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BOOK OF ABSTRACTS

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Table of Contents

Plenary Talks

From a Different Perspective: Principles, Practice and Potential of Bistatic Radar

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Bistatic radar systems have been studied and built since the earliest days of radar. They have the advantages that the receivers are passive, and hence undetectable. The receiving systems are also potentially simple and cheap. Bistatic radar may have a counter-stealth capability, since target shaping to reduce monostatic RCS will in general not reduce the bistatic RCS. In spite of those advantages, rather few bistatic radar systems have got past the 'technology demonstrator' phase. It has also been remarked that activity in bistatic radar tends to vary on a period of approximately fifteen years, and that currently we are at a peak of that cycle; there is particular current interest in passive coherent location (PCL) techniques, using broadcast and communications signals as 'illuminators of opportunity'.

This paper presents a review of some of the history, and the properties and current developments in the subject, and conjectures whether or not the present interest is just another peak in the cycle.

Radar the Next Generation – Sensors as Robots

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One can easily envision future military operations and emerging civilian requirements (e.g. intelligent unmanned vehicles for urban warfare, intelligent manufacturing plants) that will be both complex and stressing and will demand innovative sensors and sensor configurations. The goal of our research into *Sensors as Robots* is to develop a cost effective and extendable approach for providing surveillance for a variety of applications in dynamically changing military and civilian environments. Within *Sensors as Robots*, we foresee a new sensor archetype. In this paradigm, sensors and algorithms will be autonomously altered depending on the environment. Radars will use the same returns to perform detection and discrimination, to adjust the platform flight path and change mission priorities. The sensors will dynamically and automatically change waveform parameters to accomplish these goals. Disparate sensors will communicate and share data and instructions in real-time. Intelligent sensor systems will operate within and between sensor platforms such that the integration of multiple sensor data provides information needed to achieve dynamic goals and avoid electromagnetic fratricide. Intelligent sensor platforms working in partnership will increase information flow, minimize ambiguities, and dynamically change multiple sensors' operations based upon a changing environment. Concomitant with the current emphasis on more flexible defense structures, *Sensors as Robots* will allow the appropriate incremental application of remote sensing assets by matching resources to the situation at hand.

In this paper, we discuss the development of a futuristic intelligence, surveillance and reconnaissance concept utilizing the innovative integration of cutting edge technologies such as: knowledge-based signal processing, robotics, wireless networking, waveform diversity, the Semantic Web, advanced computer architectures and supporting software languages. This concept is projected as an autonomous constellation of air, space, and ground vehicles that would offer a robust paradigm to build toward future deployments.

Advantages and Problems of Wideband Radar

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Kharkov Military University , Ukraine

This paper addresses the definition, properties and modeling requirements of wideband and ultra-wideband radars. It begins by establishing the criteria by which the designation 'wideband' might be specified, since the common definition based purely on relative bandwidth fails to invoke some important associations. Next, the role of simulation is discussed and a representative simulation environment is described. The advantages and disadvantages of increasing the signal bandwidth are then evaluated quantitatively in the context of signal detection, parameter measurement, and the recognition of aerial target classes and types, with reference to specific classes of interest. In practice, certain other issues arise, including the degree of immunity to interference and electromagnetic capability. These topics are discussed in terms of their dependence on signal bandwidth and the associated signal acquisition and processing. In addition, an emerging problem is the need to take into account the possibility of signal exploitation and LPI. The essence of the theory of unauthorized signal detection that limits the LPI possibilities is briefly considered.

1A - Radar Target Imaging

Advanced Synthetic Aperture Radar Imaging and Feature Analysis

Victor C. Chen, Ronald Lipps, Maitland Bottoms
Naval Research Laboratory, USA

In this paper, we review and discuss advanced algorithms for synthetic aperture radar image formation, the effect of motion perturbation on radar imaging, synthetic aperture radar imaging of ground moving targets, and micro-Doppler feature analysis.

Performance Analysis of an ISAR Contrast-Based Autofocusing Algorithm Using Real Data

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The ISAR imaging technique is a well consolidated method for target image reconstruction. One of the main critical steps for ISAR is image focusing. This operation consists of removing from the received signal a non-linear phase term due to the motion of the target. As the target motion is not a priori known, motion parameters are typically estimated from the received data by means of autofocusing techniques. In this paper a novel technique, already proposed by the authors, namely the Contrast Based Autofocusing Technique (CBAT), is tested on real data and compared to a classic autofocusing technique, namely the "hot-spot" or Prominent Point Processing (PPP) technique. In order to also test the flexibility of the technique, two types of targets with different motion characteristics have been selected, specifically, a "bulk loader" ship and a Boeing 737 airplane. The CBAT performance has been evaluated by comparing the ISAR images reconstructed by means of a simple Range-Doppler technique to the images obtained by means of the PPP technique.

Ship 3D Model Estimation from an ISAR Image Sequence

Tristrom Cooke
CSSIP, Australia

ISAR imagery measures range and radial velocity of scatterers from targets of interest. Due to wave action, a ship will have constantly changing roll, yaw and pitch angular velocities, which makes the ISAR images quite changeable from frame to frame. In this paper, a method is described for extracting 3D model information from a sequence of two dimensional ISAR images, with no knowledge of the ship motion, but with the assumption that the scatterers can be correctly labelled from frame to frame. A later paper will describe a labelling method for use with real images which justifies this assumption.

Research on Radar Imaging of Manoeuvering Targets

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[1]*Nanjing University of Science & Technology, China;*
[2]*Nanjing Research Institute of Electronics Technology, China*

The conventional motion compensation and time-frequency imaging holds great potential for resolving the image blurring problem of complex motional targets. In this paper, the inverse synthetic aperture radar (ISAR) imaging model of manoeuvering targets is analyzed, together with some existing imaging methods. A scheme that incorporates the matching Fourier transform (MFT) and the modified CLEAN technique is recommended. The experimental simulation results indicate that the presented range-instantaneous Doppler imaging scheme can greatly improve the image quality of most manoeuvering aircraft, and therefore it is available for radar imaging of manoeuvering targets.

1B - Reduced Dimension STAP Methods

An Overview of Space-Time Adaptive Processing for Radar

Muralidhar Rangaswamy
AFRL/SNHE, USA

This paper provides a survey of space-time adaptive processing for radar target detection. Specifically, early work on adaptive array processing from the point of view of maximum signal-to-noise-ratio and minimum mean squared error perspectives are briefly reviewed for motivation. The sample matrix inversion method of Reed, Mallet and Brennan is discussed with attention devoted to its convergence properties. Variants of this approach such as the Kelly GLRT, adaptive matched filter and ACE tests are considered. Extensions to handle the case of non- Gaussian clutter statistics are presented. Current challenges of limited training data support, computational cost, and severely heterogeneous clutter backgrounds are outlined. Implementation and performance issues pertaining to reduced rank and model-based parametric approaches are presented.

Signal-Dependent Reduced-Rank Multibeam Processing

Matthew E. Weippert[1], John D. Hiemstra[1], J. Scott Goldstein[1], Vincent J. Sabio[1], Michael D. Zoltowski[2], Irving S. Reed[3]
[1]SAIC, USA; [2]Purdue University, USA; [3]University of Southern California, USA

A new implementation of the multistage Weiner filter (MWF) is developed for constrained filtering applications, such as radar surveillance, that require the formation of many filter vectors. The MWF is a "signal-dependent" reduced rank adaptive filter, which means that it uses the steering vector to form its basis for rank reduction. Signal-dependent processing provides a performance improvement over signal-independent methods, but typically incurs a computational burden that increases linearly with the number of filters. This paper describes a computationally efficient implementation of the MWF, based on the method of conjugate gradients (CG), and shows the relationship between MWF and CG. The CG-based technique uses a single SVD to impose a diagonal structure on the data matrix, and realizes an order-of-magnitude speed improvement over the conventional MWF.

Efficient Reiterative Censoring of Robust STAP Using the FRACTA Algorithm

Karl Gerlach, Shannon D. Blunt
Naval Research Laboratory, USA

This paper presents further developments of the FRACTA algorithm [1,2] which has been shown to be robust to nonhomogeneous environments containing outliers. The focus here is on the efficient implementation of the FRACTA algorithm. The key development is a censoring stopping mechanism whereby the number of reiterative steps can be minimized and computation is reduced. We introduce a data-dependent stopping rule that demonstrates excellent results as evidenced by the detection of targets in the KASSPER challenge data cube. We also present some other enhancements to the FRACTA algorithm that further improve both efficiency and performance.

A Signal Subspace Technique for Computing Weights of an Airborne Phased Array

Dan Madurasinghe, Scott Capon
DSTO, Australia

A new signal subspace technique for beamforming is analyzed and compared using simulated and measured data. The objective is to find a set of array weights to maintain a given low sidelobe radiation pattern, that accommodates specific nulls in the directions of interferers which may be present in the system due to various interference sources (aircraft body, mutual coupling etc.). The procedure is numerically intensive, since it requires complete analysis of the eigenstructure of the interference covariance matrix. Estimated weights are suitable for offline applications. Performance evaluation is carried out using simulated data as well as measured data. Some of the advantages, associated difficulties and the limitations are investigated.

Performance of the Space-Time AR Filter in Non-Homogeneous Clutter

Peter Parker
Brigham Young University, USA

The space-time autoregressive (STAR) technique has been proposed for space-time adaptive processing (STAP). This algorithm utilizes the structure inherent in airborne STAP applications (i.e., uniformly spaced pulses) to improve convergence and reduce computation. This paper addresses the performance of the STAR algorithm in the presence of non-homogeneous clutter, particularly in a littoral region. It is shown that the STAR filter produced a narrower null (and thus a lower minimum detectable velocity) than either the optimized pre-Doppler or post-Doppler algorithms. This is due to the STAR algorithm estimating a joint space-time filter for clutter suppression as well as having a small sample support region. It is also shown that the pre-Doppler algorithm does exhibit some robustness when the radar system is limited by its channel match.

1C - Propagation

Ionospheric Propagation Effects on Ground and Space Based Radars

Dennis L. Knepp, Mark A. Hausman
Mission Research Corporation, USA

This paper discusses the application of EM propagation theory to account for observations of scintillation from equatorial satellite beacon and radar measurements of transionospheric propagation. Satellite beacon measurements from the Wideband satellite experiment are used to calculate the degradation caused by scintillation in the radar coherent integration process. Coherent integration will be required in any space based radar to achieve separation in Doppler of moving targets from the large return of the earth. Measurements of ionospheric scintillation in the equatorial region taken with the VHF/UHF ALTAIR radar in the Marshall Islands are described. These measurements support the use of the strong scatter limit of the parabolic wave equation that accounts for certain features of the observations. A technique is illustrated to calculate realizations or sample functions of wide bandwidth radar signals that have passed through the ionosphere. This technique gives realizations that are consistent with the ALTAIR observations. Results are given for radar performance of target detection for several different radar signal combining techniques.

Considerations in the Development of the Advanced Propagation Model (APM) for U.S. Navy Applications

Amalia E. Barrios
SSC San Diego, USA

The Navy Radio and Sound Laboratory was originally built in San Diego during World War II to study radiowave and underwater acoustic propagation effects. The laboratory has grown over the years and has undergone many organizational and name changes since then to become what is currently the Space and Naval War-

fare Systems Center San Diego (SSC San Diego). What is now the Atmospheric Propagation branch at SSC San Diego has been in the business of researching and modeling effects due to atmospheric conditions on radiowaves since the 1940's.

