Inverse Synthetic Aperture Radar Imaging Principles Algorithms And Applications

The following topics are dealt with: ISAR imaging; ISAR motion compensation; ISAR autofocus algorithm; signal processing; ISAR target feature extraction; refocusing moving target; FMCW ISAR; bistatic ISAR; and polarimetric ISAR. Synthetic aperture radar and inverse synthetic aperture radar (SAR/ISAR) images have been largely used for monitoring small to large areas and more specifically for target recognition/identification. However, the technology has limitations due to the use of classical monostatic, single channel, single frequency and single polarization systems. To overcome these limitations, solutions have been proposed that show the benefit of using multiple frequencies, spatial channels, polarisations and perspective, in one word multi-dimensional radar imaging systems when dealing with non-cooperative targets. Multidimensional Radar Imaging introduces a new framework within which to address the problem of radar imaging and target recognition as it jointly looks at optimising the use of multiple channels to significantly outperform classical radar imaging systems. It has been used in the military within NATO for the last few years and the technology is now declassified. Topics covered include three-dimensional ISAR; STAP-ISAR; wide-band multi-look passive ISAR; radar tomography; multistatic PCL-SAR; fusion of multistatic ISAR images with large angular separation; rotor blade parameter estimation with multichannel passive radar; multistatic 3D ISAR imaging of maritime targets; challenges of semi-cooperative bi/multistatic SAR using Cosmo SkyMed as an illuminator; and lessons learnt from the NATO SET-196 RTG on multi-channel/multi-static radar imaging of non-cooperative targets. Radar-based imaging of aircraft targets is a topic that continues to attract a lot of attention, particularly since these imaging methods have been recognized to be the foundation of any successful all-weather non-cooperative target identification technique. Traditional books in this area look at the topic from a radar engineering point of view. Consequently, the basic issues associated with model error and image interpretation are usually not addressed in any substantive fashion. Moreover, applied mathematicians frequently find it difficult to read the radar engineering literature because it is jargon-laden and device specific, meaning that the skills most applicable to the problem's solution are rarely applied. Enabling an understanding of the subject and its current mathematical research issues, Radar Imaging of Airborne Targets: A Primer for Applied Mathematicians and Physicists presents the issues and techniques associated with radar imaging from a mathematical point of view rather than from an instrumentation perspective. The book concentrates on scattering issues, the inverse scattering problem, and the approximations that are usually made by practical algorithm developers. The author also explains the consequences of these approximations to the resultant radar image and its interpretation, and examines methods for reducing model-based error. Learn about the most recent theoretical and practical advances in radar signal processing using tools and techniques from compressive sensing. Providing a broad perspective that fully demonstrates the impact of these tools, the accessible and tutorial-like chapters cover topics such as clutter rejection, CFAR detection, adaptive beamforming, random arrays for radar, space-time adaptive processing, and MIMO radar. Each chapter includes coverage of theoretical principles, a detailed review of current knowledge, and discussion of key applications, and also highlights the potential benefits of using compressed sensing algorithms. A unified notation and numerous cross-references between chapters make it easy to explore different topics side by side. Written by leading experts from both academia and industry, this is the ideal text for researchers, graduate students and industry professionals working in signal processing and radar. The aim of this Printed Edition of Special Issue entitled "Recent Advancements in Radar Imaging and Sensing Technology" was to gather the latest research results in the area of modern radar technology using active and/or radar imaging sensing techniques in different applications, including both military use and a broad spectrum of civilian applications. As a result, the 19 papers