (ROC) curves. In general, the larger the area under the ROC curve (AUC), the better. We present a new method for maximizing the AUC. Desirable properties of the proposed algorithm are derived and discussed that differentiate it from previously proposed algorithms. A hypothesis test is used to compare the proposed algorithm to an existing algorithm. The false alarm rate achieved by the proposed algorithm is found to be less than that of the existing algorithm with 95% confidence [J50]

"Gamma-Ray Backscattering Tomography Approach Based on the Lidar Principle"

An approach is proposed, and its potentialities are studied, for single-sided gamma-ray in-depth sensing and tomography of dense opaque media. The approach is based on lidar (LIgth Detection And Ranging) principle or, in the present case, graydar (Gamma RAY Detection And Ranging) principle, that is, time-to-range resolved detection of the backscattering-due radiative returns from the probed object irradiated by pulsed gamma-photon pencil beams. The basic analysis and data processing delta-pulse single-scattering graydar equation is formulated by analogy with the lidar equation and is shown to be applicable, under some determinate conditions, to the problems of gamma-ray in-depth profiling of dense media. It is shown analytically and by computer simulations that the approach developed in the work would enable one, at large-enough but reasonable sensing photon fluxes and measurement time intervals, to determine with good controllable accuracy and resolution the location, the material content, and the mass density of different homogeneous ingredients inside the probed object as well as the mass (or electron) density distribution within one-material objects. This approach can be widely applied, e.g., for nondestructive material examination in industry and aviation, detection of landmines and explosives, investigating the constitution of archeological artifacts, etc [J51]

"Detection of Deeply Buried UXO Using CPT Magnetometers"

The location and identification of unexploded ordnance (UXO) from magnetometer measurements have long been an area of active research interest. Ground surface methods, which are widely used for objects buried in shallow depths, become ineffective for objects deep in the soil because the object's anomalous field diminishes rapidly with distance, and interference by metal debris on the ground surface is significant. For the location and identification of deeply buried UXO, a total-field magnetometer equipped with a cone penetrometer technology (CPT) drilling system is employed in this paper. A novel inversion method is developed to extract information from individual and multiple CPT profiles. Compared with conventional inversion methods providing a single minimum as an estimate, this approach tests the likelihood distribution over the anticipated solution space, hence providing reliability. Real-world data are collected from a test site for the location and identification of a specific target. All experiments and simulations demonstrate the superior capability of this technique in solving real-world problems when only limited data points are available [J52]

"Decision Fusion of Ground-Penetrating Radar and Metal Detector Algorithms—A Robust Approach"

Numerous detection algorithms, using various sensor modalities, have been developed for the detection of mines in cluttered and noisy backgrounds. The performance for each detection algorithm is typically reported in terms of the receiver operating characteristic (ROC), which is a plot of the probability of detection versus false alarm as a function of the threshold setting on the output decision variable of each algorithm. In this paper, we present multisensor decision-fusion algorithms that combine the local decisions of existing detection algorithms for different sensors. This offers an expedient, attractive, and much simpler alternative to the design of an algorithm that fuses multiple sensors at the data level, especially in cases of limited training data where it is difficult to make accurate estimates of multidimensional probability density functions. The goal of our multisensor decision-fusion approach is to exploit the complimentary strengths of existing multisensor algorithms so as to achieve

performance (ROC) that exceeds the performance of any sensor algorithm operating in isolation. Our approach to multisensor decision fusion is based on the optimal signal detection theory using the likelihood ratio. We consider the optimal fusion of local decisions for two sensors: a ground-penetrating radar and a metal detector. A new robust algorithm for decision fusion that addresses the problem in which the statistics of the training data are not likely to exactly match the statistics of the test data is presented. ROCs are presented and compared for field data [J53]

"Statistical Classification of Buried Unexploded Ordnance Using Nonparametric Prior Models"

We used kernel density estimation (KDE) methods to build a priori probability density functions (pdfs) for the vector of features that are used to classify unexploded ordnance items given electromagnetic-induction sensor data. This a priori information is then used to develop a new suite of estimation and classification algorithms. As opposed to the commonly used maximum-likelihood parameter estimation methods, here we employ a maximum a posteriori (MAP) estimation algorithm that makes use of KDE-generated pdfs. Similarly, we use KDE priors to develop a suite of classification schemes operating in both "feature" space as well as ldquosignal/datardquo space. In terms of feature-based methods, we construct a support vector machine classifier and its extension to support M-ary classification. The KDE pdfs are also used to synthesize a MAP feature-based classifier. To address the numerical challenges associated with the optimal data-space Bayesian classifier, we have used several approximation techniques, including Laplacian approximation and generalized likelihood ratio tests employing the priors. Using both simulations and real field data, we observe a significant improvement in classification performance due to the use of the KDE-based prior models. [J54]

"Signal Processing for Humanitarian Mine Action [JIn the Spotlight]"

{no data available} [J55]

"A Large-Scale Systematic Evaluation of Algorithms Using Ground-Penetrating Radar for Landmine Detection and Discrimination"

A variety of algorithms for the detection of landmines and discrimination between landmines and clutter objects have been presented. We discuss four quite different approaches in using data collected by a vehicle-mounted ground-penetrating radar sensor to detect landmines and distinguish them from clutter objects. One uses edge features in a hidden Markov model; the second uses geometric features in a feed-forward order-weighted average network; the third employs spectral features as its basis; and the fourth clusters edge histograms. We present the results of a large-scale cross-validation evaluation that uses a diverse set of data collected over 41 807.57 m2of ground, including 1593 mine encounters. Finally, we discuss the results of that ranking and what one can conclude concerning the performance of these four algorithms in various settings. [J56]

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

In this paper, we propose a new algorithm for the enhancement of plastic-cased antipersonnel mine detection using a video-impulse ground-penetrating radar (GPR). The algorithm is implemented as a nonlinear signal processor, which searches for the presence of a reference waveform in a 1D GPR echo return. The reference waveform represents a class of targets within a certain environment. The processor marks the presence of all responses similar to the reference waveform with a sharp mono-cycle. Simultaneously, responses with different waveforms, which presumably correspond to clutter, are suppressed. The reference waveform and other algorithm parameters are determined from training data sets acquired in a controlled environment. After training, the algorithm can be successfully applied at sites where soil, targets, and measurement scenarios are similar but not identical to those of the training site. The processor is integrated into an automated data processing and mine detection scheme as an additional clutter suppression step. The scheme consists of clutter suppression, synthetic aperture radar focusing, construction of a confidence map, and automated detection in it. The suggested algorithm is tested on experimental data, and its performance is compared against schemes where clutter suppression is organized by means of background removal and the cross correlation with a reference wavelet. The performance comparison is done in terms of receiver operating characteristic curves. It has been found that the suggested algorithm reduces the false alarm rate in about two and a half times in comparison to the cross-correlation-based clutter suppression. [J57]

"Joint TNT and RDX detection via quadrupole resonance"

Quadrupole resonance (QR) technology has been receiving increasing attention for explosive detection in applications including landmine detection. It can be used as a confirming sensor for buried plastic landmine detection by detecting the explosives within the mine. Since a single mine can contain more than one type of explosives (e.g., trinitrotoluene (TNT) and (RDX) compound), a detector designed to detect only one type of

explosive may not provide the best detection. We focus herein on the joint detection of TNT and RDX explosives for the landmine detection via the QR sensor. To mitigate the RF interferences (RFIs) associated with the QR measurements, we apply a doubly constrained robust Capon beamformer (DCRCB) to perform the spatial beamforming by exploiting the spatial correlation of the RFIs. Based on the output of the spatial DCRCB, we devise a generalized likelihood ratio test (GLRT) for the joint TNT/RDX detection, which is referred to as the DCRCB-GLRT detector. We show that our detector has the constant false alarm rate (CFAR) property and that the detection variable obeys a x2-mixture distribution in the mine-free scenario. The effectiveness of the proposed DCRCB-GLRT detector is demonstrated with the experimental data collected by Quantum Magnetics, Inc. [J58]

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

It is a trend to use airborne or vehicle-borne ultrawideband synthetic aperture radar (UWB SAR) to quickly detect subsurface objects, i.e., landmines or minefields, over large areas from a safe standoff distance. The traditional image formations without considering the refraction and dispersion of electromagnetic wave will lead to locating error and defocusing for subsurface objects. In this paper, an efficient refraction and dispersion effects compensation method is proposed, which can be integrated with the traditional three-stage automatic target detection framework for detection of subsurface landmines. The compensation method can focus and correctly locate multiple objects buried in different soils with different depths over large areas, which satisfies the operating requirement of an airborne or vehicle-borne UWB SAR system. The proposed method is proved efficient for subsurface object imaging by the field data collected by a UWB SAR system. [J59]

"Ultrawideband Synthetic Aperture Radar Landmine Detection"

In this paper, we consider landmine detection using ultrawideband synthetic aperture radar, where the two main challenges are feature extraction and discriminator design. The space-wavenumber processing is proposed to retrieve the frequency-and aspect-angle-dependent scattering features of suspected objects. In order to reduce the dimensionality of the input feature vector for a discriminator, the sequential forward floating selection method is used to choose efficient features. Based on the obtained feature vector, a fuzzy hypersphere support vector machine is designed to deal with the problem of detecting landmines in an unconstrained environment. The experimental results show that the proposed method can achieve a significant improvement in detection performance for antitank mines. [J60]

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

We propose a walled linearly tapered slot antenna (LTSA) array to visualize plastic landmines. Previously, we reported an adaptive nonlinear visualization system based on a complex-valued self-organizing map (CSOM) that deals with complex amplitude texture in reflection images at multiple frequencies. The system distinguishes landmines from clutter by paying attention to textural features obtained by high spatial resolution and wideband reflection measurement. Because the system employed a mechanical scan of a pair of horn antennas, the measurement required a long time. An array antenna can reduce the time. The antenna element to be used there should therefore be compact and wideband. This paper reports the design and fabrication of a walled LTSA array visualization system. The antenna element has a 14 times 28 mm aperture size, and works at the 8-12 GHz frequency band. Because the structure is a simple combination of glass epoxy substrates and metal plates, we can easily fabricate low-cost and lightweight arrays. Electrical switches realize a high-speed scanning of 12 times 12 = 144 elements in total. We also report the results of a visualization experiment, in which plastic landmines are clearly visualized with the array in combination with the adaptive CSOM processing. Detection of landmines at frequencies of 10 GHz is only likely to be possible for targets buried a few centimeter deep or where the soil attenuation is very low. This might be a severe limitation of applicability of the method, as in field conditions soil attenuations of 10 dB or considerably more are commonly encountered, requiring the radar to operate at frequencies below 2-3 GHz. The best solution may be a multisensor system comprising these complementary high- and low-frequency radars. [J61]

"Texture Features for Antitank Landmine Detection Using Ground Penetrating Radar"

In this paper, we consider the application of texture features for antitank landmine detection in ground-penetrating-radar data in the difficult scenario of very high clutter environments. In particular, we develop a technique for 3-D texture feature extraction, and we compare the results for landmine/clutter discrimination using classifiers that are built on 3-D as well as on 2-D texture feature sets. Our results indicate performance improvements across several different challenging testing scenarios when using the relevance-vector-machine classifiers that are trained on our 3-D feature sets as compared to the performance using the 2-D texture feature

sets. [J62]

"UWB Array-Based Sensor for Near-Field Imaging"

In this paper, the development of an ultra-wideband (UWB) array-based time-domain radar sensor for near-field imaging is described. The radar sensor is designed to be used within a vehicle-mounted multisensor system for humanitarian demining. The main novelty of the radar lies in the system design with a single transmitter and multichannel receiver. Design of the UWB antenna array is also novel. The radar produces 3D images of subsurface by 1D mechanical scanning. The imaging capability of the radar is realized via electronic steering of the receive antenna footprint in a cross-scan direction and synthetic aperture processing in an along-scan direction. Imaging via footprint steering allows for a drastic increase in the scanning speed. [J63]

"Adaptive Multimodality Sensing of Landmines"

The problem of adaptive multimodality sensing of landmines is considered based on electromagnetic induction (EMI) and ground-penetrating radar (GPR) sensors. Two formulations are considered based on a partially observable Markov decision process (POMDP) framework. In the first formulation, it is assumed that sufficient training data are available, and a POMDP model is designed based on physics-based features, with model selection performed via a variational Bayes analysis of several possible models. In the second approach, the training data are assumed absent or insufficient, and a lifelong-learning approach is considered, in which exploration and exploitation are integrated. We provide a detailed description of both formulations, with example results presented using measured EMI and GPR data, for buried mines and clutter [J64]

"Measured and Predicted Burial of Cylinders During the Indian Rocks Beach Experiment"

Burial of instrumented mine-like cylinders as a result of wave-induced scour was measured during experiments conducted in shallow water (15-16 m) with fine-sand (133-mum) and coarse-sand (566-mum) sediments off Indian rocks beach (IRB), FL. scour pits developed around the instrumented cylinders in the fine-sand site when significant waveheights exceeded 2 m, causing the cylinders to pitch, then roll into the developing scour pits, often changing heading to align parallel with the wave crest. Final cylinder burial was nearly 40 cm (about 70%-80% mine diameter) relative to the sediment-water interface, but only 20%-50% relative to surface area covered. The difference was caused by the lack of complete infilling of scour pits. Little development of scour pits and burial was noted on the coarse-sand site and the cylinders buried to only 20%-40% of the cylinder diameter below the sediment surface. Burial results, although variable, are in general agreement with the wave-induced scour model developed by Trembanis et al. (2007) for the fine sand, but not for the coarse sand where measured burial was much less than predicted. [J65]

"Foreword to the Special Issue on Subsurface Sensing Using Ground-Penetrating Radar (GPR)"