Primarily funded by the U.S. Navy, much of the work we do in the Atmospheric Propagation branch has been not only in the propagation research area but also in the development of applications displays and assessment tools specifically for use by the U.S. Navy. However, a software package with the fanciest GUI wrapped around the most scientifically accurate propagation model in the world will not be used by many if the model executes slowly. Therefore, we spend a great deal of effort in designing an efficient model, automating much of the input parameters needed to get meaningful results from the model.

This paper will focus primarily on the Advanced Propagation Model (APM), developed by the Atmospheric Propagation branch at SSC San Diego, and looks at initial developments of the model along with approximations made in its design for consideration of the operational user.

Factors Affecting Radio Holes

J.A. Hermann, A.S. Kulessa
DSTO, Australia

We present modelling results, utilising both theoretical considerations and atmospheric measurements, which demonstrate the role of environmental and system factors in determining the properties of radio holes.

A Hybrid Ray Tracing/Integral Equation Approach to the Modelling of Microwave Radar Propagation

C.J. Coleman
University of Adelaide, Australia

A technique for modelling microwave radar propagation is developed. The approach is based on ray tracing that is extended into the diffraction regime by means of integral equations. The resulting algorithm is extremely flexible and can incorporate propagation effects such as ducting, ground wave propagation and edge diffraction.

2A - Interferometric SAR

POLInSAR Regularisation Using Dual Frequency Interferometry

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In this paper we employ a two-level coherent polarimetric vegetation scattering model to investigate forest parameter estimation using fully polarimetric single baseline radar interferometry. It is shown that model inversion requires regularisation to remove multiple solutions. Traditionally this is achieved by using assumptions about polarimetric ground scattering. Here we investigate the possibility of regularisation using an extra InSAR channel obtained from a higher frequency sensor. Given that dual band InSAR systems are already used for airborne mapping applications, and that the SRTM global data base is now widely available, such a regularisation strategy has important practical implications for the efficient use of radar interferometry for quantitative parameter estimation.

Change Detection in Repeat Pass Interferometric Synthetic Aperture Radar

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In repeat pass Synthetic Aperture Radar Interferometry (InSAR) scene disturbances may be identified as areas of low coherence or possibly as areas of changed backscatter coefficient. The backscatter coefficient is dependent on the structure and dielectric properties of the scattering medium while the coherence is sensitive to changes in the distribution of scattering elements within resolution cells. The coherence and backscatter coefficient thus provide complementary information regarding possible disturbances in the underlying scattering mechanisms. The ability to detect subtle man-made disturbances using changes in backscatter coefficient or coherence however is limited by high false alarm rates unless significant averaging is carried out resulting in a degradation in the resolution of the change maps.

In this paper, models describing the changed and unchanged regions of a scene are postulated and the detection problem is expressed in a hypothesis testing framework. Forming the log likelihood ratio gives a single statistic, encoding both coherence and RCS changes, for discriminating between the unchanged and changed scene models. Expressions for the probability of detection and false alarm are derived for the likelihood ratio and show a significant improvement over both the RCS ratio and sample coherence change statistics. Finally the improved detection performance is demonstrated using data collected in a repeat pass interferometry experiment with the DSTO Ingara X-band airborne SAR.

Multi-Look Coherent Synthetic Aperture Radar (SAR)

Timothy M. Payne
DSTO, Australia

The interference between two radar images, acquired from approximately the same location, has a number of uses. In particular, the literature abounds with examples of coherent change detection (CCD) and interferometric SAR (InSAR) uses which respectively enable the detection of small changes and the extraction of terrain elevation. In almost all of these examples coherent estimates have been formed by spatially averaging the interfered images to obtain reliable estimates. This paper looks instead at averaging independent looks that, although more complicated, allow higher resolution coherent products to be formed over larger areas by reducing the constraints on the allowable quadratic phase error that typically limits image size.

Coherent Synthetic Aperture Radar (SAR) Pair Formation

Timothy M. Payne
DSTO, Australia

The interference between two radar images, acquired from approximately the same location, has a number of uses. In particular, the literature abounds with examples of coherent change detection (CCD) and interferometric SAR (InSAR) uses which respectively enable the detection of small changes and the extraction of terrain elevation. In almost all of these examples collections have been deliberately constrained so that they have almost identical collection geometries. If the geometry of the collections differ then a severe degradation in the coherence of the products results when the images are formed in a conventional manner. This paper presents a new approach to image formation which simultaneously forms, focusses and interferes two images. This approach is not subject to the same geometry constraints and indeed works best when the ideal conditions are violated. As a byproduct of the process no image warping is required, the phase unwrapping problem and atmospheric phase grating effects can be eliminated.

2B - Signal Processing

A Dual Adaptive Channel STAP Scheme for Target Detection and DOA Estimation

Pierfrancesco Lombardo, Fabiola Colone
University of Rome "La Sapienza", Italy

This paper presents a dual cancelled channel approach to the target detection and estimation with a digital beamforming radar. The proposed STAP (Space-Time Adaptive Processing) scheme is shown to yield comparable detection performance to previously known schemes and higher accuracy in the estimation of the target direction of arrival. Moreover, it has a lower computational cost, since it does not require the numerical maximization of a functional.

Sensitivity of CFAR Processors Towards the Change of Input Distribution of Pulse Jamming

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Institute of Information Technologies, Bulgaria

In this paper we study the sensitivity of cell-averaging constant false alarm rate (CA CFAR) processors towards the change of input distribution (Poisson and binomial distribution) of pulse jamming (PJ). We offer the mathematical expression for calculating the parameters of CA CFAR detectors in the entire area of the probability for the appearance of strong pulse jamming. The original results in the present work concern the determination of the sensitivity expressions of the probability of detection, probability of false alarm and the average decision threshold (ADT) for CA CFAR detectors, towards the change of distributed pulse jamming. The results show that a CA CFAR processor has high losses when the scale factor is chosen incorrectly. Research is performed in MATLAB environment.

An Approach Based on Trispectrum and Rank Statistics to Testing Departure from Gaussianity of Stationary Signals

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In this paper, a rank procedure based on trispectrum to test the departure from the Gaussianity of stationary signals is presented. Both theoretical analysis and simulation results demonstrate that the proposed algorithm, to symmetrically distributed processes, has advantages on testing performance over the conventional approaches based on bispectrum, while maintaining the nominal level of significance, even for a relative small data size. Its results are better than those of the algorithms based on bispectrum and bootstrap.

2C - Electromagnetics

An Entropy-Based Approach to Wake Echo Analysis

James Morris, Stuart J. Anderson
DSTO, Australia

This paper addresses the problem of ship wake detection and analysis at low grazing angles using eigenvalue analysis of the covariance matrix. Polarimetric measurements of the wake produced by a pilot boat operating in Port Phillip Bay were obtained using the Defence Science and Technology Organisation's (DSTO) high resolution radar system. By employing a polarimetric decomposition on the covariance matrix data, the polarimetric entropy, scattering alpha and anisotropy plots were obtained. Wake and clutter regions there then identified using suitable thresholds. These results were compared with previous results obtained using analysis of the S matrix data and the distribution of cross-polar null states and showed good agreement. The ratio of the maximum and minimum eigenvalues of the covariance matrix was also determined as an upper bound on the processing gain that might be achieved by exploiting the polarization domain.

Ship and Shipwake Enhancement in Coastal Surveillance Radar Systems Using Target Back Propagation Technique

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[1]*Applied Radar Physics, Norway;* [2]*Norcontrol IT, Norway*

Rotating incoherent radar systems are usually used for coastal surveillance of vessels. Signal to clutter / noise enhancement is obtained by averaging a number of scans. Because the vessels move and thus migrate out of the radar resolution cells the number of scans that can be averaged is limited by this effect. This paper exploits target back propagation technique to overcome this problem. Measurements show that a significant enhancement of the ship image quality is achieved using this technique. Also the ship wake is made clearly visible and is subject for further study in wavenumber domain and radon transform domain for detection and feature extraction.

Tenix Panels: A Solution to the Problem of RCS Reduction for Ships in Service

M.R. Jones[1], *P. Stafford*[1], *W.C. Anderson*[2]
[1]*Tenix Defence, Australia;* [2]*DSTO, Australia*

Tenix Defence, with support from the Defence Science and Technology Organisation (DSTO), has developed a lightweight reflective cladding for application to surface ships when it is desirable to reduce the monostatic radar cross section (RCS). The composition of this cladding and its scattering characteristics are described in this paper, together with some of the fabrication issues.

Multipath of Flat Plate Radar Cross Section Measurements

Richard Norland
IKT System Partner AS, Norway

Measuring the radar cross section (RCS) of point targets above an electromagnetic smooth surface can be difficult if the targets are subjected to interference effects i.e. multipath, as a result of a direct and indirect electromagnetic reflection from the surface. If the point target is used as a reference target for e.g. direct calibration, multipath can introduce errors in the subsequent calibration of other RCS measurements. In order to reduce the possibility of multipath, a commonly used reference target for outdoor ranges is the flat plate. It is generally assumed that the very specular backscattered reflection pattern of the flat plate does not introduce multipath. The paper shows how this assumption is constrained by the radar wavelength, geometric parameters and by the plate dimension. The results are finally compared with measured data of a flat plate.

Susceptibility of a Personal Computer to Radar

A. Piotrowski
DSTO, Australia

In this paper a generic susceptibility model of a Personal Computer (PC) was derived using generic coupling characteristics of cables, enclosure with apertures, and a circuit board. Using experimental upset data for digital semiconductor components electric field intensities were calculated for an unshielded PC board and a typical PC. The obtained results show the envelope of an electric field intensity to which a PC is susceptible with the minimum and maximum margins. A typical PC is the most susceptible at frequency ranges 3-500MHz and 700-1500MHz with the upset threshold of 250V/m for a typical PC and 55V/m for an unshielded PC board.

3A - Target Classification & Identification

Sharpening and Bandwidth Extrapolation Techniques for Radar Micro-Doppler Feature Extraction

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Oregon State University, USA

This paper presents a time-frequency analysis sharpening technique based on bandwidth extrapolation (BWE). The method utilizes a new extremely high resolution two-dimensional (2-D) linear prediction/lattice algorithm to enhance instantaneous time and instantaneous frequency details of conventional short-time Fourier transform (STFT) time-frequency analysis (TFA). The approach preserves extreme high dynamic range (DNR), over 100 dB, in the data without introducing debilitating cross-term artifacts that severely obscure weak features in the TFA, such as those introduced by quadratic TFAs like the Wigner and Cohen TFA representations. We shall demonstrate the performance of the new high detail TFA for micro-Doppler feature extraction in actual X-band airborne moving target (AMTI) and ground-borne moving target (GMTI) applications. This paper illustrates the AMTI case; GMTI will be provided at the conference.

A Doppler-Based Target Classifier Using Linear Discriminants and Principal Components

Andrew G. Stove[1], *Stephen R. Sykes*[2]
[1] *Thales Sensors, U.K.;* [2] *Thales Research Limited, U.K.*

This paper describes the design of the automatic target classifier which has been introduced into the AMSTAR Battlefield Surveillance Radar. It discusses the requirements which have driven the design of the classifier, the data which is used to make the classification, the choice of Linear Discriminant Analysis as the classification technique and the use of Principal Components Analysis to simplify the training of the discriminator. It also discusses the testing of the classifier and the performance achieved.