that have been published highlighted a variety of topics related to modern radar imaging and microwave sensing technology. The sequence of articles included in the Printed Edition of Special Issue dealt with wide aspects of different applications of radar imaging and sensing technology in the area of topics including high-resolution radar imaging, novel Synthetic Apertura Radar (SAR) and Inverse SAR (ISAR) imaging techniques, passive radar imaging technology, modern civilian applications of using radar technology for sensing, multiply-input multiply-output (MIMO) SAR imaging, tomography imaging, among others. Recent data collections with the Sandia VHF-UHF synthetic-aperture radar have yielded surprising results; trees appear brighter in the images than expected! In an effort to understand this phenomenon, various small trees have been measured on the Sandia folded compact range with the inverse-synthetic-aperture imaging system. A compilation of these measurements is contained in this report. This report summarizes the work performed for the Office of the Chief of Naval Research (ONR) during the period of 1 September 1997 through 31 December 1997. The primary objective of this research was aimed at developing an alternative time-frequency approach which is recursive-in-time to be applied to the Inverse Synthetic Aperture Radar (ISAR) imaging problem discussed subsequently. Our short term (Phase I) goals were to: 1. Develop an ISAR stepped-frequency waveform (SFWF) radar simulator based on a point scatterer vehicular target model incorporating both translational and rotational motion; 2. Develop a parametric, recursive-in-time approach to the ISAR target imaging problem; 3. Apply the standard time-frequency short-term Fourier transform (STFT) estimator, initially to a synthesized data set; and 4. Initiate the development of the recursive algorithm. We have achieved all of these goals during the Phase I of the project and plan to complete the overall development, application and comparison of the parametric approach to other time-frequency estimators (STFT, etc.) on our synthesized vehicular data sets during the next phase of funding. It should also be noted that we developed a batch minimum variance translational motion compensation (TMC) algorithm to estimate the radial components of target motion (see Section IV). This algorithm is easily extended to recursive solution and will probably become part of the overall recursive processing approach to solve the ISAR imaging problem. Our goals for the continued effort are to: 1. Develop and extend a complex, recursive-in-time, time- frequency parameter estimator based on the recursive prediction error method (RPEM) using the underlying Gauss- Newton algorithms. 2. Apply the complex RPEM algorithm to synthesized ISAR data using the above simulator. 3. Compare the performance of the proposed algorithm to standard time-frequency estimators applied to the same data sets. Radar is a technology used in several facets of modern life, with many different civilian and military applications. Although radars have been around since 1904, much work is still spent today designing, building, testing, and implementing new radars and developing new and more powerful radar signal processing techniques. Radar signal processing is still a very active area of research. Nowadays, there has been substantial interest in noise radar over a wide range of applications, such as through wall surveillance, detection, tracking, Doppler estimation, polarimetry, interferometry, ground-penetrating or subsurface profiling, synthetic aperture radar (SAR) imaging, inverse synthetic aperture radar (ISAR) imaging, foliage penetration imaging, etc. One of the major advantages of the noise radar is its essential immunity from congestion, detection, and external interference. Signal Processing in Noise Waveform Radar brings together comprehensive studies dealing
with the emerging technology of noise waveform radar and its signal processing aspects. It discusses the properties, difficulties and potential of noise radar systems, primarily for low-power and short-range civil applications. The contributions of modern signal processing techniques to making noise radar practical are emphasized, and application examples are given. This book covers a diversity of categories in radar signal processing, including radar optimization and system design valuable for both practicing engineers and engineering students.