The 17 papers in this special issue focus on subsurface sensing using ground-penetrating radar (GPR). These papers describe new approaches to subsurface sensing, including developments in electromagnetic wave propagation imaging/inversion of GPR data and antenna/radar technologies. Associated applications range from glaciology to pavement evaluation to landmine detection. [J66]

"High-Resolution Mapping of Mines and Ripples at the Martha's Vineyard Coastal Observatory"

High-resolution multibeam sonar and state-of-the-art data processing and visualization techniques have been used to quantify the evolution of seafloor morphology and the degree of burial of instrumented mines and mine-shapes as part of the U.S. Office of Naval Research (ONR, Arlington, VA) mine burial experiment at the Martha's Vineyard Coastal Observatory (MVCO, Edgartown, MA). Four surveys were conducted over two years at the experiment site with a 455-kHz, Reson 8125 dynamically focused multibeam sonar. The region is characterized by shore-perpendicular alternating zones of coarse-grained sand with 5-25-cm-high, wave orbital-scale ripples, and zones of finer grained sands with smaller (2-5-cm-high) anorbital ripples and, on occasion, medium scale 10-20-cm-high, chaotic or hummocky bedforms. The boundaries between the zones appear to respond over periods of days to months to the predominant wave direction and energy. Smoothing and small shifts of the boundaries to the northeast take place during fair-weather wave conditions while erosion (scalloping of the boundary) and shifts to the north-northwest occur during storm conditions. The multibeam sonar was also able to resolve changes in the orientation and height of fields of ripples that were directly related to the differences in the prevailing wave direction and energy. The alignment of the small scale bedforms with the prevailing wave conditions appears to occur rapidly (on the order of hours or days) when the wave conditions exceed the threshold of sediment motion (most of the time for the fine sands) and particularly during moderate storm conditions. During storm events, erosional ldquowindowsrdquo to the coarse layer below appear in the fine-grained sands. These ldquowindowrdquo features are oriented parallel to the prevailing wave direction and

reveal orbital-scale ripples that are oriented perpendicular to the prevailing wave direction. The resolution of the multibeam sonar combined with 3-D visualization-techniques provided realistic looking images of both instrumented and noninstrumented mines and mine-like objects (including bomb, Manta, and Rockan shapes) that were dimensionally correct and enabled unambiguous identification of the mine type. In two of the surveys (October and December 2004), the mines in the fine-grained sands scoured into local pits but were still perfectly visible and identifiable with the multibeam sonar. In the April 2004 survey, the mines were not visible and apparently were completely buried. In the coarse-grained sand zone, the mines were extremely difficult to detect after initial scour burial as the mines bury until they present the same hydrodynamic roughness as the orbital-scale bedforms and thus blend into the ambient ripple field. Given the relatively large, 3-D, spatial coverage of the multibeam sonar along with its ability to measure the depth of the seafloor and the depth and dimensions of the mine, it is possible to measure directly, the burial by depth and burial by surface area of the mines. The 3-D nature of the multibeam sonar data also allows the direct determination of the volume of material removed from a scour pit. [J67]

"An Acoustic-Instrumented Mine for Studying Subsequent Burial"

The U.S. Navy is supporting the research to develop and validate stochastic, time-dependent, mine burial prediction models to aid the tactical decision making process. This research requires continuous monitoring of both mine behavior during burial, and the near-field processes responsible for burial. A new instrumented mine has been developed that far exceeds the capabilities of the earlier optically instrumented mine in terms of the burial processes that can be measured. The acoustic-instrumented mine (AIM) utilizes acoustic transducers to measure burial and scour, localized flow rates, and sediment size and concentration in the water column. The AIM also includes sensors for measuring mine orientation and movement, as well as oceanographic information such as significant waveheights, wave period, and water temperature. Four AIMs were constructed and deployed during the Indian Rocks Beach (IRB, FL) and Martha's Vineyard Coastal Observatory (MVCO, Edgartown, MA) mine burial experiments. The results from the field experiments have proven that the sensor suite is viable in providing a wealth of data that are critical in understanding and modeling the complex subsequent burial process. [J68]

"A Feasibility Test of Land Mine Detection in a Desert Environment Using Neutron Back Scattering Imaging"

The neutron back scattering technique is used to search for land mines. Advantages of this technique are: the speed of detection, the ability to detect metal free mines, and the insensitivity to metal and pebbles. The method is sensitive to soil moisture, therefore a desert environment is perfectly suited for application of the neutron backscattering technique. Tests were performed using various dummy mines and real defused mines in the Egyptian desert [J69]

"On a wing and a prayer [JDARPA and MEMS]"

Defense Advanced Research Projects Agency (DARPA) is offering funding for interdisciplinary research in the area of hybrid insect MEMS (microelectromechanical systems). DARPA aims to have MEMS intimately integrated into insects during their early stages of metamorphoses. In principle, this should lead to a more reliable bio-electromechanical interface to the insect, as compared with the earlier DARPA-funded attempts to glue the electronic module to an adult insect. DARPA's final demonstration goal is the delivery of an insect within five meters of a specific target located a hundred meters away using electronic remote control and/or GPS [J70]

"Electrical Impedance Tomographic Imaging of Buried Landmines"

A prototype confirmation landmine detector, based on electrical impedancetomography (EIT), which can operate under realistic environmental conditions, has been developed. Laboratory and field experiments demonstrated that it is possible to reliably reconstruct, on the scale of the electrode spacing (ES) (in width and depth), conductivity perturbations due to a shallow buried antitank mine or a similar object in a variety of soils (black earth, clay, sand) down to depths equal to the dimensions of the object (1-1.5 ES, equivalent to 14-21 cm for a 64-electrode 1 m times 1 m array). These represent the first EIT images of real landmines computed from measured data. Occasional problems were encountered with the electrical contact in very dry soils, with excessive insertion pressure being required for reliable electrode contact. However, poor contacts could be detected, and the offending probe was either reinserted or compensation was applied. A matched filter detection algorithm based on a replica of the object of interest was developed and shown to effectively reduce the false alarm rate of the detector. EIT is especially suited for wet lands and underwater, where other mine detectors perform poorly. Experiments in a water-and sediment-filled tank have demonstrated that detection of minelike objects in such an environment with a submerged array is feasible. These experiments represent the first EIT

measurements of targets using an electrode array submerged underwater. EIT may also have an application in locating intact mines in the berms formed by mine-clearing equipment. The EIT sensor head could be made cheaply enough to be disposable and remotely inserted to improve safety [J71]

"Magnetic models of unexploded ordnance"

Magnetometry is widely used for the characterization of areas contaminated by unexploded ordnance (UXO). To successfully discriminate hazardous UXO from nonhazardous clutter requires accurate models of the ordnance response. This paper develops an ordnance library with 15 different items using total-field magnetic data collected over a test stand. The induced and remanent magnetizations were obtained by varying the three-dimensional orientation of each item and measuring the magnetic field on a horizontal plane in the dipolar regime. Replicate measurements using multiple specimens of the same ordnance returned very similar induced magnetizations. The fitted moments were used to estimate the detection depths for different sensor noise floors. A prolate spheroid with a 3.5 aspect ratio was used to provide a good approximation to the detection depths for many of the ordnance items. Assuming a 1-nT noise floor, these orientation-dependent detection depths ranged from 10 to 17 times of the object's diameter [J72]

"Landmines Ground-Penetrating Radar Signal Enhancement by Digital Filtering"

Until now, humanitarian demining has been unable to provide a solution to the landmine removal problem. Furthermore, new low-cost methods have to be developed quickly. While much progress has been made with the introduction of new sensor types, other problems have been raised by these sensors. Ground-penetrating radars (GPRs) are key sensors for landmine detection as they are capable of detecting landmines with low metal contents. GPRs deliver so-called Bscan data, which are, roughly, vertical slice images of the ground. However, due to the high dielectric permittivity contrast at the air-ground interface, a strong response is recorded at an early time by GPRs. This response is the main component of the so-called clutter noise, and it blurs the responses of landmines buried at shallow depths. The landmine detection task is therefore quite difficult, and a preprocessing step, which aims at reducing the clutter, is often needed. In this paper, a difficult case for clutter reduction, that is, when landmines and clutter responses overlap in time, is presented. A new and simple clutter removal method based on the design of a two-dimensional digital filter, which is adapted to Bscan data, is proposed. The designed filter must reduce the clutter on Bscan data significantly while protecting the landmine responses. In order to do so, a frequency analysis of a clutter geometrical model is first led. Then, the same process is applied to a geometrical model of a signal coming from a landmine. This results in building a high-pass digital filter and determining its cutoff frequencies. Finally, simulations are presented on simulated and real data, and a comparison with the classical clutter removal algorithm is made [J73]

"Signal subspace change detection in averaged multilook SAR imagery"

This paper addresses change detection in averaged multilook synthetic aperture radar (SAR) imagery. Averaged multilook SAR images are preferable to full-aperture SAR reconstructions when the imaging algorithm is approximation-based (e.g., polar format processing) or when motion data are not accurate over a long full aperture. We examine the application of a SAR change-detection method, known as signal subspace processing, which is based on the principles of two-dimensional adaptive filtering, and we use it to recognize the addition of surface landmines to a particular area under surveillance. We describe the change-detection problem as a trinary hypothesis testing problem, and define a change signal and its normalized version to determine whether: 1) there is no change in the imaged scene; 2) a target has entered the imaged scene; or 3) a target has exited the imaged scene. A statistical analysis of the error signal is provided to show its properties and merits. Results are presented for averaged noncoherent multilook and coherent single-look X-band SAR imagery. [J74]

"Enhanced discrimination among UXO-like targets using extremely low-frequency magnetic fields"

We show that the ability to discriminate among unexploded ordnance (UXO) targets is enhanced by extending the measurement range of our continuous-wave (CW) electromagnetic induction (EMI) system down to extremely low frequencies (ELFs). In particular, we demonstrate that for a typical UXO target set, when data in the range 30 Hz to 24 kHz are extended downward toward 1-Hz discrimination performance improves by a factor of 1.5. Measurements and numerical simulations show that very low frequency magnetic fields penetrate deep into the target, enabling one to discriminate between thick- and thin-walled ferrous cylinders that are otherwise visually identical. Data acquisition at extremely low frequencies is a time-consuming process especially if data averaging is required to achieve acceptable signal-to-noise ratio. Therefore, in practice, discrimination improvement using ELF is probably best carried out using a "cued" approach. In a "cued" approach, target locations would be marked using another detection technique (e.g., a simple total-field magnetometer), and the low-frequency CW EMI system would be deployed to these known target locations for classification. [J75]

"Mutual induction and the effect of host conductivity on the EM induction response of buried plate targets using 3-D finite-element analysis"

A finite-element analysis of electromagnetic induction (EMI) in the presence of multiple buried metal targets is undertaken for the purpose of unexploded ordnance (UXO) detection and discrimination. The effects of mutual coupling between metal targets and the host conductivity are shown to be important. At high frequencies, mutual coupling is strong, and effects of host conductivity are relatively minor. At lower frequencies near the resistive limit, EMI responses are very small, but the effect of host conductivity becomes important. This is due to the galvanic current flow in the host medium that dissipates charge accumulations on the host/target interfaces. Qualitative analysis of induced current patterns in metal targets demonstrates that mutual coupling is strongly affected by target orientation and skin depth. Rigorous forward modeling of EMI responses is essential to understanding UXO sensor signatures so that discrimination between live UXO items and harmless fragments and clutter may become possible. [J76]

"New Products"

In this issue, we review two products that enhance vehicular transportation: a Bluetooth audio head unit that seamlessly integrates with mobile phones and a system that: uses mobile phone network usage data to determine average traffic speeds and areas of congestion. We also report on a laptop and related WiFi technology that significantly tower the barrier to such technologies' use in developing countries and a device that helps soldiers disarm landmines. We describe Ballbot, a battery-operated omnidirectional robot that moves by balancing dynamically on a single urethane-coated metal sphere. We also report on wireless memory chip, called memory spot, that contains a built-in antenna and can store up to several Mbytes of data [J77]

"On a wing and a prayer"

The article talks about recent Defense Research Projects Agency (DARPA) presolicitation notice in the area of hybrid insect micro-electromechanical systems (MEMs). DARPA's goal is to fund promising interdisciplinary research that will permit the creation of "insect-cyborgs" [J78]

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

A two-stage algorithm for landmine detection with a ground penetrating radar (GPR) system is described. First, 3-D data sets are processed using a computationally inexpensive pre-screening algorithm which flags potential locations of interest. These flagged locations are then passed to a feature-based processor which further discriminates target-like anomalies from naturally occurring clutter. Current field trial (over 6500 square meters) and blind test results (over 39000 square meters) are presented and these show at least an order of magnitude improvement over other radar system-based detection algorithms on the same test lanes. [J79]

"Land mine detection with neutron back scattering imaging using a neutron generator"

The neutron back scattering technique may be used to search for low-metallic land mines. An advantage of this technique is the speed of detection: the scanning speed may be made comparable to that of a metal detector. The method is sensitive to soil moisture. A limitation of the method is therefore that the soil must be sufficiently dry. The neutrons are produced with a pulsed neutron generator. An image of the back scattered thermal neutron radiation is obtained with a two dimensional position sensitive detector. Getting optimal settings for the detector system is described. The mine detection time as function of the neutron pulse parameters is investigated. Results with various dummy mines are presented [J80]

"Exploiting temperature dependency in the detection of NQR signals"

Nuclear quadrupole resonance (NQR) offers an unequivocal method of detecting and identifying land mines. Unfortunately, the practical use of NQR is restricted by the low signal-to-noise ratio (SNR), and the means to improve the SNR are vital to enable a rapid, reliable, and convenient system. In this paper, an approximate maximum-likelihood detector (AML) is developed, exploiting the temperature dependency of the NQR frequencies as a way to enhance the SNR. Numerical evaluation using both simulated and real NQR data indicate a significant gain in probability of accurate detection as compared with the current state-of-the-art approach. [J81]