Joint Deinterleaving/Recognition of Radar Pulses

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Royal Military College of Canada , Canada

A radar electronic support measures (ESM) system performs the functions of threat detection and area surveillance to determine the bearing and the identity of the surrounding radar emitters. The received pulses are sorted and segregated into a number of deinterleaved radar cells depending on their measured parameters. The parameters of the deinterleaved radar cells will be submitted to the threat library of the electronic warfare (EW) system to be compared with the stored parameters of known radars to identify the intercepted radars. Consequently the appropriate actions could be taken against the identified radars. However, if the ESM system does not work properly, a number of false radars will be generated and some of the military resources may be used against them.

This paper proposes a new approach of performing the deinterleaving of radar pulses and identifying their corresponding radars into one step. The proposed approach can successfully identify radars whose angle of arrival (AOAs) are very close and their pulses are merged into a single cell. Moreover, the proposed approach can be applied as an integral part of the adaptive deinterleaving algorithm to prevent the ESM system from taking actions against false radars and consequently avoid the waste of the available resources. Computer simulation results have shown that the proposed approach can successfully deinterleave radar pulses and identify their corresponding radars. Furthermore, it is unlikely that the identified radar, is a false radar.

The Extraction of Building Dimensions from High Resolution SAR Imagery

Andrew J. Bennett, David Blacknell
QinetiQ Ltd., U.K.

In this paper, we present an automated technique for the measurement of building heights from SAR imagery. We apply a delineation algorithm to extract buildings and shadows from urban areas. From scattering and shadowing information we obtain estimates of building heights over a range of aspect angles generated using squinted SAR processing techniques.

3B - Phased Array Radar

Pattern Control for Adaptive Antenna Processing with Overlapped Sub-Arrays

Pierfrancesco Lombardo, Debora Pastina
University of Rome "La Sapienza", Italy

This paper deals with the optimization of adaptive techniques operating with partially overlapped sub-arrays. Three new adaptive schemes are introduced that properly cancel jamming signals when present, but give exactly the desired quiescent pattern in the absence of jammers. These schemes solve the problem of the antenna pattern control under adaptive operation even for the case of overlapped sub-arrays.

Radar with Separated Subarray Antennas

Jan-Erik Nilsson, Håkan Warston
Ericsson Microwave Systems AB, Sweden

In the work reported in this paper we have investigated the possibilities of using separated subarray apertures in various radar applications based on the next generation technology for active electronically scanned arrays, (AESA). We have looked at the possible benefits of using separated subarray apertures and have adapted sidelobe- and main lobe cancellation methods to such systems in order to estimate possible jammer suppression performance.

Fast MUSIC for Large 2-D Element Digitised Phased Array Radar

A.S. Paine
QinetiQ Ltd., U.K.

Super-resolution for direction of arrival (DOA) estimation has been a subject of research papers over many years. In an ideal case, super-resolution would be performed using element digitised array radar (EDAR) to give grating lobe free full-gain beam patterns during the processing. However, these techniques tend to require vast computational effort and their implementation can be limited. In this paper, an implementation of the MUSIC (MUltiple SIgnal Classification) super-resolution technique is developed that can perform fast DOA estimation covering all azimuth and elevation angles when used with large 2D planar EDAR.

A Multichannel Auto-Regressive GLR Detector for Airborne Phased Array Radar Applications

M.R. Moniri[1], *M.M. Nayebi*[2], *A. Sheikhi*[3]
[1] *Oloom-va-Tahghighat University, Iran;* [2] *Sharif University of Technology, Iran;* [3] *Shiraz University, Iran*

This paper considers the Gaussian multichannel binary detection problem. A multichannel generalized likelihood ratio (GLR) is presented using a model-based approach where the signal and its amplitude are known and additive noise is characterized by autoregressive (AR) vector processes which can be a suitable model for ground clutter in most scenarios involving airborne surveillance phased array radar. The detector can use secondary vectors to improve its performance. Although, in our model, the amplitude of signal must be known, but according to its excellent performance, an approximation of GLR on the amplitude is also presented. The detector performance in various conditions and the result of comparison with Kelly's GLR and adaptive matched filter (AMF) detectors is presented by computer simulations.

Array Shape Calibration Using Carry-On Instrumental Sensors

Bu-hong Wang, Yong-liang Wang, Hui Chen
Radar Academy, China

A novel and efficient method for calibrating a sensor array with position uncertainties is proposed in this paper. The method is

based on two non-disjoint sources in unknown directions and three carry-on instrumental sensors. It can be applied to arbitrary array geometries including linear arrays. Besides, no small position error assumption is made, which is always an essential prerequisite for many existing array shape calibration techniques. The new method achieves a favorable array shape calibration just using a one-dimensional search, with no high-dimensional nonlinear search and convergence burden involved. It is also possible to extend the proposed idea to tackle the problem of direction dependent gain and phase uncertainties. Simulation results are provided to demonstrate the effectiveness and behavior of the proposed method.

3C - Ground Penetrating Radar/UWB/Other Applications

Millimetre Wave Radar Sensors for Mining Applications

Graham M. Brooker, Steve Scheding, Ross Hennessy, Mark Bishop
University of Sydney, Australia

The paper starts by defining the issues that are required for the development of a successful underground sensor. It goes on to investigate the options before settling on millimetre wave FMCW radar. Implementation of two radar sensors for different underground applications is then discussed.

Some Experience with the Use of Spiral Antennas for a GPR for Landmine Detection

Piet van Genderen[1], *Ioan Nicolaescu*[2], *Johan Zijderveld*[1]
[1] *Delft University of Technology, The Netherlands;*
[2] *Military Technical Academy, Romania*

Ground Penetrating Radars for detection of Antipersonnel landmines operate in a UWB domain from 400 MHz up to 5 GHz. One of the radar concepts for this kind of application is a Stepped Frequency CW radar. The requirements on the antenna for this radar is, that it shall have a stable phase centre, frequency independent gain, ultra-wide band, high isolation between the two antennas in a bistatic arrangement and other more common requirements like a low VSWR. The antenna selected for the application is an Archimedean spiral. Such an antenna has a wide beam width and a radiation pattern only slightly dependent on frequency. A basic problem to the use of a spiral antenna when it is elevated above the ground is, that the small contribution of the anti personnel mine is surged by the strong reflection off the air/ground interface. This paper is addressing this effect by analysing the impact of the size of the antenna footprint on the SAR-synthesised three dimensional image of the subsurface. Experimental results like presented here are not available to the authors' knowledge elsewhere in the open literature.

M-Sequence Ultra-Wideband-Radar: State of Development and Applications

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[1] *Technische Universität Ilmenau, Germany;*
[2] *MEODAT GmbH, Germany;* [3] *Independent Consultant, Germany*

The UWB approach is a promising and challenging technique for a great deal of sensor tasks for volume applications with economical and social impact. Impulse and swept sine waves are the classical methods to cover a wide spectral band. The M-Sequence technique joins the merits of both principles without their drawbacks. The M-Sequence technique provides stable UWB-data at reasonable costs and device dimensions due to its simplicity and the absence of bulky off-chip components which are amenable to monolithic integration.

Millimetre-Wave Radars in Targeting and Data Linking Operations

H.J. Hansen[1], *A.S. Kulessa*[1], *Graham M. Brooker*[2]
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Millimetre-wave (W-band=75-110 GHz) radars are poised to form an important component of autonomous vehicle operations because high frequency systems are able to provide the conformal miniaturized solutions necessary for many robotic applications. A Serial Programmable Integrated Radar Threat Simulator (SPIRTS) that transmits 95 GHz centred emissions for investigating air-to-surface target threats has been developed and the performance of this unit in a targeting role is projected. Targeting operations at W-band are compared with those at lower K_a and X band frequencies. The upsides and downsides of W-band operation in clutter generation and in multi-path signal fading, important for future high frequency communication links, are highlighted. Clear air propagation effects for datalinking operations are also discussed for W band emissions.

Focusing Range Image in VCO Based FMCW Radar

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Warsaw University of Technology, Poland

The paper presents a simple method for focusing images in VCO based cheap FMCW radar. Image defocusing is caused by nonlinear distortions in Voltage Control Oscillator (VCO, very often YIG type). To obtain good quality FMCW radar images, linear frequency modulated (LMF) signal is required. Even small changes in voltage-frequency VCO characteristic cause range defocusing, and though decrease of radar sensitivity and resolution. The method, derived from the polynomial model of non-linear LFM signal phase, is based on Generalized Chirp Transform of the video (intermediate frequency IF) signal obtained by mixing transmitted LFM signal with received (delayed) signal. To avoid complicated laboratory equipment (such as optical delay lines) the whole procedure is performed on live radar signals, using maximum contrast approach.

4A - Multichannel Interferometric SAR

Multi-Image Satellite SAR Interferometry: State of the Art and Future Trends

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In this paper we wish to review briefly the principles funding a recently developed approach, known as Permanent Scatterers (PS) technique and aimed at the joint exploitation of series of spaceborne interferometric SAR images for the retrieval of high precision elevation and ground deformation data on a sparse grid of privileged point-wise radar targets.

Description and Applications of the Multipolarized Dual Band OrbiSAR-1 InSAR Sensor

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Orbisat da Amazônia S.A. , Brazil

In the last decade interferometric SAR (InSAR) has reached a wide acceptance as being a suitable tool to generate high-precision digital elevation models. Especially in tropical areas with nearly permanent cloud coverage InSAR provides a cost-efficient means for mapping large areas in short time periods. However, the interaction of microwaves with vegetation is strongly dependant on their frequency, demanding a careful interpretation of the extracted information. Short waves like X-band are mainly scattered back from the top of the canopy, whereas P-band penetrates the foliage and gets reflected from trunk and soil, thus carrying the phase information (and therefore the height information as well) from bald earth. For the generation of topographic maps generally the ground elevation rather than the surface elevation is required, whereas the surface and ground elevation together enable the estimation of additional physical parameters like vegetation height, density, or biomass.

Ocean Imaging Using Multichannel Along Track Interferometry

Brian C. Barber
DSTL, U.K.

An airborne Multichannel Along Track Interferometer (MATI) is described and discussed. This MATI system is based on an X-band SAR installed in a BAE/BAC 1-11 aircraft which can be set up with

2, 3 or 4 beams. It is demonstrated that a MATI can be used to doppler filter radar signals acquired from a moving platform which are scattered by moving and partially coherent scatterers. Processing techniques are described for the removal of phase errors. These phase errors are caused primarily by the separation of the antennas in range due to the aircraft installation, and by aircraft roll, pitch and yaw motions. The basis of the processing technique is a two stage phase screen which is capable of compensating the differential phase errors between each image in a multichannel set to the precision required for doppler filtering. It is shown that optimal filtering may be applied to the scattered radar signals by adaptively varying complex weights applied to each channel until an extremum of a selected image measure is obtained. Hence, if a certain type of scatterer is associated with energy located in a particular part of the doppler spectrum and an image feature results from the modulation of this type of scatterer then the visibility of the feature can be maximised using an adaptive MATI. An example is presented showing the technique applied to a sandbank image.