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

A method for obtaining the Bayesian network (BN) representation of a sensor's measurement process is

developed so that the problems of sensor fusion and management can be approached from a unified point of view. Uncertainty, reliability, and causal information embedded in the sensor data are used to build the BN model of a sensor. The method is applied to model ground-penetrating radar, electromagnetic induction, and infrared sensors for humanitarian demining. Structural and parameter learning algorithms are employed to encode relationships among mine features, sensor measurements, and environmental conditions in the BN model. Inference is used to estimate target features in the presence of heterogeneous soil and varying environmental conditions. A multisensor fusion technique operating on BN models is developed to exploit the complementarity of the sensor measurements. Through the same approach, a BN classifier is obtained to estimate the target typology. The BN models and classifier also compute so-called confidence levels that quantify the uncertainty associated with the feature estimates and the classification decisions. The effectiveness of the approach is demonstrated by implementing these BN tools for the detection and classification of metal and plastic landmines that are characterized by different shape, size, depth, and metal content. Through BN fusion, the accuracy of the feature estimates is improved by up to 64% with respect to single-sensor measurements, and the number of objects that are both detected and classified is increased by up to 62%. [J82]

"An abrupt change detection algorithm for buried landmines localization"

Ground-penetrating radars (GPRs) are very promising sensors for landmine detection as they are capable of detecting landmines with low metal contents. GPRs deliver so-called Bscan data which are, roughly, vertical slice images of the ground. However, due to the high dielectric permittivity contrast at the air-ground interface, a strong response is recorded at early time by GPRs. This response is the main component of the so-called clutter noise and it blurs the responses of landmines buried at shallow depths. The landmine detection task is therefore quite difficult. This paper proposes a new method for automated detection and localization of buried objects from Bscan records. A support vector machine algorithm for online abrupt change detection is implemented and proves to be efficient in detecting buried landmines from Bscan data. The proposed procedure performance is evaluated using simulated and real data. [J83]

"Fuzzy spatial pattern processing using linguistic hidden Markov models"

In this work, we propose a hidden Markov model (HMM), called the linguistic HMM, suitable for processing sequences of fuzzy vectors. A fuzzy vector B is an n-tuple of fuzzy numbers. Since fuzzy numbers are often associated with linguistic terms, such as "small," "medium," etc., a fuzzy vector can also be called a linguistic vector. Similarly, an HMM that processes linguistic vectors can be called a "linguistic HMM." The derivation of the linguistic HMM (LHMM) from the continuous HMM is performed using the extension principle and the decomposition theorem. We prove that a LHMM behaves in the same fashion as the CHMM in the degenerate linguistic case when the fuzzy numbers are singletons (real numbers). We also provide an example where an LHMM was used for the recognition of a play (pick-and-shoot) during a basketball game. The positions of the players were described using spatial fuzzy relations. For the recognition experiment, we generated two sets of 100 sequences containing pick-and-shoot and non pick-and-shoot sequences, respectively. The LHMM results obtained for the fuzzy sequences were compared to the CHMM results obtained on a crisp version of the same sequences. The results obtained showed that the fuzzy spatial relations together with the LHMM provide a better description of the movement than the CHMM. [J84]

"Mars exploration rover surface operations: driving opportunity at Meridiani Planum"

Since landing on the Meridiani Planum region of Mars in January 2004, the Mars exploration rover (MER) vehicle named Opportunity has been sending back pictures taken from several different craters that would provide evidence that the region did indeed have a watery past. This paper details the experience of driving Opportunity through this alien landscape during its first 400 days on Mars, from the point of view of the other rover planners, the people who tell the rover where to drive and how to use its robotic arm [J85]

"Deployment of mobile robots with energy and timing constraints"

Mobile robots can be used in many applications, such as carpet cleaning, search and rescue, and exploration. Many studies have been devoted to the control, sensing, and communication of robots. However, the deployment of robots has not been fully addressed. The deployment problem is to determine the number of groups unloaded by a carrier, the number of robots in each group, and the initial locations of those robots. This paper investigates robot deployment for coverage tasks. Both timing and energy constraints are considered; the robots carry limited energy and need to finish the tasks before deadlines. We build power models for mobile robots and calculate the robots' power consumption at different speeds. A speed-management method is proposed to decide the traveling speeds to maximize the traveling distance under both energy and timing constraints. Our method uses rectangle scanlines as the coverage routes, and solves the deployment problem using fewer robots. Finally, we provide an

approach to consider areas with random obstacles. Compared with two simple heuristics, our solution uses 36% fewer robots for open areas and 32% fewer robots for areas with obstacles. [J86]

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

Ground-penetrating radar (GPR) has been widely used for landmine detection due to its high signal-to-noise ratio (SNR) and superior ability to image nonmetallic landmines. Processing GPR data to obtain better target images and to assist further object detection has been an active research area. Phase-shift migration is a widely used method; however, its wavenumber space is nonuniformly sampled because of the nonlinear relationship between the uniform frequency samples and the wavenumbers. Conventional methods use linear interpolation to obtain uniform wavenumber samples and compute the fast Fourier transform (FFT). This paper develops two- and three-dimensional migration methods that process GPR data to obtain images close to the actual target geometries using a nonuniform fast Fourier transform (NUFFT) algorithm. The proposed method is first compared to the conventional migration approaches on simulated data and then applied to landmine field data sets. Results suggest that the NUFFT migration method is useful in focusing images, estimating landmine structure, and retaining relatively high signal-to-noise ratio in the migrated data. The processed data sets are then fed to the normalized energy and least-mean-square-based anomaly detectors. Receiver operating characteristic curves of data sets processed by different migration methods are compared. The NUFFT migration shows potential improvements on both classifiers with a reduced false alarm rate at most probabilities of detection. [J87]

"Effects of soil electromagnetic properties on metal detectors"

This paper presents an analysis, based on existing work in geophysics and nondestructive testing, of the effects of soil electromagnetic properties on the functioning of metal detectors widely used to detect buried landmines. The host soil is modeled as a half-space having real and frequency-independent electrical conductivity but frequency-dependent complex magnetic susceptibility. The analysis technique has been applied to three examples of soil of practical importance, namely, nonconducting soil with frequency-independent susceptibility, nonconducting soil with frequency-dependent susceptibility, and nonmagnetic soil with constant conductivity. Simplifications are made to clearly explain a number of previous field and experimental observations, for example, the greater influence of magnetic properties than of electrical conductivity on the performance of metal detectors. Results also show that soil magnetic properties affect continuous wave and pulsed-induction detectors differently. The effect that electrical conductivity and magnetic susceptibility of the host soil have on the signal produced by a target is investigated by computing the response of a buried small metallic sphere. Computations show that in some cases, which could represent practical landmine detection scenarios, the signal from the soil can dominate that due to the target, making it hard to detect the target. Further, it is shown that magnetic soil can alter a target's spectral response, which implies that, contrary to present practice, object identification techniques should take into account the electromagnetic parameters of the host medium. [J88]

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

Two common Fourier imaging algorithms used in ground penetrating radar (GPR), synthetic aperture radar (SAR), and frequency-wavenumber (F-K) migration, are reviewed and compared from a theoretical perspective. The two algorithms, while arising from seemingly different physical models: a point-scatterer model for SAR and the exploding source model for F-K migration, result in similar imaging equations. Both algorithms are derived from an integral equation formulation of the inverse scalar wave problem, which allows a clear understanding of the approximations being made in each algorithm and allows a direct comparison. This derivation brings out the similarities of the two techniques which are hidden by the traditional formulations based on physical scattering models. The comparison shows that the approximations required to derive each technique from the integral equation formulation of the inverse problem are nearly identical, and hence the two imaging algorithms and physical models are making similar assumptions about the solution to the inverse problem, thus clarifying why the imaging equations are so similar. Sample images of landmine-like targets buried in sand are obtained from experimental GPR data using both algorithms. [J89]

"Landmine detection and classification with complex-valued hybrid neural network using scattering parameters dataset"

Neural networks have been applied to landmine detection from data generated by different kinds of sensors. Real-valued neural networks have been used for detecting landmines from scattering parameters measured by ground penetrating radar (GPR) after disregarding phase information. This paper presents results using complex-

valued neural networks, capable of phase-sensitive detection followed by classification. A two-layer hybrid neural network structure incorporating both supervised and unsupervised learning is proposed to detect and then classify the types of landmines. Tests are also reported on a benchmark data. [J90]

"Neutron beam design for low-intensity neutron and gamma-ray radioscopy using small neutron sources"

Two small neutron sources of 252Cf and 241Am-Be radioisotopes were used for design of neutron beams applicable to low-intensity neutron and gamma-ray radioscopy (LINGR). In the design, Monte Carlo code (MCNP) was employed to generate neutron and gamma-ray beams suited to LINGR. With a view to variable neutron spectrum and neutron intensity, various arrangements were first examined, and neutron-filter, gamma-ray shield, and beam collimator were verified. Monte Carlo calculations indicated that with a suitable filter-shield-collimator arrangement, thermal neutron beam of 3900 ncm-2s-1with neutron/gamma ratio of 7 Ч 107, and 25 ncm-2s-1with very large neutron/gamma ratio, respectively, could be produced by using a 252Cf (122 μg) and a 241Am-Be (37 GBq) radioisotopes at the irradiation port of 35 cm from the neutron sources. [J91]

"Use of fiducials and unsurveyed landmarks as geolocation tools in vehicular-based landmine search"

When searching for land mines using vehicular-mounted sensors, it is important that the ground locations of the detected mines be accurately determined. This is useful for data association when one has multiple looks at a mine by a single sensor or if one uses multiple sensors. It is of ultimate importance for the primary mission, which is to neutralize the detected mines or mark them for avoidance. This paper addresses the use of surveyed landmarks, i.e., fiducials, as well as unsurveyed but visible landmarks within the sensor field of view for improving the geolocation accuracy. Preliminary results show that in fact geolocation accuracy can be improved significantly by using these tools. The method is primarily applicable to combat situations where a road is to be cleared for advancing troops and equipment. This is in contrast to humanitarian demining where one has more time and can approach suspected landmines from different viewpoints. [J92]

"Kalman filtering for enhanced landmine detection using quadrupole resonance"

Quadrupole resonance (QR) is a novel technology recently applied to landmine detection. The detection process is specific to the chemistry of the explosive, and therefore is less susceptible to the types of false alarms experienced by metal detectors and ground-penetrating radars. Although QR is vulnerable to radio-frequency interference (RFI) when the sensor is deployed in the field, adaptive RFI mitigation can remove most of the RFI. In this paper, advanced signal processing algorithms applied to the postmitigation signal are studied to enhance explosive detection. A new Kalman filtering strategy is proposed to estimate and detect the QR signal in the postmitigation signal. The results using both simulated data and experimental data show that the proposed algorithm can provide robust landmine detection performance. [J93]

"Optimizing receiver configurations for resolution of equivalent dipole polarizabilities in situ"

Equivalent dipole polarizabilities are a succinct way to summarize the inductive response of an isolated conductive body at distances greater than the scale of the body. At any time lag or frequency, an equivalent dipole polarizability response is comprised of nine parameters: six specifying an equivalent dipole polarizability matrix (which is symmetric) and three specifying the apparent location of the body center. Smith and Morrison have given equations for calculating uncertainties in equivalent dipole polarizability and position based on analysis of an iterative linearized inversion. Here, the root mean squared uncertainty in polarizability is weighted and summed over a number of control points and minimized using an evolutionary algorithm for a number of instrument designs. Three families of designs are presented: single-transmitter systems for use on a two-dimensional grid of positions with negligible error in relative instrument location, two-transmitter systems for use on a line of positions with negligible error in relative instrument location, and three-transmitter systems for stand alone use. Results for the one- and two-transmitter systems are strongly degraded by errors in instrument position, whereas the three-transmitter systems are insensitive to instrument positioning errors. [J94]

"Kernel RX-algorithm: a nonlinear anomaly detector for hyperspectral imagery"

We present a nonlinear version of the well-known anomaly detection method referred to as the RX-algorithm. Extending this algorithm to a feature space associated with the original input space via a certain nonlinear mapping function can provide a nonlinear version of the RX-algorithm. This nonlinear RX-algorithm, referred to as the kernel RX-algorithm, is basically intractable mainly due to the high dimensionality of the feature space produced by the nonlinear mapping function. However, in this paper it is shown that the kernel RX-algorithm can

easily be implemented by kernelizing the RX-algorithm in the feature space in terms of kernels that implicitly compute dot products in the feature space. Improved performance of the kernel RX-algorithm over the conventional RX-algorithm is shown by testing several hyperspectral imagery for military target and mine detection. [J95]

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

Ground-penetrating radar (GPR) has been proposed as an alternative to classical electromagnetic induction techniques for the landmine detection problem. The Wichmann/Niitek system provides a good platform for novel GPR-based antitank mine detection and classification algorithm development due to its extremely high SNR. When the GPR sensor is mounted on a moving vehicle, the target signatures are hyperbolas in a time-domain data record. The goal of this work is to extract useful features that exploit this knowledge in order to improve target detection. The algorithms can be divided into two steps: feature extraction and classification. Preprocessing is also considered to remove both stationary effects and nonstationary drift of the data and to improve the contrast of the desired hyperbolas. The algorithm is evaluated using real data over primarily plastic antitank mines collected with a fielded GPR sensor at a government test site. [J96]

"Scattering by a finite set of perfectly conducting cylinders buried in a dielectric half-space: a spectral-domain solution"

An analytical-numerical technique, for the solution of the two-dimensional electromagnetic plane-wave scattering by a finite set of perfectly conducting circular cylinders buried in a dielectric half-space, is presented. The problem is solved for both the near- and the far-field regions, for TM and TE polarizations. The diffracted field is represented in terms of a superposition of cylindrical waves and use is made of the plane-wave spectrum to take into account the reflection and transmission of such waves by the interface. The validity of the approach is confirmed by comparisons with results available in the literature, with very good agreement. The multiple interactions between two buried cylinders have been studied by considering both the induced currents and the scattered field diagrams. Applications of the method to objects of arbitrary cross-section simulated by a suitable configuration of circular cylinders are shown. [J97]

"Landmine geo-location using dynamic modeling and target tracking"

Geo-location is essential for landmine search using vehicular-mounted sensors. The vehicle and targets were combined into an incorporated model versus a separated model. Colored noise modeling is required for the separated model since the vehicle estimate errors are colored. An inventory is introduced for maintaining information on detected mines. Results from simulations using actual data indicate precision of 0.25 m indicating promise for the method. [J98]

"Practical landmine detector using forward-looking ground penetrating radar"

A practical landmine detector using forward-looking ground penetrating radar is presented. The detector uses a wavelet packet transform and the sequential feature selection algorithm to extract the most discriminant information distributed in the joint time-frequency domain for detecting landmines. A cascade training method that allows the detector to continue learning from errors made on unseen environments to improve its detection performance is also proposed. The testing results based on a recently conducted blind test are presented. [J99]

"Metalloporphyrins as sensing material for quartz-crystal microbalance nitroaromatics sensors"

Five octaethylporphyrins (OEP) and tetraphenylporphyrins (TPP): (OEP)InCl, (OEP)MnCl, (OEP)GaCl, (TPP)Pd, and (TPP)RhI have been deposited as sensitive coating onto quartz-crystal microbalances. The sensitivities of the resulting sensors have been measured with respect to 2,4-dinitrotrifluoromethoxybenzene vapors. When exposed to the nitroaromatic compound, a large and significative response is recorded for every tested porphyrin, the detection process being slightly reversible. Along with a good sensitivity, the sensors exhibit an excellent selectivity when common solvents are used as interfering vapors. Among all the studied derivatives, (OEP)MnCl appears as the most sensitive and selective coating. [J100]

"Frequency-selective detection of nuclear quadrupole resonance signals"

Nuclear quadrupole resonance (NQR) offers an unequivocal method of detecting and identifying both hidden explosives, such as land mines, and a variety of narcotics. Unfortunately, the practical use of NQR is restricted by a low signal-to-noise ratio (SNR), and means to improve the SNR are vital to enable a rapid, reliable, and convenient system. In this paper, we introduce a frequency-selective approximate maximum-likelihood (FSAML)

detector, operating on a subset of the available frequencies, making it robust to the typically present narrow-band interference. The method exploits the inherent temperature dependency of the NQR frequencies as a way to enhance the SNR. Numerical evaluations, using both simulated and real NQR data, indicate a significant gain in probability of accurate detection as compared to a current state-of-the-art approach. [J101]

"Characterization and comparative evaluation of novel planar electromagnetic sensors"

The characterization of three types of novel planar electromagnetic sensors: 1) meander; 2) mesh; and 3) interdigital configuration, has been studied and their comparative performance has been evaluated based on their areas of applications. All of them are suitable for inspection and evaluation of system properties without destroying them. The experiments on fabricated sensors have been conducted and the results are presented here. The target application is to use a mixture of different types of sensors to detect plastic landmines. [J102]

"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. [J103]

"Adaptive learning approach to landmine detection"

We consider landmine detection using forward-looking ground penetrating radar (FLGPR). The two main challenging tasks include extracting intricate structures of target signals and adapting a classifier to the surrounding environment through learning. Through the time-frequency (TF) analysis, we find that the most discriminant information is TF localized. This observation motivates us to use the over-complete wavelet packet transform (WPT) to sparsely represent signals with the discriminant information encoded into several bases. Then the sequential floating forward selection method is used to extract these components and thereby a neural network (NNW) classifier is designed. To further improve the classification performance and deal with the problem of detecting mines in an unconstraint environment, the AdaBoost algorithm is used. We integrate the feature selection process into the original AdaBoost algorithm. In each iteration, AdaBoost identifies the hard-to-learn examples and a new set of features which provide the specific discriminant information for these hard samples is extracted adaptively and a new classifier is trained. Experimental results based on measured data are presented, showing that a significant improvement on the classification performance can be achieved. [J104]

"Adaptive imaging for forward-looking ground penetrating radar"

Most of the current forward-looking ground-penetrating radar (FLGPR) systems use conventional delay-and-sum (DAS) based methods to form radar images for detection of the target (such as a landmine). However, DAS is a data-independent approach which is known to suffer from low resolution and poor interference and clutter rejection capability. We present a data-adaptive imaging approach for FLGPR image formation based on APES (amplitude and phase estimation) and rank-deficient RCB (robust Capon beamforming). Due to the data-adaptive nature of both APES and RCB, our approach has better resolution and much better interference and clutter rejection capability than the standard DAS-based imaging methods. The excellent performance of the proposed method is demonstrated using experimental data collected via two FLGPR systems recently developed by PSI (Planning Systems, Inc.) and SRI (Stanford Research Institute). [J105]

"Laser-induced breakdown spectroscopy (LIBS): a promising versatile chemical sensor technology for hazardous material detection"

A series of laboratory experiments have been performed highlighting the potential of laser-induced breakdown spectroscopy (LIBS) as a versatile sensor for the detection of terrorist threats. LIBS has multiple attributes that

provide the promise of unprecedented performance for hazardous material detection and identification. These include: 1) real-time analysis, 2) high sensitivity, 3) no sample preparation, and 4) the ability to detect all elements and virtually all hazards, both molecular and biological. We have used LIBS to interrogate a variety of different target samples, including explosives, chemical warfare simulants, biological agent simulants, and landmine casings. We have used the acquired spectra to demonstrate discrimination between different chemical warfare simulants, including those on soil backgrounds. A linear correlation technique permits discrimination between an anthrax surrogate and several other biomaterials such as molds and pollens. We also use broadband LIBS to identify landmine casings versus other plastics and environmental clutter materials. A new man-portable LIBS system developed as a collaborative effort between the U.S. Army Research Laboratory and Ocean Optics, Inc., is described and several other schemes for implementing LIBS sensors for homeland security and force protection are discussed. [J106]

"A novel surface plasmon resonance immunosensor for 2,4,6-trinitrotoluene (TNT) based on indirect competitive immunoreaction: a promising approach for on-site landmine detection"

A surface plasmon resonance (SPR) immunosensor for the determination of 2,4,6-trinitrotoluene (TNT) has been developed based on the principle of indirect competitive immunoreaction. 2,4,6-trinitrophenol-bovine serum albumin (TNP-BSA) conjugate was immobilized onto a SPR gold chip by means of simple physical adsorption. Binding of anti-TNP antibody with TNP-BSA conjugate was detected based on an increase in resonance angle due to antigen-antibody interaction. Preincubation of anti-TNP antibody with TNT suppresses its interaction with immobilized TNP-BSA conjugate, which leads to a decrease in resonance angle shift. Following the dependence of the resonance angle shift, concentration of TNT was detected. Pepsin solution was used for the regeneration of the sensing surface. The response time for TNT measurement is about 22 min. The immunosensor showed excellent sensitivity to TNT in a wide concentration range from 60 ppt to 1000 ppb with good selectivity, stability, and reproducibility. The proposed system is promising for future application for the on-site detection of landmines. [J107]

"Fast and accurate calculation of physically complete EMI response by a heterogeneous metallic object"

In this paper, the coupling and close-proximity effects arising between highly conducting and permeable metallic objects are exposed and analyzed, for the electromagnetic induction (EMI) frequency range (from tens of hertz up to several hundreds of kilohertz). To understand the physics of the interaction phenomena, a numerical technique is applied, consisting of the full method of auxiliary sources (MAS) at low frequencies and a combination of the MAS with thin-skin approximation (TSA) at high frequencies. Both numerical MAS-MAS/TSA and experimental studies have shown that the scattered field from a heterogeneous target generated as a simple superposition of independent responses from each part can be very different from the field determined from whole object with full internal interaction. A new numerical technique for fast and accurate representation of EMI responses for heterogeneous objects is pursued here, applicable to any three-dimensional heterogeneous object placed in an arbitrary time-varying EMI field. First, any primary magnetic field input is decomposed into the spheroidal modes over a fictitious surface surrounding the object. Then, for each input spheroidal mode, the full EMI problem including all interaction is solved using the MAS-MAS/TSA technique, and each modal response is reproduced using a compact reduced set of sources (RSS). Finally, the total response from the given target for any other excitation can be synthesized simply by calculating that primary field's constituent spheroidal modes and combining their stored responses. Several numerical examples are designed to show how an object's electromagnetic parameters, geometry, distance between objects, antenna positions, and orientations relative to the object affect the coupling. Comparisons between numerical and measured data for a machined composite object and for an actual unexploded ordnance demonstrate the superior accuracy and applicability of the MAS-MAS/TSA RSS model over simple dipole approximations, for certain classes of heterogeneous objects. [J108]

"Eddy-current and current-channeling response to spheroidal anomalies"

We derive the electromagnetic induction (EMI) response to conducting anomalies of spheroidal shape embedded in a weakly conducting host medium. As one application, prolate and oblate spheroids are convenient shapes for modeling buried unexploded ordnance, landmines, and naval mines. Under the assumptions of a perfectly conducting or nonconducting target and the assumption of a uniformly incident field, simple analytical solutions are obtained. Both the eddy-current and the current channeling responses are derived for prolate and oblate spheroids. For example, in a marine environment the current-channeling contribution can be quite large. As expected, these responses differ depending on the direction of the incident field relative to the spheroidal symmetry axis. The problem is solved separately for axial and transverse incidence, with the general case being a superposition of the two. These solutions could be used for fitting a spheroidal model to EMI data in which a small number of parameters, such as the location, size, shape, and orientation of the object, are to be

determined. [J109]

"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. [J110]

"New approximate formulations for EM scattering by dielectric objects"

The extended Born approximation (ExBorn) has been shown an efficient formulation in the electromagnetic (EM) scattering by dielectric objects in both free-space and air-Earth half-space problems. In most cases, ExBorn is much more accurate than the conventional Born approximation at low frequencies. When the frequency is high or the contrast of dielectric objects is large, however, the ExBorn approximation becomes inaccurate. In this paper, new approximations are proposed for the EM scattering by dielectric objects buried in a lossy Earth, which are also suitable for the case of free space. It has been shown that the zeroth-order form of new approximations is completely equivalent to ExBorn. Hence, high-order approximations can be regarded as high-order ExBorn. Closed-form formulations are derived for the new approximations. Using the fast Fourier transform (FFT), these formulations can be implemented efficiently at a cost of CNlogN, where N is the number of unknowns and C is a small number. Numerical simulations show that high-order ExBorn approximations are much more accurate than the ExBorn approximation. [J111]

"Cramer-Rao lower bound for estimating quadrupole resonance signals in non-Gaussian noise"

Quadrupole resonance (QR) technology for the detection of explosives is of crucial importance in an increasing number of applications. For landmine detection, where the detection system cannot be shielded, QR has proven to be highly effective if the QR sensor is not exposed to radio-frequency interference (RFI). However, strong non-Gaussian RFI in the field is unavoidable. A statistical model of such non-Gaussian RFI noise is given in this letter. In addition, the asymptotic Cramer-Rao lower bound for estimating a deterministic QR signal in this non-Gaussian noise is presented. The performance of several convenient estimators is compared to this bound. [J112]

"On the low-frequency EMI response of coincident loops over a conductive and permeable soil and corresponding background reduction schemes"

The performance of metal detectors (low-frequency electromagnetic induction (EMI) devices) employed for landmine and ordnance detection is well known to be adversely affected by the soil response, a fact which is, however, not very often considered in the scientific literature. We have, therefore, started from the analytical model of a frequency domain coincident loop system over a homogeneous half-space to calculate directly the voltage induced in the system's receive coil, for a number of scenarios and soil parameters of interest, and with emphasis on the operating conditions prevailing in humanitarian demining applications. The role of the soil's permeability, which heavily affects the real part of the system's response function, has been clearly shown (plateau effect at low-frequencies), as well as the effects of changes in the detector's height . Some of the background rejection techniques used in practice, in particular frequency differencing methods to suppress the effect of magnetic and/or conductive soil, have been described as well, and two of them studied in more detail, including the unavoidable target response reduction. Finally, we have briefly dealt with the effect of a conductive soil on the primary and scattered fields themselves, which could affect in a nonadditive way the target signature. Practical background information and an extensive list of references complement the paper. [J113]

"Application of the biorthogonal multiresolution time-domain method to the analysis of elastic-wave interactions with buried targets"

The biorthogonal multiresolution time-domain (Bi-MRTD) method is introduced for the analysis of elastic-wave interaction with buried targets. We provide a detailed discussion on implementation of the perfectly matched layer and on treatment of the interface between two different materials. The algorithm has also been parallelized by the use of the message-passing interface. The numerical results show that numerical dispersion can be

significantly improved by using biorthogonal wavelets as bases, as compared to the conventional pulse expansion employed in the finite-difference time-domain (FDTD) method. We demonstrate that with comparison to the second-order FDTD, the Bi-MRTD yields significant CPU time and memory savings for large problems, for a fixed level of accuracy. [J114]

"The illusion of web privacy"

The author discusses how, for the ordinary netizen, it's surprisingly hard to be anonymous online. [J115]

"Discrimination mode processing for EMI and GPR sensors for hand-held land mine detection"