Multiple Reflectivities Estimation for Multibaseline InSAR Imaging of Layover Extended Sources

Fabrizio Lombardini, Fulvio Gini
University of Pisa, Italy

In this paper the problem of retrieving radar reflectivity of natural layover areas is addressed. It is formulated as the problem of estimating a multicomponent sinusoidal spatial signal corrupted by multiplicative complex correlated noise – the speckle in the radar imaging jargon – and by additive white Gaussian noise. Application of non-parametric adaptive and parametric spectral estimators for amplitude estimation is investigated for a multiple looks scenario. Performance analysis is investigated through Cramér-Rao lower bound calculation and Monte Carlo simulation. The method of least squares (LS), coupled with Capon's approach for interferometric phase estimation, multilook-RELAX and multilook-APES outperform conventional beamforming and provide accurate reflectivity estimates for undistorted image formation of layover areas.

4B - Atmospheric Radar

Atmospheric Radar for the 0.5–110 km Region

Iain M. Reid
University of Adelaide, Australia

Radar can be used to make measurements of the dynamics and structure of the atmosphere by detecting irregularities in refractive index due to variations in humidity and temperature in the lower atmosphere (0 - 20 km), and due to variations due to fluctuations in electron density in the Mesosphere Lower Thermosphere (MLT) region of the upper atmosphere (50 - 110 km). MF and HF radars have been used to routinely investigate the MLT for over 50 years. Wind Profiling Radars operating in the VHF band have been used for about 25 years to investigate the Stratosphere Troposphere (ST) region, but only routinely in the last 15 years. Considerable development has occurred within the past decade. In particular, great attention has been paid to interferometric and imaging techniques, to a re-examination and extension of MF radar techniques, to the application of VHF radars developed for atmospheric research to meteor studies, and finally, a rebirth of dedicated meteor radars has occurred. Here we briefly describe some of these recent improvements.

Meteorological Applications of Radar Wind Profilers

Christopher Lucas
University of Adelaide, Australia

An overview of the meteorological applications of wind profilers is given, focusing on the VHF boundary-layer wind profiler developed at the University of Adelaide. Discussion is centered on 1.) a comparison of signal-to-noise ratio plots and their meteorological interpretation; 2.) the discussion of a wind profiler front-finding algorithm and the characteristics of profiler detected fronts and 3.) precipitation retrievals with a wind profiler. Illustrative examples are provided for each area. The possible directions of future research are also briefly discussed.

Mesospheric and Lower Thermospheric Observations Using the Buckland Park Medium Frequency Radar

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[1]*Atmospheric Radar Systems, Australia;* [2]*University of Adelaide, Australia*

This paper describes the analysis techniques employed for atmospheric observations using medium (MF) and high frequency (HF) radars, focusing on the current routine observations scheme implemented for the Buckland Park medium frequency (BPMF) radar. These observations are rare among current routine MF/HF radar observations in that they are made using relatively narrow transmit polar diagram. The flexibility of the radar allows a number of analyses to be performed simultaneously. The analyses described include the full correlation analysis (FCA), spatial correlation analysis (SCA), hybrid Doppler interferometry (HDI) and imaging Doppler interferometry (IDI) for observations of mesospheric dynamics and the temporal and spatial characteristics of their scatterers, the differential absorption experiment (DAE) for the estimation of electron densities and collision frequencies, and meteor analysis for estimation of meteor height, time and AOA distributions.

The Tasman International Geospace Environment Radar (TIGER) – Current Development and Future Plans

Peter L. Dyson, John C. Devlin, Murray L. Parkinson, J.S. Whittington
La Trobe University, Australia

The Tasman International Geospace Environment Radar (Radar) is a dual HF radar system with overlapping footprints designed to map ionospheric motions by detecting ionospheric scatter. The first radar was set up on Bruny Island, Tasmania at the end of 1999 and development of the second radar to be placed near Invercargill, NZ, has begun. TIGER is part of the Super Dual Auroral Radar Network (SuperDARN) which currently consists of 15 radars deployed in the northern and southern hemispheres. TIGER is located more equatorward than other SuperDARN radars enabling it to observe new phenomena, such as Auroral Westward Flow Channels (AWFCs). This paper describes TIGER's capabilities and presents examples of observations, including an AWFC. Plans to develop digital transmitters and receivers are discussed as is a proposal to extend the network to even lower latitudes by deploying two additional radars.

4C - Bistatic/ Multistatic/ Passive Radar

Results from an Experimental Continuous Wave Low Probability of Intercept Bistatic Radar – The First Steps Toward Multistatic Radar

K.E. Olsen, T. Johnsen, S. Johnsrud, R. Gundersen, H. Bjordal, I. Tansem, P. Sørnes
FFI , Norway

The Norwegian Defence Research Establishment (FFI) has developed an experimental Continuous Wave (CW) Low Probability of Intercept (LPI) bistatic radar. The radar is transmitting a CW binary phase coded signal at a maximum power of 1W. The radar has been used to detect different targets in various trials. Selected results are presented, and future work is indicated.

The Design and Development of an Experimental Netted Radar System

Tom Derham, Karl Woodbridge, Hugh D. Griffiths, Christopher J. Baker
University College London, U.K.

In this paper we report on the development of a low-cost, four-node netted radar system operating at S-band. The system has been designed using 'commercial off the shelf' sub-systems and components wherever possible. A detailed computer simulation has been implemented to provide an environment for testing design options

and development of a test strategy for the completed network. This has been invaluable as the extra dimensionality of the system, uncertainty in component specification and potential variability in the synchronisation signal make design and performance prediction complex.

Digital Signal Processing in Binary Phase Coded CW Multistatic Radar

Richard Norland
IKT System Partner AS, Norway

Electronic countermeasures (ECM) and homing anti-radiation missiles (ARM) pose a threat to the operability of radar. One solution to counteract the threat and continue operating radar is to separate the transmitter and receiver and spread the emitted signal in both frequency and space. The Norwegian Defence Research Establishment (FFI) has developed a low power, bistatic, coherent, spread spectrum and continuous wave (CW) radar for radar cross section (RCS) measurements. The experience with the measurement radar initiated a project to investigate the operational characteristics of a multistatic radar system. The paper presents the digital processing of a multistatic radar concept for a low-level air defence radar system using one receiver unit and several transmitters.

Position-Adaptive UAV Radar for Urban Environments

Atindra K. Mitra
Air Force Research Laboratory, USA

A bistatic radar concept is presented where a low-altitude UAV (Unmanned Aerial Vehicle) "position-adaptively" converges to line-of-sight (LOS) locations for objects that are embedded between buildings. The concept is developed by deriving approximate electromagnetic signal models based on the uniform theory of diffraction (UTD). In addition, a new signature exploitation technique is formulated that allows for the estimation of target parameters in cases when neither the transmitting nor the receiving platform is in LOS with an embedded target or object. This technique is denoted as "exploitation of leakage signals via path trajectory diversity" (E-LS-PTD). Additional areas for further research are cited.

Direct Path Interference Suppression in Bistatic System: DTV Based Radar

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Over the past 20 years bistatic radar has been an emerging technology. One of the major problems in continuous wave bistatic radar is the direct path interference (DPI). The reflected signal from the target is received at the background of this interference; the target would be buried under the sidelobes of the DPI in the receiver circuit. Conventional solution to this problem is the use of an adaptive antenna, steering null towards the interference. Unfortunately this technology is most effective in quasi-stationary receiver. For surveillance radar the null depth obtained is not enough. This paper proposes a new technique of DPI suppression, based on dynamic compensation. Some aspects of cross-polarisation isolation between the transmitter and receiver is also considered.

Poster Session A

Scatterer Labelling Estimation for 3D Model Reconstruction from an ISAR Image Sequence

Tristrom Cooke
CSSIP, Australia

In the previous paper [1], a method was described for estimating a 3D point scatterer model from a sequence of two dimensional ISAR images, with no knowledge of the ship motion. It assumed, however, that each scatterer could be correctly associated with a Doppler measurement in the ISAR image sequence. This is usually not an accurate assumption, so it is the purpose of the current paper to describe a relabelling algorithm, which will accurately assign image maxima to the correct model scatterer. This relabelling will allow useful 3D ship models to be generated for realistic ISAR image sequences.

Performance Analysis of an Airborne High PRF Phased Array Radar in a Jamming Environment

Dan Madurasinghe
DSTO, Australia

This study focuses on algorithms currently available for a high PRF airborne phased array radar, where the system is designed to unambiguously detect fast targets, such as fighters, under intense jamming. It is shown that under the constrained conditions, the best processing option is not the well known Space Time Adaptive Processor (STAP), but a dual processor which provides the optimal solution at lowest possible computational cost maintaining the overall optimal performance.

Low-Cost Realisation of Space-Borne Synthetic Aperture Radar – MICROSAR (September 2003)

D.J.Q. Carter[1], *C.D. Hall*[1], *M.A.B. Cohen*[1], *E.A. Alderson*[1], *D.C. Rutten*[2]
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Civilian space-borne remote sensing has been exploited in the areas of meteorology and optical imaging since the early 1970s. Until recently, these satellite systems have generally been commissioned exclusively by government institutions or agencies. There have been only a limited number of Synthetic Aperture Radar (SAR) missions amongst these civilian remote sensing missions, even though SAR offers another dimension of information and additional capability including all-weather, day-night imaging.

Three factors may explain this situation:

1. SAR images are not visible images that humans are used to interpreting and the relationships between the SAR processed data/images to the specific information needs have not been widely understood or robust.
2. There is a chicken and egg paradox, that the demand does not exist as the availability of suitable sources, at the relevant performance and data quality, have been inadequate to provide service assurance that is necessary to sustain commercial businesses.
3. Costs associated with developing a SAR capability including building, launching and operating a space-borne SAR sensor have not been low enough to achieve an acceptable return on investment.

Radar Target Identification Based on Adaptive Joint Time-Frequency Processing in High Frequency Domain

Jin Yan, Xiaobin Feng, Peikang Huang
National Electromagnetic Scattering Laboratory , China

A new radar target feature extraction method based on adaptive joint time-frequency processing is presented for radar target recognition in high frequency domain. After applying the adaptive Gaussian representation to the range profile, some of the decomposing

parameters are extracted as feature vectors used for identification. Comparing with range profiles, the extracted feature vectors proposed by this method increase the identification information and decrease the computation and storing burden significantly when compared to the adaptive spectrogram. The physical meaning is also more definite. This method is used for identifying six kinds of aircraft scaling models. The experiment results show that the new feature extraction method is practical.

Ambiguity Function for Bistatic SAR and its Application in SS-BSAR Performance Analysis

M. Cherniakov[1], T. Zeng[2], E. Plakidis[1]
[1]University of Birmingham, U.K.; [2]Beijing Institute of Technology, China

The ambiguity function (AF) for bistatic synthetic aperture radar (BSAR) is deduced and the performance of Space-Surface Bistatic SAR (SS-BSAR) is analyzed. SS-BSAR can operate utilizing non-cooperative transmitters such as GPS, GALILEO, etc due to its bistatic nature.

A Novel Pulse Compression Scheme Based on Minimum Mean-Square Error Reiteration

Shannon D. Blunt, Karl Gerlach
Naval Research Laboratory, USA

This paper presents an alternative approach to pulse compression that is based upon iterative Minimum Mean-Square Error (MMSE) estimation. It is similar to the well-known least squares (LS) approach but does not suffer from the adverse effects caused by scatterers closer than some nominal range. This results in a more robust estimate of the radar returns while maintaining nearly the same sidelobe level. Furthermore, the proposed pulse compression scheme is highly parallelizable in range and therefore can be computed efficiently.