Signal processing algorithms for hand-held mine detection sensors are described. The goals of the algorithms are to provide alarms to a human operator indicating the likelihood of the presence of a buried mine. Two modes of operations are considered: search mode and discrimination mode. Search mode generates an initial detection at a suspected location and discrimination mode confirms that the suspected location contains a land mine. Search mode requires that the signal processing algorithm generate a detection confidence value immediately at the current sample location and no delay in producing an alarm confidence is tolerable. Search mode detection has a high false-alarm rate. Discrimination mode allows the operator to interrogate the entire suspected location to eliminate false alarms. It does not require that the signal processing algorithm produce an alarm confidence immediately for the current sample location, but rather allows the system to process all the data acquired over the region before producing an alarm. This paper proposes discrimination mode processing algorithms for metal detectors (MDs), or electromagnetic induction sensors (EMIs), ground-penetrating radars (GPRs), and their fusion. The MD discrimination mode algorithm employs a model-based approach and uses the target model parameters to discriminate between mines and clutter objects. The GPR discrimination mode algorithm uses the consistency of detection as well as the shape of the detection peaks over several sweeps to improve the discrimination accuracy. The performances of the proposed algorithms were examined on a dataset collected at a government test site, and performance was compared with baseline techniques. Experimental results showed that the proposed method can reduce the probability of false alarm by as much as 70% at a 100% correct detection rate and performed comparable to the best human operator on a blind test with data collected at approximately 1000 locations. [J116]

"A neural network approach to complete coverage path planning"

Complete coverage path planning requires the robot path to cover every part of the workspace, which is an essential issue in cleaning robots and many other robotic applications such as vacuum robots, painter robots, land mine detectors, lawn mowers, automated harvesters, and window cleaners. In this paper, a novel neural network approach is proposed for complete coverage path planning with obstacle avoidance of cleaning robots in nonstationary environments. The dynamics of each neuron in the topologically organized neural network is characterized by a shunting equation derived from Hodgkin and Huxley's (1952) membrane equation. There are only local lateral connections among neurons. The robot path is autonomously generated from the dynamic activity landscape of the neural network and the previous robot location. The proposed model algorithm is computationally simple. Simulation results show that the proposed model is capable of planning collision-free complete coverage robot paths. [J117]

"Simulation of near-surface detection of objects in layered media by the BCGS-FFT method"

Near-surface electromagnetic characterization of objects buried in multilayered earth is important for the detection and identification of landmines, unexploded ordnance, and underground structures. However, so far little progress has been made in the development of fast algorithms for inhomogeneous objects in a layered medium. We report an iterative technique, the stabilized biconjugate gradient fast Fourier transform (BCGS-FFT) method, that simulates near-surface detection of three-dimensional, inhomogeneous objects buried in multilayered media. The CPU time and memory cost of the BCGS-FFT method is O(NlogN) and O(N), respectively, where N is the number of unknowns. This method is significantly more efficient than method of moments. It is capable of solving large-scale electromagnetic scattering problems with an arbitrary inhomogeneous object embedded in a layered medium with an arbitrary number of layers. Examples in subsurface detection of large buried objects are shown to demonstrate the efficacy of this method. At present, the object must be located completely within one single layer in this multilayer medium, but efforts are underway to remove this limitation. [J118]

"GPR phase-based techniques for profiling rough surfaces and detecting small, low-contrast landmines under flat ground"

We present a new technique whereby phase variation signatures are used to profile two-dimensional (2-D)

rough surfaces and to discern shallowly buried, small, low-contrast landmines under a flat ground. The method has been tested using data measured over a composite surface containing two rough dielectric surface patches, and over a flat ground under which small, low-contrast antipersonnel landmines are shallowly buried. The results show that the phase-based technique is capable of profiling rough surfaces and of detecting small, low-contrast landmines with different internal structures buried underneath a flat ground. [J119]

"Land mine detection by infrared thermography: reduction of size and duration of the experiments"

The effectiveness of infrared thermography applied to the detection of abandoned land mines is not yet acceptable. It can probably be improved, however, by computerized processing of the thermal images. This requires reference data, which must be provided mainly by experiments. A method is presented here, by which the heating and cooling cycles of a soil with a buried land mine can be replicated with reduced size and duration. The reference data acquired in the laboratory can be associated to realistic on-field tests by simply stretching the space and time scales. This will permit to reproduce indoors, quickly and effortlessly, the outdoor conditions of any place where the detection of buried land mines must be performed. In this paper, the general thermal problem is described, and the proposed method is comprehensively explained. The results of computer simulations and some laboratory tests are finally reported for validation. [J120]

"Detection of land-mines using ultra-wideband radar data and time-frequency signal analysis"

The authors present a study of the backscattered signatures from various types of land-mines placed either on the Earth's surface or buried underground, and their time-frequency (t-v) distributions. A BoomSAR designed by the Army Research Laboratory (ARL) transmits ultra-wideband (UWB) signals to a test area to be inspected. The backscattered signals are used to form synthetic aperture radar (SAR) imagery and also the corresponding time-frequency distributions. The t-v plots are generated of the distributions of several mines and 'confusers' (i.e. undesirable debris that are similar to mines in terms of amplitude and shape). For both metal and plastic mines, SAR images are generated and the t-v distributions are obtained using the backscattered signals generated by an electromagnetic (EM) numerical model and are compared against the measured data. Time-frequency characteristics of mines and confusers that may be useful for demining purposes are investigated. Although measurements and EM predictions show good agreement in most cases, the main purpose of the work is to obtain the characteristics of the t-v distributions of the actual (dielectric and conducting) mines used, as well as those of the 'confusers' so that they can be distinguished from the true mines. This has been achieved in all cases shown, and many distinctive features of each have been identified. These could later be used for the development of automated algorithms for in-situ mine detection and could be combined with alternative approaches that have also shown promise for classification purposes, as planned for future research. [J121]

"Trained detection of buried mines in SAR images via the deflection-optimal criterion"

In this paper, we apply a deflection-optimal linear-quadratic detector to the detection of buried mines in images formed by a forward-looking ground-penetrating synthetic aperture radar. The detector is a linear-quadratic form that maximizes the output SNR (deflection), and its parameters are estimated from a set of training data. We show that this detector is useful when the signal to be detected is expected to be stochastic, with an unknown distribution, and when only a small set of training data is available to estimate its statistics. The detector structure can be understood in terms of the singular value decomposition; the statistical variations of the target signature are modeled using a compact set of orthogonal "eigenmodes" (or principal components) of the training dataset. Because only the largest eigenvalues and associated eigenvectors contribute, statistical variations that are underrepresented in the training data do not significantly corrupt the detector performance. The resulting detection algorithm is tested on data that are not in the training set, which has been collected at government test sites, and the algorithm performance is reported. [J122]

"Autonomous exploration and mapping of abandoned mines"

This article discusses the software architecture of an autonomous robotic system designed to explore and map abandoned mines. A new set of software tools is presented, enabling robots to acquire maps of unprecedented size and accuracy. On 30 May 2003, the robot "Groundhog" successfully explored and mapped a main corridor of the abandoned Mathies mine near Courtney, Pennsylvania. This article also discusses some of the challenges that arise in the subterranean environments and some the difficulties of building truly autonomous robots. [J123]

"Dynamic networking and smart sensing enable next-generation landmines"

To address the hazards to civilians, recent landmine systems have incorporated command detonation by remote operator and self-destruct capabilities. To improve military performance and prevent civilian casualties, the US military is integrating wireless networking and autonomous sensing into next-generation landmines. These new

systems increase target discernment, enhance battle-shaping capabilities, and facilitate disposal or self-destruction of next-generation minefields when they're no longer needed. [J124]

"Detection of buried targets via active selection of labeled data: application to sensing subsurface UXO"

When sensing subsurface targets, such as landmines and unexploded ordnance (UXO), the target signatures are typically a strong function of environmental and historical circumstances. Consequently, it is difficult to constitute a universal training set for design of detection or classification algorithms. In this paper, we develop an efficient procedure by which information-theoretic concepts are used to design the basis functions and training set, directly from the site-specific measured data. Specifically, assume that measured data (e.g., induction and/or magnetometer) are available from a given site, unlabeled in the sense that it is not known a priori whether a given signature is associated with a target or clutter. For N signatures, the data may be expressed as {xi,yi}i=1,N, where xiis the measured data for buried object i, and yiis the associated unknown binary label (target/nontarget). Let the N xidefine the set X. The algorithm works in four steps: 1) the Fisher information matrix is used to select a set of basis functions for the kernel-based algorithm, this step defining a set of n signatures Bn X that are most informative in characterizing the signature distribution of the site; 2) the Fisher information matrix is used again to define a small subset Xs X, composed of those xifor which knowledge of the associated labels yiwould be most informative in defining the weights for the basis functions in Bn; 3) the buried objects associated with the signatures in Xsare excavated, yielding the associated labels yi, represented by the set Ys; and 4) using Bn,Xs, and Ys, a kernel-based classifier is designed for use in classifying all remaining buried objects. This framework is discussed in detail, with example results presented for an actual buried-UXO site. [J125]

"Laser Doppler vibrometer-based acoustic landmine detection using the fast M-sequence transform"

Acoustic landmine detection using a laser Doppler vibrometer (LDV) has demonstrated success in recent field tests. However, low detector signals and speckle noise are still challenging problems in the LDV-based acoustic-to-seismic detection of buried landmines. This letter describes the use of binary maximum-length sequences as the acoustic excitation for achieving high SNRs of scanning results. Some relevant issues associated with the detection system design and experimental field results are discussed. [J126]

"Improved thermal analysis of buried landmines"

In this paper, we address the problem of the detection and identification of surface-laid and shallowly buried landmines from measured infrared images. A three-dimensional thermal model has been developed to study the effect of the presence of landmines in the thermal signature of the bare soil. Based on this model, a target identification procedure is proposed aiming at detecting and classifying the anomalies found on the soil thermal signature. In our approach, landmines are thought of as a thermal barrier in the natural flow of the heat inside the soil, which produces a perturbation of the expected thermal pattern on the surface. The detection of these perturbations will put into evidence the presence of potential mine targets. We propose an iterative procedure to classify the detected perturbations as mines or nonmines and to estimate their depth of burial. This paper describes the main principles of our method and illustrates classification results on a set of acquired images. Qualitative and quantitative comparisons with independent component analysis are also given. [J127]

"Detecting landmines with ground-penetrating radar using feature-based rules, order statistics, and adaptive whitening"

An approach to detecting landmines using ground-penetrating radar (GPR) based on feature-based rules, order statistics, and adaptive whitening (FROSAW) is described. FROSAW relies on independent adaptation of whitening statistics in different depths and combining feature-based methods with anomaly detection using rules. Constant false alarm rate (CFAR) detectors are used for anomaly detection on the depth-dependent adaptively whitened data. A single CFAR confidence measure is computed via a function of order statistics. Anomalies are detected at locations with high CFAR confidence. Depth-dependent features are computed on regions containing anomalies. Rules based on the features are used to reject alarms that do not exhibit mine-like properties. The utility of combining the CFAR and feature-based methods is evaluated. The algorithms and analysis are applied to data acquired from tens of thousands of square meters from several outdoor test sites with a state-of-the-art array of GPR sensors. [J128]

"Multisensor fusion in the frame of evidence theory for landmines detection"

In the frame of humanitarian antipersonnel mines detection, a multisensor fusion method using the Dempster-Shafer evidence theory is presented. The multisensor system consists of two sensors-a ground penetrating radar (GPR) and a metal detector (MD). For each sensor, a new features extraction method is presented. The method for the GPR is mainly based on wavelets and contours extraction. First simulations on a limited set of data show that an improvement in detection and false alarms rejection, for the GPR as a standalone sensor, could be obtained. The MD features extraction method is mainly based on contours extraction. All of these features are then fused with the GPR ones in some specific cases in order to determine a new feature. From these results, belief functions, as defined in the evidence theory, are then determined and combined thanks to the orthogonal sum. First results in terms of detection and false alarm rates are presented for a limited set of real data and a comparison is made between the two cases: with or without multisensor fusion. [J129]

"Unsupervised iterative detection of land mines in highly cluttered environments"

An unsupervised iterative scheme is proposed for land mine detection in heavily cluttered scenes. This scheme is based on iterating hybrid multispectral filters that consist of a decorrelating linear transform coupled with a nonlinear morphological detector. Detections extracted from the first pass are used to improve results in subsequent iterations. The procedure stops after a predetermined number of iterations. The proposed scheme addresses several weaknesses associated with previous adaptations of morphological approaches to land mine detection. Improvement in detection performance, robustness with respect to clutter inhomogeneities, a completely unsupervised operation, and computational efficiency are the main highlights of the method. Experimental results reveal excellent performance. [J130]

"Training DHMMs of mine and clutter to minimize landmine detection errors"

Minimum classification error (MCE) training is proposed to improve performance of a discrete hidden Markov model (DHMM)-based landmine detection system. The system (baseline) was proposed previously for detection of both metal and nonmetal mines from ground-penetrating radar signatures collected by moving vehicles. An initial DHMM model is trained by conventional methods of vector quantization and the Baum-Welch algorithm. A sequential generalized probabilistic descent (GPD) algorithm that minimizes an empirical loss function is then used to estimate the landmine/background DHMM parameters, and an evolutionary algorithm (EA) based on fitness score of classification accuracy is used to generate and select codebooks. The landmine data of one geographical site was used for model training, and those of two different sites were used for evaluation of system performance. Three scenarios were studied: 1) apply MCE/GPD alone to DHMM estimation, 2) apply EA alone to codebook generation, and 3) first apply EA to codebook generation and then apply MCE/GPD to DHMM estimation. Overall, the combined EA and MCE/GPD training led to the best performance. At the same level of detection rate as the baseline DHMM system, the false-alarm rate was reduced by a factor of two, indicating significant performance improvement. [J131]

"Sensor fusion in anti-personnel mine detection using a two-level belief function model"

A two-level approach for modeling and fusion of antipersonnel mine detection sensors in terms of belief functions within the Dempster-Shafer framework is presented. Three promising and complementary sensors are considered: a metal detector, an infrared camera, and a ground-penetrating radar. Since the metal detector, the most often used mine detection sensor, provides measures that have different behaviors depending on the metal content of the observed object, the first level aims at identifying this content and at providing a classification into three classes. Depending on the metal content, the object is further analyzed at the second level toward deciding the final object identity. This process can be applied to any problem where one piece of information induces different reasoning schemes depending on its value. A way to include influence of various factors on sensors in the model is also presented, as well as a possibility that not all sensors refer to the same object. An original decision rule adapted to this type of application is proposed, as well as a way for estimating confidence degrees. More generally, this decision rule can be used in any situation where the different types of errors do not have the same importance. Some examples of obtained results are shown on synthetic data mimicking reality and with increasing complexity. Finally, applications on real data show promising results. [J132]

"Characterization of UXO-like targets using broadband electromagnetic induction sensors"

We have inverted broadband electromagnetic induction data over an isolated target to determine its electrical conductivity, magnetic permeability, radius, and depth using a sphere model. Studies using synthetic data of a concentric, broadband, electromagnetic sensor indicate that the technique is dependable and produces fast-converging solutions. The geometrical parameters obtained through this technique are very close to true values, and the electric parameters for noise-free data are correct to within a few percent. When 10% noise is added to the data, the geometric parameters are still well determined, but the electric parameters are poorly resolved,

particularly for a sphere that is both conductive and permeable. Tests on the experiment data show that volume-equivalent size and depth to a target can be reasonably estimated for a nonspherical object. [J133]

"Effects of thin metal outer case and top air gap on thermal IR images of buried antitank and antipersonnel land mines"

A numerical simulation is carried out to study the effect of the thin metal outer case of an antitank mine and the top air gap of an antipersonnel mine on the passive infrared imaging signature. In addition, an antipersonnel surface mine is also analyzed in the present investigation to show its effect on the soil thermal content. The effect of short- and long-wavelength radiation as well as the convective heat transfer is incorporated in this analysis. The temporal development of the temperature distribution over a diurnal cycle is presented for both buried mines. The results show that the thin metal outer case of a buried antitank mine and the top air space of a buried antipersonnel mine have a pronounced effect on the depthwise temperature through the soil. Also, the results show that both buried mines have a noticeable effect on the intensity of the landmine signature on the soil-top surface over a diurnal cycle. A nonexisting mine signature on the soil-top surface is established for an antitank mine with a thin metal outer case. An almost nonexistent signature is also in evidence for the antipersonnel mine with or without an air gap. The results of the present investigation show that the thermal signature of a surface mine produces much larger temperature extremes than the thermal signature of a buried mine. These results play an important role in producing more effective techniques for mine imaging detection. [J134]

"Resonant frequency evaluation of microstrip antennas using a neural-fuzzy approach"

The accurate evaluation of the resonant frequency of microstrip antennas is a key factor to guarantee their correct behavior. To this aim, the Method of Moments technique is currently employed. A fast technique to evaluate the resonant frequency of microstrip antennas using neuro-fuzzy networks, is proposed. Numerical results obtained by using this technique agree quite well with the Method of Moments results. The proposed technique can be fruitfully used in microwave CAD applications. [J135]

"Automated identification of buried landmines using normalized electromagnetic induction spectroscopy"

Electromagnetic induction spectroscopy (EMIS) is used to identify a buried metallic object such as a landmine, based on its EMI spectrum. EMIS, however, depends on the object's electrical conductivity, magnetic permeability, shape, size, depth, and orientation. For a given mine made of specific metals, shape, and size, however, the only variables are the mine's burial depth and orientation. This paper describes a method of identifying a landmine using a normalized EMIS spectrum, which is independent of the orientation or depth. We assume that the target is small compared with its distance to or size of the sensor so that the source field at a target is uniform. In this case, the normalized spectrum will be range-independent and, therefore, the target identification is based on only spectral shapes. We have developed and tested an algorithm that matches a normalized EMIS spectrum to those of library targets. We applied the new process to 1) numerically simulated data, 2) experimental data from controlled sites using inert mines, mine simulants, and clutter items, and 3) finally extensive field data collected at a blind test site established by the U.S. Army. Test results show that targets are correctly identified with a misfit of less than 10%; they also show that 80% of clutter may be rejected, based on a misfit over 30%. [J136]

"Mine countermeasures HTS magnet"

American Superconductor has designed, manufactured, and tested a model high-temperature superconducting (HTS) magnet system for airborne mine countermeasures (MCM) for the Office of Naval Research. The magnet has a magnetic moment of 80 kA-m2, or about one-fourth that of the full-scale magnet. The magnet is a solenoid consisting of 16 layers of laminated Bi-2223 HTS wire. The coil was manufactured at Everson Electric and tested at American Superconductor. The coil has an inside diameter of 455 mm, an outside diameter of 476 mm, and is 914 mm in length. The magnet was successfully ramped to its operating current of 193 A at 30 K. It was also successfully modulated with ±26 A current at 0.5 Hz. The magnet is conduction-cooled with a single-stage GM cryocooler. The design, manufacture, and test results of the magnet will be presented. [J137]

"Propagation velocity uncertainty on GPR SAR processing"

To detect buried landmines, Planning Systems Incorporated (PSI) has developed a ground-penetrating synthetic aperture radar (GPSAR) system. Since the electromagnetic wave propagation velocity in the soil depends on many factors, velocity uncertainty is inevitable. However, we have observed that, unlike conventional

airborne/spaceborne synthetic aperture radar (SAR) systems, the PSI GPSAR system is very robust against the velocity uncertainty under mild conditions. Theoretical analysis is provided to explain this observation. Although our discussion is based on the PSI GPSAR system, it applies to other GPR-based (ground-penetrating radar) landmine detection systems as well. [J138]

"Time-frequency analysis for plastic landmine detection via forward-looking ground penetrating radar"

Time-frequency analysis techniques are used for buried plastic landmine detection with a forward-looking ground penetration radar (GPR) system. Several time-frequency distributions are considered to characterise and interpret the scattering phenomena of both targets and clutter. An ambiguity function based detector is also presented, which employs principal component analysis and feature selection for data dimensionality reduction and linear discriminant analysis for signal classification. Experimental results based on the SRI (Stanford Research Institute) experimentally measured forward-looking GPR data are presented, showing a significant detection performance improvement over the conventional detector [J139]

"Top 10 architecture land mines [Jenterprise]"

IT professionals hear plenty of advice regarding enterprise architecture. Although good in theory, many of the recommendations are impractical because they are time-consuming or just plain difficult. People and organizations tend to repeat common mistakes that make a mess of their enterprise architecture. The implications of these mistakes are not immediately apparent. By the time you take corrective actions, it is often too late to undo the direct damage, much less the collateral damage. Rather than offering recipes for success, this article points out the top 10 list of land mines along the architecture roadway. The list are as follows: declaring the architecture effort done; assuming that technical people make good architects; saying no; failing to communicate early and often; speaking in tongues; mistaking standards for architecture; forgetting to assess people and process impacts; aligning (and realigning) with strategies, rather than with business goals and cultural values; crashing the party when you are not invited; and introducing technology before its time. The correct measure of success is not how fast you can introduce a new technology. Instead, it is whether you can make the correct or appropriate investment decision. Avoiding the 10 pitfalls will not guarantee your architecture program's success, but will certainly increase your profitability of avoiding failure. [J140]

"Moderately rough surface underground imaging via short-pulse quasi-ray Gaussian beams"

An adaptive framework is presented for ultra-wideband ground penetrating radar imaging of shallow-buried low-contrast dielectric objects in the presence of a moderately rough air-soil interface. The proposed approach works with sparse data and relies on recently developed Gabor-based narrow-waisted quasi-ray Gaussian beam algorithms as fast forward scattering predictive models. First, a nonlinear inverse scattering problem is solved to estimate the unknown coarse-scale roughness profile. This sets the stage for adaptive compensation of clutter-induced distortion in the underground imaging problem, which is linearized via Born approximation and subsequently solved via various pixel-based and object-based techniques. Numerical simulations are presented to assess accuracy, robustness and computational efficiency for various calibrated ranges of problem parameters. The proposed approach has potential applications to antipersonnel land mine remediation. [J141]

"Minimum entropy regularization in frequency-wavenumber migration to localize subsurface objects"

Optimized versions of frequency-wavenumber (F-K) migration methods are introduced to better focus ground-penetrating radar (GPR) data in applications of shallow subsurface object localization, e.g., landmine remediation. Migration methods are based on the wave equation and operate by backpropagating the received data into the earth so as to localize buried objects. Traditional F-K migration is based on an underlying assumption that the wavefields propagate in a homogeneous medium. The presence of a rough air-ground interface in the GPR case degrades the localization ability. To overcome this problem in the context of the F-K algorithm, we introduce lateral variations in the velocity of waves in the medium. An optimization approach is employed to choose that velocity function that results in a well-focused image where an entropy-like criterion is used to quantify the notion of focus. Extension of the basic method to lossy medium is also described. The utility of these techniques is demonstrated using field data from a number of GPR systems. [J142]

"Ultra-wideband multistatic SAR for the detection and location of landmines"

Techniques for improving the signal to clutter ratio of an ultra-wideband SAR designed to detect small mine-like objects in the surface of the ground were investigated. In particular, images were collected using different bistatic

antenna configurations in an attempt to decorrelate the clutter with respect to the targets. The images were converted to a reference depression angle, summed, and then converted to ground coordinates. The resulting target strengths were then compared with the amplitude distribution of the ground clutter to show the improvement obtained. While some improvement was demonstrated, this was for the relatively easy scenario of targets on the surface partially obscured by grass. Detection based on thresholding the raw RF signal (the bipolar response) rather than the envelope (baseband I2+Q2) was also considered to further enhance target-to-clutter ratios. [J143]

"Voting fusion adaptation for landmine detection"

This paper presents a voting fusion application for use with a remotely controlled multisensor vehicle platform for antitank landmine detection. Data from three landmine detection sensors mounted at the front of the vehicle enhance the probability of detection and, when combined via data fusion, limit the false alarm density to practical levels. The performance of the voting fusion scheme presented in this paper is contrasted with a heuristic data fusion approach developed by General Dynamics Canada. [J144]

"Signal processing techniques for landmine detection using impulse ground penetrating radar"

Landmines are affecting the lives and livelihoods of millions of people around the world. A number of detection techniques, developed for use with impulse ground penetrating radar, are described, with emphasis on a Kalman filter based approach. Comparison of results from real data show that the Kalman filter algorithm provides the best detection performance, although its computational burden is also the highest [J145]

"Effective imaging of buried dielectric objects"

Ultrawide-band CW radar have shown good potential for remote imaging of surface laid or shallow buried landmine-like objects. However when sensing fields near to the ground, a number of factors including direct antenna coupling, air/ground coupling, receiver noise floor, and effective dynamic range conspire to degrade or mask the scattered return, resulting in a loss of signal magnitude, range accuracy, and range resolution. The present paper addresses the latter problems using a near-field detection methodology and providing a thorough experimental and systems analysis of the signal-to-clutter issues. The method proves advantageous in sensing weak echoes in the vicinity of the sensor from objects of low dielectric contrast with their environment. To enhance image processing gains, an effective space frequency synthetic aperture technique applicable to the two-media problem is outlined. The algorithm is straightforward and robust enough to be implemented on compact GPR systems operating in real time. The remaining problem of object identification will not be addressed here. To demonstrate the utility of these combined techniques, field experiments, over different frequency bands, were conducted and their results are reported [J146]

"A statistical approach to landmine detection using broadband electromagnetic induction data"

The response of time-domain electromagnetic induction (EMI) sensors, which have been used almost exclusively for landmine detection, is related to the amount of metal present in the object and its distance from the sensor. Unluckily, there is often a significant amount of metallic clutter in the environment that also induces an EMI response. Consequently, EMI sensors employing detection, algorithms based solely on metal content suffer from large false alarm rates. To mitigate this false alarm problem for mines with substantial metal content, statistical algorithms have been developed that exploit models of the underlying physics. In such models it is commonly assumed that the soil has a negligible effect on the sensor response, thus the object is modeled in "free space." We report on studies that were performed to test, the hypotheses that for broadband EMI sensors: 1) soil cannot be modeled as free space when the buried object has low metal content and 2) advanced signal processing algorithms can be applied to reduce the false alarm rates. Our results show that soil cannot be modeled as free space and that when modeling soil correctly our advanced algorithms reduced the false alarm probability by up to a factor of 10 in blind tests [J147]

"Microwave underground propagation and detection"

The detection of buried targets has been a problem of significant interest for decades, with microwave-based sensing constituting an important tool. In this paper, we review the basic issues that characterize microwave-based subsurface sensing. Issues considered include the use of microwaves in the context of an airborne synthetic aperture radar, as well for radars deployed close to the air-soil interface. Rough-surface induced clutter is also discussed. Particular examples are presented for detection of land mines and unexploded ordnance [J148]

"Landmine detection research pushes forward, despite challenges"

The paper discusses technology for landmine detection, including: detection sensors; Comet II six-legged walking mine detection robot; a multisensor approach in the Hudem project; and the Swarm concept for mini robots that operate like insects. Although numerous basic research projects are in progress, integrating the work into a testable system is itself a significant challenge. At CCMAT, promising technologies that are field ready are tested and evaluated at DRES for mine detection effectiveness. [J149]

"Thermal analysis of buried land mines over a diurnal cycle"

The passive infrared (IR) imaging signature of buried mines under three different soil surface conditions is investigated in this work. The three-dimensional (3-D) nature of the mine, the site, and the temporal attributes of surrounding climate and exposed radiation are accounted for with large and moderate-scale clutter surfaces as well as a smooth surface. The effect of the short- and long-wavelength radiation as well as the convective heat transfer is incorporated in this analysis and the temporal development of the temperature distribution over a diurnal cycle is presented for different surface conditions. The occurrence of false alarm mine spots is demonstrated using the moderate scale clutter surface and a critical period of time for the landmine signature is established for different soil surface conditions. The present results show that mines buried at moderate depths in the soil would not produce a direct signature [J150]

"A novel 3-D subsurface radar imaging technique"