Poster Session B

Impulsive Noise Rejection in HF Radar Using a Linear Prediction Technique

Michael D. Turley
DSTO, Australia

The performance of an HF Doppler radar is degraded by signal corruption due to impulsive interferers such as atmospherics and meteor train echoes. These interferers raise the Doppler spectrum background noise level, thereby reducing target to noise power ratios. In this paper, we make modifications to a known linear prediction missing data technique, and show that this technique is effective against HF radar impulsive interference.

An Inversion Technique for Obtaining Quasi-Parabolic Layer Parameters from VI Ionograms

R.J. Norman
La Trobe University, Australia

Vertical incidence ionograms are obtained from sweep HF pulsed vertical incidence radar and provide information on the state of the ionosphere directly above the transmitter/receiver location. This paper describes a vertical incidence inversion technique where the ionospheric electron density profile is determined from the recorded layer echo traces found on vertical incidence ionograms. The vertical incidence inversion method is user friendly, in that the required inputs from the ionogram are readily obtainable. The inversion method is robust, in that the constraints within the method are flexible enough to accommodate the required input data from the ionograms and is able to home-in to the best possible solution.

Backscatter Ionogram Inversion

R.J. Norman
La Trobe University, Australia

A Backscatter Ionogram, BSI, is a plot showing the group path or time delay against operating frequency when using ground-based swept frequency radar. In the case of ground backscatter the received signals are reflected from distant locations on the Earth's surface. The ionosphere is the medium through which both the transmitted and received signals traverse. A Backscatter ionogram contains useful information regarding the state of the ionosphere at the time and over the range of the returned signal, which could be a few thousand kilometers from the transmitter/receiver location. Backscatter ionograms differ from the more conventional vertical incidence ionograms, where the received signals are reflected from a region of the ionosphere vertically above the sounder location. Methods of inverting backscatter ionograms to obtain ionospheric profiles offer an important means of remote sensing the distant ionosphere and regions in which land and sea scatter occur. Thus, backscatter ionograms can play an important role in the frequency management systems of over-the-horizon radar (e.g., [1]).

Two-Dimensional Analytic HF Ray Tracing in the Ionosphere

R.J. Norman
La Trobe University, Australia

This paper describes a method to accurately ray trace through horizontal gradients in the ionosphere that vary with altitude in the direction of the propagated ray path. In the past tilting methods have been employed to approximate the effects of horizontal gradients where these methods involve tilting the ionosphere relative to the earth's surface. These methods can be quite cumbersome whereas this method is relatively simple and in general will produce more accurate results and is considerably faster, in elapsed computational time, than ionospheric tilting methods. This method can also be added to SMART (Norman and Cannon 1997).

Real-Time Complex Signal Processing in a SAW Broad-Band Convolver

Adam M. Kawalec
Military University of Technology, Poland

The result of theoretical and experimental studies of a broad-band convolver in piezoelectric-semiconductor configuration ($Bi_{12}GeO_{20}$-Si) are presented. Dispersive excitation transducers were used to improve the matching of the convolver inputs to the external sources of the signals in the passband. A new measurement system for the amplitude characteristics of the convolver output has been proposed. Experimental analysis of the convolver for compression a signal with linear frequency modulation have been reported.

Integrated Maritime Surveillance: Protecting National Sovereignty

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Protection of National Sovereignty requires the ongoing, systematic collection of data from a range of sensors and other sources and the assembly and maintenance of a picture of the position, classification, identification and movement of cooperative and non-cooperative ships, aircraft and hazards in the Exclusive Economic Zone.

Integrated Maritime Surveillance maintains a continuous and affordable real-time picture of ship and aircraft tracks to beyond the 200 nautical mile limit of the EEZ using land based HF and Microwave radar systems. The system associates ancillary data from other sources to provide a knowledge-based "Recognized Maritime Picture" and the most effective surveillance of all significant targets within the EEZ. Overlays of GIS referenced data such as sea-state, currents, ice, water temperature, phytoplankton, etc., can be included to support the deployment of air and surface assets and maximize their effectiveness in dealing with fisheries protection, drug interdiction, illegal immigration, terrorist threats, search and rescue and other aspects of National Sovereignty.

Deinterleaving of Radar Pulses in a Dense Emitter Environment

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An ESM system consists of a passive radar receiver that receives

pulses from the surrounding radars and measures their monopulse parameters, and a deinterleaver that sorts the digital words representing the parameters of theses pulses and groups them in individual radar cells. The parameters of the deinterleaved radar cells are then compared with those of known radars to identify the intercepted radars. The high pulse rate and the low processing speed of both the ESM receiver and the deinterleaver may lead to a large number of missing pulses from the radar cells which consequently results in errors in the deinterleaving process. In this paper, we derive an expression for the factor of successful processing of the ESM system (F_s) as a function of the pulse rate and the parameters of the ESM system. For the given ESM parameters, and the minimum acceptable value of F_s we can determine the highest pulse rate that allows the ESM system to work properly. Inversely, if the pulse rate is known or measured, the performance of the ESM system can be predicted for the given parameters of the ESM system. All derived expressions are supported by extensive computer simulations.

Two Digital Receivers Based on Time-Frequency Analysis for Signal Interception

Gustavo López-Risueño, Jesús Grajal, Omar A. Yeste-Ojeda, Álvaro Sanz-Osorio, José A. Moreno
Universidad Politécnica de Madrid, Spain

Two digital receivers for detection and modulation classification of non-stationary signals, including signals with low probability of interception, are analyzed. They use two different joint time-frequency signal approaches to improve the performance of classical receivers. They can be used to identify and monitor signals for both civilian and military applications.

Poster Session C

Subsurface Sounding of Mars: Multi-Pulse Detection of Water-Related Interfaces

Massimo Sciotti, Pierfrancesco Lombardo, Debora Pastina, Alberto Macrì Pellizzeri
University of Rome "La Sapienza", Italy

We introduce optimized multi-pulse algorithms for the analysis of Mars surface and subsurface radar data, referring in particular to the data which should be acquired by the MARSIS instrument in the near future. The proposed processing schemes aim at detecting the presence and estimating the depth of water-related subsurface interfaces. A statistical model is introduced to cope with the expected scenario, and Maximum Likelihood based detection and estimation techniques are derived. The performance of the new techniques is deeply investigated proving the effectiveness of the proposed approaches.

Conical-Scan Antennas for W-Band Radar Systems

Graham M. Brooker
University of Sydney, Australia

Conical-scan implementations for three antenna types are discussed in terms of the beam nutation method, reference signal generation and angle error demodulation. Various applications for these antennas including their use in teaching are discussed.

Calibration Procedures of a Stepped Frequency Continuous Wave Radar for Landmines Detection

Ioan Nicolaescu[1], Piet van Genderen[2], Keith Palmer[3]
[1]Military Technical Academy, Romania; [2]Delft University of Technology, The Netherlands;
[3]University of Stellenbosch, South Africa

This paper deals with the calibration procedures for stepped frequency continuous wave radar, which operates from 400 MHz to 4845 MHz and transmits 128 frequencies in steps of 35 MHz. Because it is a continuous wave radar the information about distance is included in the phase variation of the received signal, so the behavior of the antenna is a very important issue. Two Archimedean spiral antennas have been employed for this radar. As it is known, spiral antennas show a dispersive behavior, thus, in time domain, a "chirp" pulse will be displayed at the output. The calibration of the system has to correct the phase dispersion produced within the system.

In order to identify the phase dispersion given by the antenna a reference metallic plate is placed at a certain distance. The received signal is passed in time domain by applying an ifft, the multiple reflection are removed and the phase variation due to the time propagation is subtracted. After phase correction the time domain response as well as the side lobes level are decreased.

Design and Implementation of an Experimental GSM Based Passive Radar

Hongbo Sun, Danny K.P. Tan, Yilong Lu
Nanyang Technological University, Singapore

Passive radar is a special kind of radar system that utilizes electromagnetic radiation already present in the environment to detect targets as well as estimate target parameters. This paper discusses the use of GSM base station as a non-cooperative illuminator for bistatic passive radar operation. The design and implementation of this novel passive radar system is introduced. Some initial experimental results show the viability of using GSM signal to detect ground moving targets.

Passive Detection of Aircraft Utilising Shadowing Techniques

James Palmer, John Homer
University of Queensland, Australia

This paper introduces the possibility of passively detecting aircraft based on the radiation shadows cast by targets illuminated by non-dedicated satellite borne transmitters (e.g. GPS, LEOs communication satellites).

Various aspects of the system are considered, from frequency selection based on diffraction, to power considerations for the signals involved. The effect of the sea surface is also taken into consideration, and preliminary conclusions about modelling techniques are given.

An Analysis of Some Problems of Bistatic and Multistatic Radars

Kesheng Liu
East China Research Institute of Electronic Engineering, China

Bistatic and multistatic radars are subject to some special problems, such as, ultralow sidelobe digital beam forming, nanosecond-order-of-magnitude time and phase synchronization, multistation plot fusion and displaying calibration. This paper gives an analysis of these problems, and presents some test results.

Analytical Solution for Target Location Using Bistatic Multi-Transmitter and Multi-Receiver Techniques

B. Mojarrabi, John Homer, K. Kubik, I.D. Longstaff, James Palmer
University of Queensland, Australia

The three-dimensional bistatic radar solution determines the coordinates of a target from bistatic radar measurements, where the transmitter and receiver are at different positions. This involves the solution of non-linear equations. The conventional approach is linearising these equations. In this paper, we propose a direct solution of the non-linear equations. This allows the evaluation of the multiple solutions, study of singularities and the design of geometric configurations which lead to unique solutions. The solution is demonstrated for satellite based transmitters which are used as sources of opportunity.

Design of Ultralow Sidelobe Antenna Arrays with Inclined Slots in the Narrow Wall of Rectangular Waveguide

Yu-mei Zhang, Zu-ji Zhang, Xiao-peng Lu
East China Research Institute of Electronic Engineering, China

The paper presents an integrated design of slotted waveguide antenna arrays with inclined slots cut in the narrow wall of rectangular waveguide and with radome (hereinafter called conformal radome) tightly stuck on the radiation slots. By use of this design method, an S-band planar array antenna has been developed. The far-field test of the antenna beam pattern shows that the antenna achieves a horizontal sidelobe level of better than -40dB within 12% of its entire frequency band, and an ultralow sidelobe level of -45dB at its typical frequency points, indicating that the design method is very effective.

5A - SAR Processing

Metrics for SAR-GMTI Based on Eigen-Decomposition of the Sample Covariance Matrix

Ishuwa Sikaneta[1], *Christoph Gierull*[1], *Jean-Yves Chouinard*[2]
[1]*Defence R&D Canada, Canada;* [2]*University of Ottawa, Canada*

This paper investigates different metrics for indication of ground moving targets in multi-channel SAR data (SARGMTI). These metrics have in common that they are all based on the eigen-decomposition of the sample covariance matrix. Their statistical properties are analytically compared and their detection capabilities demonstrated on measured two-channel airborne data.

The Analysts' Detection Support System for Deploying a Network of Target Detection and Recognition Algorithms in SAR Exploitation

Nicholas J. Redding[1], *David I. Kettler*[1], *Guy Blucher*[1], *Peter G. Perry*[2]
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A novel software system that assists analysts to find small targets in SAR imagery is described. The system consists of a set of image processing algorithms and a framework to undertake synchronisation, control and data flow between the algorithms. The system is designed to operate in near real-time, allowing processing on very large images to occur whilst sensor data collection proceeds. It allows algorithms to be connected in arbitrary ways and has functionality to facilitate system performance measurement. This paper discusses the design of the framework.

Prescreening Algorithm Assessment Within the Analysts' Detection Support System

Guy Blucher[1], *David Blacknell*[2], *Nicholas J. Redding*[1], *Danny Vagg*[1]
[1]*DSTO, Australia;* [2]*QinetiQ Ltd., U.K.*

This Analysts' Detection Support System (ADSS) contains a suite of target detection algorithms for Wide Area Aerial Surveillance using synthetic aperture radar (SAR) imagery. The ADSS provides a framework to combine the operation of these algorithms in user-specified configurations. This paper compares and contrasts the performance of the various pre-screening algorithms singly and in combination within the ADSS framework on a broad range of SAR imagery. The algorithms include adaptive threshold, K-distributed CFAR, average grey absolute difference magnitude map, and segmenting K-distributed CFAR. The performance of these algorithms is compared on polarimetric imagery to assess the contribution of polarimetry to target detection.

The Use of Random Frequency-Hopped Waveforms for the Recovery of Motion-Degraded SAR Imagery

K. Morrison
University of Cranfield, U.K.

There is a conflict between the requirement of a very low RCS target support system, and the need for high stability and accurate target setting during the SAR imaging of signature-critical targets. To meet the ideal of measuring targets in free space, multiple string suspension systems from overhead gantries have been devised. Despite measures to the contrary, air turbulence and mechanical vibration can produce complex perturbations of the target during the SAR imaging process. Model code was written to provide representative motion models. Simulations were made over a wide range of motion patterns to assess the effects on the imagery. The pattern of the image degradation has a complex dependence on the frequency sampling rate and characteristic period of the oscillation. A comparison is made between monotonically stepped-frequency waveforms and random frequency-hopped waveforms, and the benefits to image recovery of the latter discussed.

Inverting the Spherical Radon Transform for 3D SAR Image Formation

Nicholas J. Redding, Timothy M. Payne
DSTO, Australia

In this paper we show how image formation or reconstruction in synthetic aperture radar (SAR) in three dimensions can be viewed as the inversion of the spherical Radon transform. The advantage of viewing image formation in this way is that it could be used in situations where more standard methods could fail such as high squint and ultra-wideband SAR. We build upon previous work by others and ourselves on the circular Radon transform in two dimensions to develop inversion formulae for the spherical Radon transform that employs Hankel and Fourier transforms along with coordinate mappings. We extend the theory to include finite bandwidth signals and finite synthetic apertures.

5B - Tracking & Fusion

Low Elevation Sea-Surface Target Tracking Using IPDA Type Filters

Xuezhi Wang, Darko Mušicki
University of Melbourne, Australia

The Integrated Probabilistic Data Association (IPDA) type filters provide estimates of the underlying target probability of existence /perceivability/visibility apart from track state maintenance. These quantities are conveniently used as a track quality measure and can be used for track confirmation and termination. The sea-surface induced multipath fading reduces the detection probability of the target at certain ranges which can lead to track loss. In this paper we use IPDA type filters to tracking a target in such scenario. The primary results presented in this paper is encouraging for a further study in the future.

Augmented State IMM-PDA for OOSM Solution to Maneuvering Target Tracking in Clutter

Xuezhi Wang, Subhash Challa
University of Melbourne, Australia

Out-of-Sequence Measurement (OOSM) problem is one of the most important issues for target tracking in a multi-sensor fusion network. Optimal solution is to augment the state vector to include the past states which correspond to those delayed measurements in the filtering process. In this paper, the maneuvering target tracking in clutter with OOSM problem is considered. An AS-IMM-PDA algorithm that uses OOSM to improve tracking performance is presented. The benefit of the AS-IMM-PDA is demonstrated via a maneuvering target tracking example.

Random Finite Sets and Sequential Monte Carlo Methods in Multi-Target Tracking

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Random finite set provides a rigorous foundation for optimal Bayes multi-target filtering. The major hurdle faced in Bayes multi-target filtering is the inherent computational intractability. Even the Probability Hypothesis Density (PHD) filter, which propagates only the first moment (or PHD) instead of the full multi-target posterior, still involves multiple integrals with no closed forms. In this paper, we highlight the relationship between Radon-Nikodym derivative and set derivative of random finite sets that enables a Sequential Monte Carlo (SMC) implementation of the optimal multi-target filter. In addition, a generalised SMC method to implement the PHD filter is also presented. The SMC PHD filter has an attractive feature-its computational complexity is independent of the (time-varying) number of targets.

Optimal Adaptive Waveform Selection for Target Detection

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Modern phased array radars are able to adaptively modify their performance to the environment. To make full use of this capability, scheduling algorithms need to be designed. This paper poses the problem of adaptive waveform scheduling for detecting new targets in the context of finite horizon stochastic dynamic programming. The result is a scheduling algorithm that minimises the time taken to detect new targets, detecting these targets in accordance with importance, while minimising the use of radar resources.

5C - HF Radar I

Limits to the Extraction of Information from Multi-Hop Skywave Radar Signals

Stuart J. Anderson
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The performance of HF skywave radar systems is customarily referred to in terms of single-hop propagation, a mechanism which provides illumination of the earth's surface out to ranges of around 4000 kilometres. In practice, the process of ionospheric reflection often supports multiple hops, though the signals are inevitably subjected to much greater distortion and contamination. In this paper we address the issue of adequacy of conventional models of multi-hop propagation. We formulate a detailed model which accounts for intermediate surface scattering, and obtain a representation in terms of integrals in $\vec{x} - \vec{k}$ space. We proceed to evaluate the resulting expressions for several cases of interest. The results demonstrate that it is vital to understand the complexities of multi-hop propagation if this method of observation is to be exploited for remote sensing of the ocean at extreme ranges.

Use of STAP Techniques to Enhance the Detection of Slow Targets in Shipborne HFSWR

Marc Lesturgie
ONERA, France

This paper addresses the detection of low velocity target from a shipborne HFSWR (High Frequency Surface Waves Radar). In a shipborne configuration, as a consequence of the ship motion first order of Bragg lines is spread in the useful Doppler interval where detections of ship target are expected to appear. Space time techniques like STAP, usually studied for airborne radar purposes are candidate to reduce the effect of ship motion. Influence of pitch and roll components is also discussed. Simulations of STAP techniques are given, based on a conventional architecture of processing. Estimation of the clutter covariance matrix is studied with respect of the characteristics of the radar waveform. Interleaving between the classical HFSWR waveform and a wide band learning waveform is proposed to enable the covariance estimation.

Development of HF Ocean Radar in Japan

Yukiharu Hisaki
University of the Ryukyus, Japan

The HF ocean radar was developed in Japan from 1987 by Okinawa Radio Observatory, Communications Research Laboratory. We measured ocean surface currents and developed the method to estimate wave spectra. The observations of ocean surface currents were conducted in various areas. The observation in the east of Okinawa, where mesoscale eddies are dominant, is presented. We can observe the convergent zone associated with the front of a mesoscale eddy. Furthermore, the short-wave directions and spread parameters were estimated from first-order scattering. We also developed the method to estimate ocean wave spectra from Doppler spectra. We extended the theory of HF radio wave scattering from the sea surface. It is possible to explain the underestimation of wave-heights, which was previously pointed out.

Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS): Subsurface Performances Evaluation

G. Picardi[1], *D. Biccari*[1], *A. Bazzoni*[1], *F. Fois*[1], *M. Iorio*[1], *R. Seu*[1], *P. Melacci*[2], *C. Federico*[2], *A. Frigeri*[2], *G. Minelli*[2], *L. Marinangeli*[3], *R. Orosei*[4], *D. Calabrese*[5], *E. Zampolini*[5], *W.T.K. Johnson*[6], *R.L. Jordan*[6], *J. Plaut*[6], *A. Safaenili*[6]
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According to the Mars Express mission, the MARSIS primary *scientific objectives* are to *map the distribution of water, both liquid and solid, in the upper portions of the crust of Mars.* Three *secondary objectives* are also defined *subsurface geologic probing*, *surface characterization*, and *ionosphere sounding.*

In order to obtain the primary objectives the Radar Sounder design was based on the *Ice/water interface* and *Dry/ice interface* scenario: defining the material composition of the first layers and porosity and the pore filling materials. Concerning the surface, we have characterized the geometric structure in terms of a *large-scale* morphology, on which a *small-scale* geometric structure, due to rocks, is superimposed, taking into account also that recently the structure of the planets surface was described by means of fractals and in particular the new MARS surface models obtained by processing of the MOLA data.

According to these models, this paper provides a description of the operational planning approach and expected performances of MARSIS.

Progress in HFSWR Research at Harbin Institute of Technology

Yongtan Liu, Rongqing Xu, Ning Zhang
Harbin Institute of Technology, China

The Experimental HF Surface Over-The-Horizon Radar set up in the late of 80's has been updated by installation of multi-channel receivers with digitization at the second IF stage, new designed transmitting and receiving antennas, wideband solid-state power amplifiers, frequency synthesizer with low phase noise and flexible signal generator, a new radar controller added to allow the automatic and manual control of the radar, a new designed signal and data processor built mainly with 16bits A/D converters and several multiprocessor boards with Sharc chip processors added in, and a electromagnetic spectrum monitor equipped in the updated radar system to be able to automatically survey HF spectrum occupancy for providing so called clear frequency channel suitable for radar operation. The purpose of the setting up of the updated radar system is to demonstrate some of new functions of the radar system, and to prove some new techniques to be possibly used in a near future. In the paper, some latest developments of countering measures with radio frequency interferences are presented, too.

6A - SAR Applications and Radar System Design

Bistatic Synthetic Aperture Radar with Application to Moving Target Detection

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Bistatic radar involves the use of a physically separated transmitter and receiver. This paper describes a bistatic radar system which uses the combination of a spaceborne synthetic aperture radar transmitter on board the European Space Agency's Envisat satellite, and a low-cost, stationary, ground-based receiver. The advantages of this variant of the bistatic configuration involve the passive and therefore undetectable nature of the receiver, in addition to standard bistatic considerations such as forward scatter.

Experimental results obtained using the receiver, and an analysis into the utility of the system for moving target detection in the presence of clutter, based on a simulation in Matlab of the electronic Displaced Phase Centre Antenna technique are both presented. It is found that the DPCA method considered has a possible signal-to-clutter-and-noise ratio after cancellation and processing of approximately 10dB, although this is with the assumption of adequate received pulses and so integration gain, to offset the signal-to-noise ratio degradation caused by the canceller.

A discussion of future experimental work, including the possible use of two such receivers for an investigation into interferometry concludes.