The problem of the formation of subsurface images using stand-off forward looking radar is by far more severe than that of forming the radar images in the free-space. A subsurface image needs to be accurately focused taking into account both the refraction and dispersion of the wavefield. This paper presents a novel imaging algorithm specially tailored for subsurface sensing. A simple and effective characterization technique for the retrieval of the dielectric permittivity is outlined. The proposed soil characterization and subsurface imaging techniques are validated experimentally. Results show that the geometric distortion in the subsurface images due to the refraction and dispersion of the wavefields is successfully corrected [J151]

"Statistical method to detect subsurface objects using array ground-penetrating radar data"

We introduce a combination of high-dimensional analysis of variance (HANOVA) and sequential probability ratio test (SPRT) to detect buried objects from an array ground-penetrating radar (GPR) surveying a region of interest in a progressive manner. Using HANOVA, we exploit the transient characteristic of GPR signals in the time domain to extract information about buried objects at fixed positions of the array. Based on the output of the HANOVA, the SPRT is employed to make detection decisions recursively as the array moves downtrack. The method is on-line implementable and of low computational complexity. Our approach is validated using field-data from two quite different GPR sensing systems designed for landmine detection applications [J152]

"Land mine detection"

Currently, very little technology is used in real-world demining activities. Active programs by the U.S. Army in both land mine detection sensor development and systems integration are evaluating new technologies, incrementally improving existing technologies, increasing the probability of detection, reducing the false alarm rate, and planning out usable deployment scenarios. Through iterative design/build test cycles, and blind and scored testing at Army mine lanes, steady progress is being made. [J153]

"A group-theoretic analysis of symmetric target scattering with application to landmine detection"

Landmines are generally constructed such that they possess a high level of geometric symmetry and are then buried in a manner that preserves this symmetry. The scattered response of such a symmetric target will likewise exhibit the symmetry of the target, as well as the electromagnetic reciprocity exhibited by all scatterers. Group theory provides a mathematic tool for describing geometric symmetry, and it can likewise be used to describe the symmetries inherent in the bistatic scattering from mines. Specifically, group theory can be used to determine specific forms of the dyadic Green's function of symmetric scatterers, such that multiple scattering solutions can be determined from a knowledge of a single bistatic geometry. Likewise, group theory can be used both to determine and analyze degenerate cases, wherein specific bistatic responses can be identified as zero regardless of target size, shape, or material. These results suggest a method for classifying subsurface targets as either symmetric or asymmetric. From the group-theoretic analysis, scattering features can be constructed that are indicative of target symmetry, but invariant with respect to other target parameters such as size, shape, or material. These features provide a physically based, target-independent value to aid in mine detection and/or clutter rejection. To test the efficacy of this idea, an extensive collection of bistatic ground-penetrating radar

(GPR) measurements was taken for both a symmetric and an asymmetric target. The two targets were easily discernable using symmetry features only, a result that suggests symmetry features can be effective in identifying subsurface targets. [J154]

"Elastic waves interacting with buried land mines: a study using the FDTD method"

A three-dimensional (3-D) finite-difference model for elastic waves in the ground has been developed and implemented. The model has been created to supplement the development of a sensor that uses elastic waves to detect buried land mines. The model is used to investigate the propagation characteristics of elastic waves in the ground and to explore the interaction of elastic waves with buried land mines. When elastic waves interact with a buried mine, a strong resonance occurs at the mine location. The resonance can be used to enhance the mine's signature and to distinguish the mine from clutter. Results presented in this paper explain the features of elastic wave propagation in the ground and show the interaction of elastic waves with both an anti-personnel mine and an anti-tank mine. [J155]

"The dielectric wedge antenna"

A new modification of the TEM-horn antenna has been developed for ground-penetrating radar (GPR) applications. The antenna is based on a dielectric wedge, and thus, was named the dielectric wedge antenna. Tapering of the metal flairs has been used to match the antenna to the ground and to reduce the late-time ringing. The finite-difference time-domain model of the antenna has been created to investigate physical processes within the antenna and to optimize its performance. The dielectric wedge antenna has shown a superior (in comparison with the TEM-horn) performance by radiation in different types of the ground and has been used in a novel antenna configuration within a GPR system, which is dedicated for landmine detection. [J156]

"Multiresolution feature detection using a family of isotropic bandpass filters"

Presents a novel method which uses a special type of multi-scale isotropic band-pass filters to detect image landmark and corner features. This paper mainly contributes to the solutions of the following problems: (1) defining a general family of feature detectors under a unified framework that are able to enhance and detect the desired features; (2) explaining theoretically and experimentally why these feature points can be detected by the proposed detectors; and (3) extending the detectors to multi-scale versions for jointly achieving good detectability and localization where an automatic scale selection method is applied. The paper then presents several applications for detecting landmarks and corners using the proposed methods, in order to illustrate their usage. These include detecting landmarks from gesture images (of the face and hand), from airborne and vehicle-borne IR landmine images, and from images containing object corners. Experiments have been performed using the proposed detectors to these applications. Some comparisons and evaluations have also been performed. The results have demonstrated the effectiveness of the proposed detectors in terms of feature detectability and localization [J157]

"A linear prediction land mine detection algorithm for hand held ground penetrating radar"

Land mine detection using ground penetrating radar (GPR) is a difficult task because the background clutter characteristics are nonstationary and the land mine signatures are inconsistent. A particularly difficult scenario is the case for which a GPR is mounted on a hand held device with no position or velocity information available to a signal processing algorithm. This paper proposes the use of linear prediction in the frequency domain for land mine detection in this scenario. A frequency domain clutter vector sample is partitioned into subbands. Each subband is modeled by a linear prediction model; the current vector sample is expressed as a linear combination of the past few vector samples plus random noise. The detector first computes the maximum likelihood estimate of the prediction coefficients, and then uses the generalized likelihood method to determine if a land mine is present. The effect of subband processing on the accuracy of the detector is evaluated. Detection results are presented on data collected from a variety of geographical locations. The data sets contain over 2300 mine encounters of different size, shape and content, and a larger number of measurements from locations with no mines. The proposed detector is compared to the baseline differential energy detector. The proposed algorithm reduces the false alarm rate by 60% for all the targets at 90% probability of detection, and 70% for the deep anti-tank mines at 90% probability of detection. [J158]

"Subsurface object sensing with a multifrequency microwave radiometer"

Experimental results are reported for sensing of subsurface objects with a multifrequency radiometer (MFRAD) system. Properties of the MFRAD system are reviewed, and the calibration and experimental procedures are discussed. Results with subsurface metallic, styrofoam, and plastic targets are then provided that demonstrate an

oscillatory behavior in brightness temperatures versus frequency in the presence of a subsurface object. Measured data are also compared with a simple layered medium brightness temperature model and show reasonable agreement with predicted trends of brightness temperatures versus frequency. The oscillatory behaviors versus frequency obtained in the presence of both metallic and nonmetallic subsurface objects should prove advantageous for designing object detection procedures. [J159]

"Subsurface discrimination using electromagnetic induction sensors"

This paper reviews the problem of subsurface discrimination using electromagnetic induction (EMI) sensors. Typically, discrimination is based on differences in the multiaxis magnetic polarizability between different objects. They review work on frequency and time domain systems, and their interrelationship. They present the results of comprehensive measurements of the multiaxis EMI response of a variety of inert ordnance items, ordnance fragments, and scrap metal pieces recovered from firing ranges. The extent to which the distributions of the eigenvalues of magnetic polarizability for the different classes of objects do not overlap establishes an upper bound on discrimination. For various reasons, the eigenvalues cannot always be accurately determined using data collected above a buried target. This tends to increase the overlap of the distributions, and hence degrade discrimination performance [J160]

"Simple phenomenological models for wideband frequency-domain electromagnetic induction"

The authors propose three phenomenological models for wideband electromagnetic induction (EMI) response of buried conductors, such as unexploded ordnance (UXO) or metal parts in landmines. The models are based on analytic solutions for spheres, cylinders, and wire loops, and produce physically reasonable predictions for a variety of targets at all frequencies of interest including matches to theory in the low- and high-frequency limits. All three produce excellent fits to test data and run quickly enough to be of practical use in data inversion schemes. The authors present a three-parameter model capable of exactly matching permeable spheres and cylinders, a four-parameter version which adds the capability to match wire loops, and a five-parameter version which adds the capability to match signals due to driving bands, a feature found only on UXO. Driving bands, also called rotating bands, are soft metal rings near the tail of a projectile designed to engage rifles in the gun bore when the projectile Is fired. The author observe that driving bands produce a distinctive loop-like signal in EMI spectra, possibly because they are in the shape of a loop and typically have much greater conductivity than the body of the UXO. They demonstrate that the five-parameter model is capable of accurately fitting this signal and expressing its presence or absence through model fit parameters [J161]

"Model-based characterization of electromagnetic induction signatures obtained with the MTADS electromagnetic array"

A sensor response model based on empirically determined orthogonal response coefficients β is presented for the analysis of electromagnetic induction (EMI) sensor data. The model is applied to high-quality survey data from the multi-sensor towed array detection system (MTADS) program. Data from both a prepared test range and a live-site survey are analyzed. At the test field, the authors show that the model successfully reproduces the measured signatures of ordnance, ordnance simulants, flat plates, and clutter. At the live site, fit statistics were collected showing that for the most abundant ordnance target, 81-mm mortars, the three beta response parameters are distributed log-normally. This allows for a simple method of discrimination. A receiver operating characteristic (ROC) analysis based on this discrimination method is performed and the results discussed [J162]

"Landmine detection with ground penetrating radar using hidden Markov models"

Novel, general methods for detecting landmine signatures in ground penetrating radar (GPR) using hidden Markov models (HMMs) are proposed and evaluated. The methods are evaluated on real data collected by a GPR mounted on a moving vehicle at three different geographical locations. A large library of digital GPR signatures of both landmines and clutter/background was constructed and used for training. Simple, but effective, observation vector representations are constructed to naturally model the time-varying signatures produced by the interaction of the GPR and the landmines as the vehicle moves. The number and definition of the states of the HMMs are based on qualitative signature models. The model parameters are optimized using the Baum-Welch algorithm. The models were trained on landmine and background/clutter signatures from one geographical location and successfully tested at two different locations. The data used in the test were acquired from over 6000 m2of simulated dirt and gravel roads, and also off-road conditions. These data contained approximately 300 landmine signatures, over half of which were plastic-cased or completely nonmetal [J163]

"Multi-aspect detection of surface and shallow-buried unexploded ordnance via ultra-wideband synthetic aperture radar"

An ultra-wideband (UWB) synthetic aperture radar (SAR) system is investigated for the detection of former bombing ranges, littered by unexploded ordnance (UXO). The objective is detection of a high enough percentage of surface and shallow-buried UXO, with a low enough false-alarm rate, such that a former range can be detected. The physics of UWB SAR scattering is exploited in the context of a hidden Markov model (HMM), which explicitly accounts for the multiple aspects at which a SAR system views a given target. The HMM is trained on computed data, using SAR imagery synthesized via a validated physical-optics solution. The performance of the HMM is demonstrated by performing testing on measured UWB SAR data for many surface and shallow UXO buried in soil in the vicinity of naturally occurring clutter [J164]

"Landmine detection with the neutron backscattering method"

Neutron backscattering was selected as a promising new method for the detection of landmines. With this technique, 252Cf source and a thermal neutron detector are used. Fast neutrons from the Californium source are better moderated by the landmine, especially plastic mines, than in the surrounding soil. This leads to an increase in the number of reflected thermal neutrons above the mine. Results from experimental trials with the Delft University Neutron Backscattering Landmine Detector (DUNBLAD) are presented and compared with results from Monte Carlo simulations. The limitations of this method and the radiation dose for the user are investigated. Based on these results, a new portable prototype detector is presented [J165]

"Multiresolution time-domain analysis of plane-wave scattering from general three-dimensional surface and subsurface dielectric targets"

The multiresolution time domain (MRTD) is used to analyze wide-band plane-wave scattering from general dielectric targets embedded in a lossy half-space, with free-space scattering as a special case. A Haar wavelet expansion is used for simplicity, this constituting a generalization of the widely used finite-difference time-domain (FDTD) method. In addition to developing the mathematical formulation, example results are presented for several targets, with the MRTD results validated through comparison with an independent frequency-domain method-of-moments solution and an FDTD model [J166]

"Adaptive ground bounce removal"

An adaptive ground bounce (GB) removal algorithm is presented for landmine detection with a downward looking stepped frequency ground penetrating radar (GPR). The main idea is to estimate and eliminate the GB from a given scan as a shifted and scaled version of an adaptively estimated reference GB. Experimental results are provided to demonstrate that the new algorithm outperforms existing approaches [J167]

"A comparison of algorithms for subsurface target detection and identification using time-domain electromagnetic induction data"

The performance of subsurface target identification algorithms using data from time-domain electromagnetic induction (EMI) sensors is investigated. The response of time-domain EMI sensors to the presence of a conducting object may be modeled as a weighted sum of decaying exponential signals. Although the weights associated with each of the modes are dependent on the target/sensor orientation, the decay rates are a function of the target's composition and geometry and therefore are intrinsic to the target. Since the decay rates are not dependent on target/sensor orientation or other unobservable parameters, decay rate estimation has previously been proposed as a viable method for target identification. The performance attained with Bayesian target identification algorithms operating on the entire time-domain signal and decay rate estimates is compared through both numerical simulations and application to experimental data. The decay rate estimates utilized in the numerical simulations are assumed to achieve the Cramer-Rao lower bound (CRLB), which provides a lower bound on the variance of an unbiased parameter estimate. The simulations as well as results obtained with experimental data show that processing the entire time-domain signal provides better target identification and discrimination performance than processing decay rate estimates [J168]

"Feature-level and decision-level fusion of noncoincidently sampled sensors for land mine detection"