Demonstration of Reduced False Alarm Rates Using Simulated L-Band Polarimetric SAR Imagery of Concealed Targets

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Coherent scattering calculations have been performed to produce L-Band SAR images of targets below a forest canopy. The calculations, which are fully polarimetric, are described. High clutter levels permit detection of all concealed targets only at the cost of a very high false alarm rate. The simulated imagery is analysed using the entropy-alpha polarimetric decomposition technique. Using alpha and entropy in addition to a co-polar intensity channel, and combining the results of separate CFAR algorithms, the number of false alarms is reduced dramatically. The consequences for application of polarimetric SAR to concealed target detection and identification are considered.

Moving Target Indicator (MTI) Applications for Unmanned Aerial Vehicles (UAVS)

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This paper provides an overview of Moving Target Indicator (MTI) applications and employment on DoD Unmanned Aerial Vehicles (UAVs). The ability to receive MTI data on ground, maritime/littoral or aerial moving systems significantly enhances the ability of a UAV to locate, track, classify, and identify enemy targets or platforms of interest. An overview of the United States Air Force (USAF) UAV Battlelab's (UAVB) initiatives utilizing MTI applications is discussed. Results from these demonstrations and tests are presented including a synopsis of warfighter comments and requirements. An overview of the capability to utilize collaborative or situational awareness (SA) tools/systems in the management and dissemination of this information/data is also presented. Additional discussions surrounding other UAV systems and their mission applicability are presented and include ground, littoral and air MTI applications.

Performance Evaluation for Modern Radars

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Modern radar systems are procured with tight specifications on a large number of different parameters. It is in the interests both of the customer and of the supplier that the procedures used evaluate radar performance are mathematically rigorous, precise and as cost-effective as possible. This paper describes some methods of evaluating the performance of different modes of modern radar systems and discusses the accuracy of which they are capable. The important place of modeling within these methods is emphasized.

L-Band Wide Area Surveillance Radar Design Alternatives

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Wide area surveillance systems are becoming more important for border and homeland security, earth resources monitoring and mitigation of natural disasters such as floods and seismic activity. As the frequency spectrum is being utilized for communications and business networking, the available bandwidth for these important efforts is more difficult. Historically, airborne surveillance radars have been fielded at either UHF or S-Band for airborne vehicle detection, and at X-Band for surface vehicle imaging and moving target detection. This paper will examine the impact of new technologies on the design of L-Band surveillance radars that employ solid state active arrays, multiple phase center apertures and adaptive processing to enable fixed and moving target detection from air and space platforms. The operational advantages of the use of small apertures on business jets, medium apertures on high altitude platforms and very large apertures in space will be contrasted.

6B - Tracking & Resource Management

PDAF versus PMHT Performance on OTHR Data

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Over the Horizon Radar (OTHR) is the primary Australian wide area surveillance sensor. The radar tracking system currently used for OTHR is based on the Probabilistic Data Association Filter (PDAF). Research and development(R&D)has continued to improve tracking performance. R&D has been extended to include the Probabilistic Multiple Hypothesis Tracker (PMHT). This paper deals with the comparison of the PDAF and the PMHT for tracking targets in experimentally recorded OTHR data. The data has been selected over a range of conditions and every effort has been made to ensure that both trackers have been optimised. The comparison uses a Tracker Assessment Tool (TAT) which measures performance against a total of 15 metrics. This report presents a quantitative performance comparison of the current tracking algorithm and these new tracker developments.

Least Squares Algorithms for Constant-Acceleration Target Tracking

Kutluyıl Doğançay
University of South Australia, Australia

A unified treatment of several least squares (LS) algorithms is presented for bearings-only tracking of a target moving at constant acceleration. The close link between the maximum likelihood (ML) estimator and other nonlinear and "linearized" LS algorithms is explored under the assumption of Gaussian bearing noise. In this context, a new asymptotically unbiased closed-form instrumental variables (IV) algorithm is derived. Reduced-bias total least squares (TLS) and constrained TLS (CTLS) algorithms are developed. The equivalence of the ML algorithm to the structured TLS (STLS) algorithm is established. Simulation examples are provided to demonstrate the improved performance of the IV and TLS estimators *vis-à-vis* the pseudolinear estimator.

On the Use of Entropy for Optimal Radar Resource Management and Control

Paul E. Berry, David A.B. Fogg
DSTO, Australia

The use of information entropy as a quantitative measure of uncertainty for radar resource management and control objectives is explored and applied to issues of current interest. It is seen to be rigorous and objective, and therefore potentially superior to heuristic, rule-based approaches for problems which can be formulated in probabilistic terms. It is particularly appropriate for sensor systems in general which have as their objective the acquisition of information, but which are dominated by uncertainty and subject to time and resource constraints. Examples of the application of this control and management methodology are given to radar problems on widely differing time-scales: the scheduling of track updates in a beam-agile radar (ms), and the tasking of a constellation of SAR surveillance satellites for maritime search and tracking (hours).

Multifunction Radar Resource Management Using Tracking Optimisation

Shirley L. Coetzee, Karl Woodbridge, Christopher J. Baker
University College London, U.K.

In this paper we report on the relationship between track update intervals and track accuracy in a Multifunction phased array radar system. Strategies for selecting the update rate are highlighted and the degradation of performance as update rate reduces is demonstrated. It is shown that using suitable techniques considerable radar resources can be liberated for non-tracking tasks.

6C - HF Radar II

Ship Echo Discrimination in HF Radar Sea-Clutter

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HF radar can provide Over the Horizon detection of ships on very large oceanic areas, making use of the ionospheric refraction of radio waves. The Doppler spectrum of the sea clutter is composed of the first-order Bragg lines with a second-order continuum, as described in [1]. Normally, the Doppler shift produces by ships is small, of the same order of magnitude of the Doppler shift of the sea clutter. Consequently, it is not always easy to discriminate a ship line from a sea clutter line only on a velocity basis, though dual frequency operation can enhance ship detectability [2]. Different sources of ionospheric contamination often increase the difficulty by introducing smearing effects of the Doppler spectrum. Sometimes, these deleterious effects can be corrected by using adapted signal processing methods (see e.g. [3]-[5]).

Using HF radar with large antenna arrays, it should be possible to find arrangement in radar data manipulation to obtain two signals coming back from the sea with low coherence, while the signal from a discrete target would stay relatively coherent. If verified, this property would allow the discrimination of discrete targets against sea clutter. In this paper the coherence of sea clutter is considered in the context of a radar interferometer. It is shown that the coherence function can be useful to discriminate between a ship line and sea clutter spectral peaks. The dependence of the coherence value with the signal to clutter ratio is also studied.

Probing of the Artificial Hole in the Ionosphere with the HF Skywave Radar

Pei-nan Jiao, Tie-han Ma, Guo-liang Xu, Zong-qiang Li, Xin-sheng Zhang, Fei Xu
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This paper explains the experiment that HF skywave radar probed the artificial ionospheric hole, which is caused by the flames of the rocket vertically launched and penetrated the ionosphere. After the rocket had passed through the ionosphere, the minimum time-delay P_{min}-f on the backscatter ionograms obviously appeared with wave and focusing stripes resulting from the irregular structure etc. The results indicated that there was a low electron density zone, the artificially created hole in the ionosphere along the propagation path. Under the asymmetry quasi-cosine ionospheric hole model, the experimental P_{min}-f was simulated with the technique of ray tracing. It was deduced that the range size of the hole in ionosphere along the radar beams was some 573 km and the critical frequency of the center was 2.6 MHz lower than the background critical frequency (12MHz). The ionospheric environment 350km away from the launching site was disturbed and the propagation velocity of the ionospheric disturbance was about 50m/s.

HF Surface Wave Radar Operation in Adverse Conditions

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For the past 12 years the Canadian Department of National Defence and Raytheon Canada Limited have collaborated on a cost-shared programme to develop an Integrated Maritime Surveillance (IMS) system based on HF Surface Wave Radar (HFSWR).

The primary objective behind the programme was to demonstrate the capability of HFSWR to continuously detect and track surface targets (ships and icebergs) as well as airborne targets, at all altitudes, to ranges in excess of 200 nautical miles, reliably and consistently in real time and in all weathers. A secondary objective was to demonstrate the concept of IMS, involving the fusing of data from HFSWR radars and other sensors.

This paper reviews techniques and methods used in the processing of HFSWR data to ensure that performance is maintained, even under adverse operating conditions.

Development of Over-the-Horizon Radar in the United States

Joseph F. Thomason
U.S. Naval Research Laboratory, USA

This paper provides a chronology of the development of high-frequency, over-the-horizon radar in the United States.

Stochastic Modeling and Simulation Studies for the Surface Wave High Frequency Radars: Problems and Challenges

Levent Sevgi
Dogus University, Turkey

Modeling and simulation strategies for the Surface Wave High Frequency Radars (SWHFR) are discussed in this tutorial paper. Their potential application areas are summarized, together with problems related to ground wave propagation, radar cross section (RCS) prediction, clutter elimination, noise and interference cancellation, etc. Challenges in SWHFR system design, antenna requirements, signal processing techniques as well as detection and tracking approaches are reviewed.

7A - Clutter

Clutter Simulation for Airborne Pulse-Doppler Radar

Anthony P. Szabo
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A method is described for sampling the surface clutter seen in the receiver of an airborne pulse Doppler radar. The clutter return is modelled as a two dimensional Gaussian random field with uncorrelated increments and is characterised by the mean clutter power of the field. The clutter signal in the radar receiver is also modelled as a random process and is obtained by sampling a realisation of the clutter return and convolving with the impulse response of the radar. The impulse response of the radar is described in terms of the ambiguity function of the receiver. Examples of realisations of the clutter signal are used to illustrate the key ideas.

Adaptive Modelling of Sea Clutter and Detection of Small Targets in Heavy Clutter

Sofia Suvorova[1], *Bill Moran*[2], *Marian Viola*[1]
[1]*DSTO, Australia;* [2]*University of Melbourne, Australia*

This paper describes and compares three methods for detection of low RCS radar targets in heavy sea clutter using a high PRF radar. Two methods are based on auto-regressive processes, one on Karhunen-Loève decomposition. Experiments have been performed on DSTO sea clutter dataset using these methods and the results are presented in this paper.

Clutter Simulation in Maritime Environments

Peter E. Lawrence, Anthony P. Szabo
DSTO, Australia

Knowledge of clutter characteristics are an important factor in determining radar system performance, especially for target detection. Clutter may be modelled as a random process, with the clutter characteristics embodied in the statistics of the process. Most modern pulsed-Doppler radars utilize range-Doppler maps in their detection schemes, and so it is crucial to understand the statistical properties of clutter in these maps in order to develop effective target detection algorithms.

In this paper, we discuss the simulation of the sea clutter seen on the range-Doppler map of an X-band pulse-Doppler radar operating in a maritime environment. We shall implement the compound K-distribution model for maritime clutter returns and incorporate temporal and spatial correlations in clutter map realizations.

L-Band VV Clutter Analysis for Natural Land

Yunhan Dong
DSTO, Australia

Land clutter is statistical by nature, and its values vary in many dimensions. This paper analyzes L-band VV polarized land clutter characteristics acquired by the NASA JPL AirSAR system. In particular, this paper mainly concentrates on the distribution of clutter values with respect to grazing angle for typical vegetation communities in the Northern Territory region in Australia.

Clutter Characterization and Propagation Measurements During Adverse Weather Conditions

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The evaluation of sensor performance under adverse weather conditions is critical for the determination of usability during all weather conditions. The Precisions Armaments Laboratory (PAL) located at the US Army Picatinny Arsenal, New Jersey, USA development will enable automated measurement of propagation effects and clutter characterization under adverse conditions.