We present and compare methods for feature-level (predetection) and decision-level (postdetection) fusion of multisensor data. This study emphasizes fusion techniques that are suitable for noncommensurate data sampled at noncoincident points. Decision-level fusion is most convenient for such data, but it is suboptimal in principle, since targets not detected by all sensors will not obtain the full benefits of fusion. A novel algorithm for feature-level fusion of noncommensurate, noncoincidently sampled data is described, in which a model is fitted to the sensor data and the model parameters are used as features. Formulations for both feature-level and decision-

level fusion are described, along with some practical simplifications. A closed-form expression is available for feature-level fusion of normally distributed data and this expression is used with simulated data to study requirements for sample position accuracy in multisensor data. The performance of feature-level and decision-level fusion algorithms are compared for experimental data acquired by a metal detector, a ground-penetrating radar, and an infrared camera at a challenging test site containing surrogate mines. It is found that fusion of binary decisions does not perform significantly better than the best available sensor. The performance of feature-level fusion is significantly better than the individual sensors, as is decision-level fusion when detection confidence information is also available (“soft-decision” fusion) [J169]

"Ultrawide-bandwidth fully-polarimetric ground penetrating radar classification of subsurface unexploded ordnance"

An ultrawide-bandwidth (UWB) ground penetrating radar (GPR) was used to collect fully-polarimetric backscattered data from 10 to 800 MHz using a dual-polarization version of the previously developed dielectric-loaded horn-fed bow-tie (HFB) antenna. Special processing algorithms were developed to extract the polarization, orientation, depth, and length features of the target under investigation. The polarization and resonance features were utilized to discriminate subsurface ordnance from false-alarm objects that do not have elongated bodies. The classification of a specific type of unexploded ordnance (UXO) was also performed using the known length information. The processed results obtained from an initial blind field test show a very encouraging discrimination performance [J170]

"Using physics-based modeler outputs to train probabilistic neural networks for unexploded ordnance (UXO) classification in magnetometry surveys"

The outputs from a physics-based modeler of magnetometry data have been successfully used with a probabilistic neural network (PNN) to discriminate unexploded ordnance (UXO) from ordnance-related scrap. Cross-validation predictions were performed on three data sets to determine which modeler parameters were most valuable for UXO classification. The best performing parameter combination consisted of the modeler outputs depth, size, and inclination. The cross-validation results also indicated that good prediction performance could be expected. Model outputs from one location at a site were used to train a PNN model, which could correctly discriminate UXO from scrap at a different location of the same site. In addition, data from one site, the former Buckley Field, Arapahoe County, CO, was used to predict targets detected at an entirely different training range. The Badlands Bombing Range, Bull's Eye 2 (BBR 2), Cuny Table, SD. Through careful selection of the probability threshold cutoff, the UXO detection rate obtained was 95% with a false alarm rate of only 37%. The ability to distinguish individual UXO types has been demonstrated with correct classifications between 71% and 95% [J171]

"Foreword"

First Page of the Article [J172]

"Remote sensing by nuclear quadrupole resonance"

Detection of explosives has the flavor of those mathematical problems that are not invertible. It is easier to hide explosives than to find them. Many approaches have been proposed and executed for the remote detection of explosives, contraband materials, weapons of mass destruction, currency, etc. Most detection technologies suffer from a common problem: the features they look for, such as discontinuities in electrical conductivity, are not unique properties of the target but are contained, to some degree, in the more benign surroundings. Such a degeneracy leads to “clutter” in the response. For example, resolving the false alarms generated by this clutter can determine the rate of advance of a conventional electromagnetic metal detector employed as a landmine detector. One approach that provides a “unique” signature is nuclear quadrupole resonance (NQR) (the technique is also called QR, to avoid confusion with strictly nuclear techniques). This paper outlines the important physical principles behind the use of NQR for remote detection, indicates areas of applicability, and presents results of field trials of a prototype landmine detection system [J173]

"Electromagnetic induction spectroscopy for clearing landmines"

An estimated 110 million landmines, mostly antipersonnel mines laid in over 60 countries, kill or maim over 26000 people a year. One of the dilemmas for removing landmines is the amount of false alarms in a typical minefield. Broadband electromagnetic induction spectroscopy (EMIS) is a promising technology that can both detect and identify buried objects as landmines. By reducing the number of false alarms, this approach significantly reduces costs associated with landmine removal. Combining the EMIS technology and a broadband

EMI sensor, the scientific phenomenology that has potential applications for identifying landmines, unexploded ordnance, and hidden weapons at security checkpoints can now be explored [J174]

"Radar images of penetrable targets generated from ramp profile functions"

Images can be generated for penetrable targets from their scattered fields when the time dependence of the incident electromagnetic (EM) wave takes the form of a ramp function. Previous researchers have developed these concepts for conducting targets. This paper focuses attention on penetrable targets. Ramp response signatures of the targets for cases where the dielectric constant of the target is greater than and also less than that of the ambient medium are included. The latter case can be applied as a signature of antipersonnel mines. The results contained herein are based on: (1) scattering measurements in The Ohio State University ElectroScience Laboratory compact range; (2) scattering computation using an eigenfunction solution and a method of moments solution; and (3) a very limited set of measurements generated from a buried land mine using the ElectroScience Laboratory ground penetrating radar. The targets presented in this paper include metallic and dielectric spheres and actual land mines [J175]

"Guest editorial- foreword to the special issue on recognition technology"

First Page of the Article [J176]

"Recognition technology for the detection of buried land mines"

As described by Zadeh, recognition technology refers to systems that incorporate new sensors, novel signal processing, and soft computing. In this paper, we discuss these principles applied to the problem of land mine detection. We describe a complex recognition system that is evolving from basic research into a fielded system. Some components of this system have been field tested with excellent results, whereas other components have achieved such results in the laboratory. Fuzzy set-based information fusion algorithms are central to the excellent results obtained. Multiple-detection algorithms are applied to signals acquired from an innovative ground penetrating radar that produces volumetric sub-surface imagery. The outputs of the detection algorithms are combined using the fuzzy logic and Sugeno and Choquet fuzzy integrals to produce overall detection scores. Experimental results are provided on training data and on completely blind test data collected in the field and scored by the US Army [J177]

"Using novel fluorescent polymers as sensory materials for above-ground sensing of chemical signature compounds emanating from buried landmines"

Chemical vapors originating from the explosive charge within landmines and unexploded ordnance (UXO) form a chemical “signature” unique to these devices. The fact that canines can detect this signature was a primary motivation for the Defense Advanced Research Projects Agency's (DARPA) Dog's Nose Program. One goal of this program was to develop electronic chemical sensors that mimic the canine's ability to detect landmines. The sensor described here, developed under this program, utilizes novel fluorescent polymers to detect landmine signature vapors in air at ultratrace concentration levels (parts-per-trillion or less). Thin films of the polymers are highly emissive but undergo a dramatic reduction in emission intensity when molecules of target analytes bind to the polymer. Binding of a single explosive molecule can quench the fluorescence from hundreds of polymer repeat units, resulting in an amplification of the quenching response. The polymer structure contains receptor sites designed to interact specifically with nitroaromatic explosives, enhancing the selectivity of the polymers for target analytes. A man-portable sensor prototype, similar in size and configuration to metal detectors currently used for mine detection, has demonstrated performance comparable to that of canines during field tests monitored by DARPA at Fort Leonard Wood, MO [J178]

"Complex natural resonances of conducting planar objects buried in a dielectric half-space"

A scheme is presented to incorporate a mixed potential integral equation (MPIE) using Michalski's “formulation C” with the method of moments (MoM) for analyzing the scattering of a plane wave from conducting planar objects buried in a dielectric half-space. The robust complex image method with a two-level approximation is used for the calculation of the Green's functions for the half-space. To further speed up the computation, an interpolation technique for filling the matrix is employed. While the induced current distributions on the object's surface are obtained in the frequency domain, the corresponding time domain responses are calculated via the inverse fast Fourier transform (FFT). The complex natural resonances of targets are then extracted from the late time response using the generalized pencil-of-function (GPOF) method. The authors investigate the pole trajectories as they vary the distance between strips and the depth and orientation of single, buried strips. The variation from the pole position of a single strip in a homogeneous dielectric medium was only a few percent for most of these parameter variations [J179]

"On the wideband EMI response of a rotationally symmetric permeable and conducting target"

A simple and accurate model is presented for computation of the electromagnetic induction (EMI) resonant frequencies of canonical conducting and ferrous targets, in particular, finite-length cylinders and rings. The imaginary resonant frequencies correspond to the well known exponential decay constants of interest for time-domain EMI interaction with conducting and ferrous targets. The results of the simple model are compared to data computed numerically, via method-of-moments (MoM) and finite-element models. Moreover, the simple model is used to fit measured wideband EMI data from ferrous cylindrical targets (in terms of a small number of parameters). It is also demonstrated that the general model for the magnetic-dipole magnetization, in terms of a frequency-dependent diagonal dyadic, is applicable to general rotationally symmetric targets (not just cylinders and rings) [J180]

"Coupled canonical grid/discrete dipole approach for computing scattering from objects above or below a rough interface"

A numerical model for computing scattering from a three-dimensional (3D) dielectric object above or below a rough interface is described. The model is based on an iterative method of moments solution for equivalent electric and magnetic surface current densities on the rough interface and equivalent volumetric electric currents in the penetrable object. To improve computational efficiency, the canonical grid method and the discrete dipole approach (DDA) are used to compute surface to surface and object to object point couplings, respectively, in O(N log N), where N is the number of surface or object sampling points. Two distinct iterative approaches and a preconditioning method for the resulting matrix equation are discussed, and the solution is verified through comparison with a Sommerfeld integral-based solution in the flat surface limit. Results are illustrated for a sample landmine detection problem and show that a slight surface roughness can modify object backscattering returns [J181]

"Three-dimensional subsurface analysis of electromagnetic scattering from penetrable/PEC objects buried under rough surfaces: use of the steepest descent fast multipole method"

The electromagnetic scattering from a three-dimensional (3D) shallow object buried under a two-dimensional (2D) random rough dielectric surface is analyzed. The buried object can be a perfect electric conductor (PEC) or can be a penetrable dielectric with size and burial depth comparable to the free-space wavelength. The random rough ground surface is characterized with Gaussian statistics for surface height and for surface autocorrelation function. The Poggio, Miller, Chang, Harrington, and Wu (PMCHW) integral equations are implemented and extended. The integral equation-based steepest descent fast multipole method (SDFMM), that was originally developed at UIUC, has been used and the computer code based on this algorithm has been successfully modified to handle the current application. The significant potential of the SDFMM code is that it calculates the unknown moment method surface electric and magnetic currents on the scatterer in a dramatically fast, efficient, and accurate manner. Interactions between the rough surface interface and the buried object are fully taken into account with this new formulation. Ten incident Gaussian beams with the same elevation angle and different azimuth angles are generated for excitation as one possible way of having multiple views of a given target. The scattered electric fields due to these ten incident beams are calculated in the near zone and their complex vector average over the multiple views is computed. The target signature is obtained by subtracting the electric fields scattered from the rough ground only from those scattered from the ground with the hurled anti-personnel mine [J182]

"An investigation of acoustic-to-seismic coupling to detect buried antitank landmines"

When an acoustic wave strikes the ground surface, energy is coupled into the motion of the fluid/solid frame comprising the ground. This phenomenon is termed acoustic-to-seismic (A/S) coupling In the ground, the Biot Type II or Biot slow waves travel with a speed well below the speed of sound in air. The porous nature of the ground causes the entering acoustic wave to bend toward the normal and the acoustic wave propagates downward into the ground. When an object is buried a few cm below the ground surface, it distinctly changes the A/S coupled motion. These changes can be sensed by measuring vibrational particle velocity on the ground surface. Taking advantage of a noncontact remote measurement technique, the A/S coupling measurements for antitank landmine detection are conducted using a laser Doppler-vibrometer (LDV). Recent field measurements in both calibration and blind mine lanes and the resulting data analysts, which demonstrate the effectiveness of this technique, are described in this paper [J183]

"Experimental model for a seismic landmine detection system"

A laboratory-scale experimental model has been developed and tested for a system that uses artificially generated high-frequency seismic waves in conjunction with a radar-based noncontact displacement sensor to detect buried landmines. The principle of operation of the system is to measure the transient displacement field very close to a mine location. In this way, the absorption and the geometrical spreading of the seismic waves have not reduced the effects of the mine. By using a seismic excitation, the system exploits the large difference between the elastic properties of a mine and the surrounding soil. This difference causes seismic wave interactions in the vicinity of a mine to be quite distinctive and provides a method for imaging mines and distinguishing them from typical buried clutter. Images of a variety of simulated and inert anti-tank and anti-personnel mines have been formed using this system. Burial scenarios involving natural clutter (rocks and sticks), light surface vegetation, localized burial effects, and multiple mines in close proximity have been studied. None of these scenarios appears to pose serious problems for detection performance [J184]

"Acoustic detection of buried objects in 3-D fluid saturated porous media: numerical modeling"

Acoustic waves can be a viable tool for the detection and identification of land mines, unexplored ordnance (UXO), and other buried objects. Design of acoustic instruments and interpretation and processing of acoustic measurements call for accurate numerical models to simulate acoustic wave propagation in a heterogeneous soil with buried objects. Compared with the traditional seismic exploration, high attenuation is unfortunately ubiquitous for shallow surface acoustic measurements because of the loose soil and the fluid in its pore space. To adequately model such acoustic attenuation, we propose a comprehensive multidimensional finite-difference time-domain (FDTD) model to simulate the acoustic wave interactions with land mines and soils based on the Biot theory for poroelastic media. For the truncation of the computational domain, we use the perfectly matched layer (PML). The method is validated by comparison with analytical solutions. Unlike the pure elastic wave model, this efficient PML-FDTD model for poroelastic media incorporates the interactions of waves and the fluid-saturated pore space. Several typical land mine detection measurements are simulated to illustrate the application [J185]

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