7B - Waveforms & Architectures

Novel PRF Schedules for Medium PRF Radar

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Previous work has demonstrated that Evolutionary Algorithms (EAs) are an effective tool for the selection of optimal pulse repetition frequency (PRF) sets to minimise range-Doppler blindness of a medium PRF radar. This paper re-considers the concepts of decodability in medium PRF radar, and how new and novel schedules can be generated using an EA. Traditionally target data is required in a minimum of 3 PRFs (e.g. a 3 of 8 scheme). In this paper we describe the generation of schedules requiring data in only 2 PRFs. Results are presented for a comparison between schemes requiring target data in two and three PRFs. The results indicate that blindness is minimised in schedules with greater numbers of PRFs and requiring target data in fewer PRFs. The concept of dynamic selection of PRI schedules that are fully decodable and have no blind velocities is outlined and is concluded to be feasible.

Compression Ratio Expansion for Complementary Code Set Compressing a Signal to a Width of Several Sub-Pulses

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We present the compression ratio expansion methods for the complementary code set compressing a signal to a width of several sub-pulses. We also proposes the complementary code sets that consist of more that three individual codes and compress a signal to a width of several sub-pulses.

New Binary Complementary Codes Compressing a Pulse to a Width of Several Sub-Pulses

Hiroshi Takase, Masanori Shinriki
Nippon Institute of Technology, Japan

In this paper, we propose new binary complementary codes, which compress a pulse to a width of several sub-pulses, and survey all combinations of the binary complementary codes with several code lengths. We are able to find a large number of binary complementary codes and complete complementary codes. Furthermore, we show that longer such complementary codes can be acquired using the expansion method shown by Golay. In addition, we show that the auto-correlation sidelobe of an individual code for the proposed binary complementary code pair is smaller than that of the conventional.

Mutually Dispersive Pulse Coding to Enhance Non-Linear Ambiguity Suppression

John Kurian[1], *Michael A. Temple*[1], *Matthew J. Papaphotis*[1], *William M. Brown*[2]
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Results from design, synthesis, and analysis of optimal mutually dispersive symbols are presented as an improvement over existing symbol sets employed in Non-linear Ambiguity Suppression (NLAS). A recently proposed theorem formulates the existence of symbol families having optimal mutual dispersion, a highly desirable property for NLAS applications. Results from theorem analysis are presented and compared to other suitable NLAS symbol sets, showing significant improvement in mutual dispersion characteristics. NLAS ambiguity suppression effectiveness is demonstrated using a set of optimal mutually dispersive symbols.

Digital Monopulse Receivers for Phase Modulated Signals

Mateo Burgos-García, Gema Ferreiro-Collar, Alberto Asensio López, Javier Gismero Menoyo, Jose Luis Jiménez
Universidad Politécnica de Madrid, Spain

The great success achieved by the monopulse technique in the last years and the fact that the new technology is beginning to allow the construction of digital radar receivers, make us thinking about the digital implementation of the monopulse technique. In this paper different architectures based on amplitude and phase measurement are analyzed. Finally, the results of each architecture are given in some figures.

7C - HF Radar III

History, Present Status, and Future Directions of HF Surface-Wave Radars in the U.S.

Don Barrick
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HF surface-wave radars (HFSWRs) offer two distinct advantages when used over the sea: with vertical polarization, they see beyond the horizon, and the interaction of their signals with ocean waves is simple and well understood. As a result, many HFSWR research test programs were conducted in the U.S., beginning 35 years ago. This author was fortunate to have been immersed in these programs from the beginning. Early projects by the Defense Department focused on military target surveillance: ships, aircraft, and missiles. In the mid-70s, their potential was explored for environmental measurements: surface currents and sea state.

Why after 35 years of testing and evaluation are none found in operational service today, except those made by CODAR for environmental monitoring? I discuss this question in the present paper. My answer is: they did not offer cost-effective solutions for military applications based on conventional technology. I summarize first the status of the technology, both conventional and CODAR's unconventional approaches. The big cost-driver has been the huge phased-array antenna systems that constitute "the conventional approach". These also raise an outcry of objection to installation at overused, valuable, or pristine coastal locations because of their size and obtrusiveness. Perhaps some of the unconventional approaches taken by CODAR and summarized below will overcome these obstacles to military deployment.

Plume Effect on Radar Cross Section of Missiles at HF Band

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The Radar Cross Section of missiles at HF band is affected by the presence of the missile plume. In fact, although the plume is transparent at the microwave frequencies, it reflects almost the totality of the energy at the HF band.

In this paper we evaluate the effect of the missile plume on its Radar Cross Section (RCS) at HF band. In order to achieve the goal we: 1) verify that the missile plume can be physically represented by a plasma through a chemical analysis of the combustion; 2) define the time-varying non-linear differential equation that rules the electron density equilibrium in the plume; 3) solve the time -varying non-linear differential equation in order to evaluate the length of the plume that contributes to the RCS calculation; 4) evaluate the RCS of the missile+plume by means of the Method of Moments (MoM). As a numerical case, the application of both a surface and sky wave Over The Horizon (OTH) radar has been considered. Specifically, the RCS (as a function of the incidence angle) of the missile during the boost phase trajectory has been evaluated.

Exploitation of Elevation Angle Control for a 2-D HF Skywave Radar

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ONERA, France

ONERA, sponsored by the French Ministry of defence (Aeronautics program department SPAé), has conducted the realization and experimentations of the skywave HF radar, called NOSTRADAMUS.

This is a new concept of Over The Horizon radar constituted of a monostatic surface array on a three arms star. This choice of structure allows an azimuthal coverage of 360 degrees and elevation beam forming capability.

This paper presents the NOSTRADAMUS system and describes the real time frequency management system of the radar by using the elevation focalization. We present new soundings techniques which have been developed and implemented in the management of the system such as the radar is completely autonomous.

Ship Detection with Short Coherent Integration Time in Over-the-Horizon Radar

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[1]*Nanjing University of Science & Technology, China;*
[2]*Nanjing Research Institute of Electronics Technology, China*

To realize the ship detection with short coherent integration time (CIT) is an operational requirement for skywave over-the-horizon radar (OTHR). However, short CIT and the resulting low Doppler resolution cannot separate the ship from the close powerful ocean clutter. To resolve this problem, Fourier transform based clutter cancellation is proposed as well as some super-resolution spectral estimation techniques. In this paper, we still use clutter subtraction scheme but the clutter parameter estimation is improved by analyzing the Fourier phase information. As the result, the estimation accuracy is enhanced and better cancellation performance may be achieved, which to some extent will decrease the power and spreading of clutter residue and benefit the ship visibility and identification.

Non-Stationary Interference Cancellation in HF Surface Wave Radar

Giuseppe A. Fabrizio[1], *Alex B. Gershman*[2], *Michael D. Turley*[1]
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High frequency (HF) interference in surface wave over-the-horizon (OTH) radars typically exhibits a time-varying or non-stationary spatial structure. Adaptive beamformers that update the spatial filtering weight vector *within* the coherent processing interval (CPI) are likely to suppress such interference most effectively, but the intra-CPI antenna pattern fluctuations result in temporal de-correlation of the clutter which severely degrades sub-clutter visibility after Doppler processing. A robust adaptive beamformer that effectively suppresses non-stationary interference without degrading sub-clutter visibility is proposed. The new algorithm is computationally efficient and suitable for practical implementation. Its operational performance is evaluated using experimental data recorded by the Iluka HF surface wave (HFSW) OTH radar, located near Darwin in far north Australia.

8C - HF Radar IV

HF Surface Wave Radar for Oceanography – A Review of Activities in Germany –

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The remote sensing group of the University of Hamburg is working in the field of HF radar since 1980. For the start three CODAR systems have been purchased from NOAA/ERL (developed by D. Barrick's NOAA group). Based on 16 years of experience a new system called WEllen RAdar (WERA) has been designed at the University of Hamburg in 1996. The new design aims to be as flexible as possible in order to allow easy adjustment to different requirements, i.e. working frequency, spatial resolution, and antenna configurations. The first part of this paper describes the technical solutions available to achieve resolution in range and azimuth. Modulation techniques for range resolution like Pulses and Frequency Modulation (FMCW) are compared, as well as Direction Finding and Beam Forming for azimuthal resolution. A short introduction to the algorithms is given. The second part discusses the hardware and software components which form a WERA and are now commercially available. The third part shows an example of a monitoring system bringing together HF radar remote sensed data and numerical models.

A Multiple-Sweep-Frequencies Scheme Based on Eigen-Decomposition to Compensate Ionospheric Phase Contamination

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This paper presents an improved scheme to compensate nonlinear phase path contamination when the backscattered signal propagates through the ionosphere in high-frequency skywave radar systems. The ionospheric variation often causes the spread of the ocean clutter spectrum in the frequency domain. The energy of the first-order component of ocean clutter dominates in Doppler spectrum, and thus its spreading may submerge the neighboring low-velocity target easily. The instantaneous frequency (IF) estimating algorithm based-on eigen-decomposition has been introduced to estimate the frequency fluctuation due to ionospheric phase path variation and the compensation is carried out before the coherent integration. In the proposed multiple-sweep-frequencies scheme we construct a new "sweep-frequency" dimension by using different transmitting frequencies, and because of the different variation of Doppler frequencies for the target echo and ocean clutter first-order Bragg lines with the varying transmitting frequencies, that can be considered as different "sweep-frequency angles", the full-rank autocorrelation matrix used in eigen-decomposition can be formed. Better estimation accuracy is achieved and significant spectral sharpening can be observed in the resultant spectrum. To avoid the additional systemic complexity due to the multiple frequencies sweep operation, a segmenting range transform in an assistant channel is proposed to obtain the 'sweep-frequencies' dimension data and estimate the ionospheric contamination. Experiments show that the proposed scheme is effective and its performance is discussed.

An Estimation and Verification of Vessel Radar-Cross-Sections for HF Surface Wave Radar

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The radar cross sections (RCS) of both small and large ships for High Frequency Surface Wave Radar (HFSWR) were studied by using Numerical Electromagnetics Code [4] and by using measurements from a HFSWR system at Cape Race, Newfoundland, Canada. The results of the study indicate that Teleost, a 2405-ton Canadian Coast Guard ship, and large cargo-container vessels (~36000 ton) have comparable RCS values at 3.1 and 4.1 MHz. This was verified by comparing Teleost signals with the reflections of seven cargo-container vessels identified during an operational evaluation of the HFSWR. The conclusion of the study is that Teleost and the large cargo-container vessels have an angle-averaged RCS of ~40dBm^2, while small vessels (~1000 tons) could reasonably be characterized by an angle-averaged RCS of ~30 dBm^2, in the lower end of the HF band (3-5 MHz).

Investigations with SECAR – A Bistatic HF Surface Wave Radar

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This paper describes a bistatic HF surface wave radar, designated SECAR, which was deployed near Darwin, Australia, and used to conduct a variety of scientific investigations related to radar design, siting and target detection, as well as providing a test-bed for evaluating the operational utility of HFSWR as an element of a national surveillance network. The scientific results are significant because of their implications for improved radar design and effective deployment.

Author Index

V

W

X

Y

Z