**ISARLAB** ("Inverse Synthetic Aperture Radar Laboratory") is a computer program designed as a research and training tool for those interested in the field of radar imaging. The system runs under MATLAB and is capable of simulating the radar returns from complex targets such as ships and aircraft, and processing these to form high range resolution (HRR) profiles and inverse synthetic aperture radar (ISAR) images. In addition to simulating various radars and targets in realistic scenarios, ISARLAB can accept and process experimentally collected radar data. This document represents the combination of a reference guide and a user's guide to the software package, as well as providing a brief introduction to radar imaging.

A method for a fast two-dimensional inverse synthetic aperture radar (ISAR) imaging process is presented. A coherent short pulse radar is used to sample amplitude and phase of the backscattered field from a continuously rotating object. This is being done while a narrow range gate is sweeping in range steps of 15 cm across the target plane at a typical speed of 150 m/s. Applying fast synthetic aperture radar (SAR) principles, in an off-line process for each range cell an acceptable good cross-range resolution can be obtained when processing range intervals of less than 30. The influence of analytical approximations as well as the effect of moving scattering centers through several range resolution cells during the process interval can cause severe image degradations. Two methods for partial and complete compensation of these effects under the aspect of minimum loss in processing speed have been developed and will be presented here.

A coherent transceiver using a THz quantum cascade (TOCL) laser as the transmitter and an optically pumped molecular laser as the local oscillator has been used, with a pair of Schottky diode mixers in the receiver and reference channels, to acquire high-resolution images of fully illuminated targets, including scale models and concealed objects. Phase stability of the received signal, sufficient to allow coherent image processing of the rotating target (in azimuth and elevation), was obtained by frequency-locking the TOCL to the free-running, highly stable optically pumped molecular laser. While the range to the target was limited by the available TOCL power (several hundred microwatts) and reasonably strong indoor atmospheric attenuation at 2.408 THz, the coherence length of the TOCL transmitter will allow coherent imaging over distances up to several hundred meters. Image data obtained with the system is presented.

**Micro-Doppler Characteristics of Radar Targets** is a monograph on radar target's micro-Doppler effect theory and micro-Doppler feature extraction techniques. The micro-Doppler effect is presented from two aspects, including micro-Doppler effect analysis and micro-Doppler feature extraction, with micro-Doppler effects induced by different micro-motional targets in different radar systems analyzed and several methods of micro-Doppler feature extraction and three-dimensional micro-motion feature reconstruction presented. The main contents of this book include micro-Doppler effect in narrowband radar, micro-Doppler effect in wideband radar, micro-Doppler effect in bistatic radar, micro-Doppler feature analysis and extraction, and three-dimensional micro-motion feature reconstruction, etc. This book can be used as a reference for scientific and technical personnel engaged in radar signal processing and automatic target recognition, etc. It is especially suitable for beginners who are interested in research on micro-Doppler effect in radar. Presents new views on micro-Doppler effects, analyzing and discussing micro-Doppler effect in wideband radar rather than focusing on narrowband Provides several new methods for micro-Doppler feature extraction which are very helpful and practical for readers Includes practical cases that align with main MATLAB codes in each chapter, with detailed program annotations.

This book is based on the latest research on ISAR imaging of moving targets and non-cooperative target recognition (NCTR). With a focus on the advances and applications, it provides readers with a working knowledge of various algorithms of ISAR imaging of targets and implementation with MATLAB.

Synthetic aperture radar (SAR) is an imaging technique based on the radio reflectivity of the target being imaged. SAR instruments offer many advantages over optical imaging due to the ability to form coherent images in inclement weather, at night, and through ground cover. High resolution is achieved in azimuth through a synthesized aperture much larger than the physical antenna of the imaging device. Consequently, proper focusing requires accurate information about the relative motion between the antenna phase center and the scene. Any unknown target velocity, acceleration, rotation, or vibration will introduce errors in the image. This work addresses a novel method of focusing a moving target in a SAR image through the estimation of various motion parameters. The target azimuth position is determined through monopulse radar, at which point range velocity and acceleration are estimated across a series of overlapping sub-apertures. Cross-range velocity is then estimated through a search to optimize an image quality metric such as entropy or contrast. A final focused image is then generated based on this velocity vector. Methods of extending this work for a single phase center system are considered. This technique is demonstrated with real radar data from an experimental system, and the performance of this technique is compared both subjectively and with a variety of image metrics to the MITRE keystone technique. Finally, extensions to this current line of research are considered.

Build your knowledge of SAR/ISAR imaging with this comprehensive and insightful resource. The newly revised Second Edition of Inverse Synthetic Aperture Radar Imaging with MATLAB Algorithms covers in greater detail the fundamental and advanced topics necessary for a complete understanding of inverse synthetic aperture radar (ISAR) imaging and its concepts. Distinguished author and academician, Caner Özdemir, describes the practical aspects of ISAR imaging and presents illustrative examples of the radar signal processing algorithms used for ISAR imaging. The topics in each chapter are supplemented with MATLAB codes to assist readers in better understanding each of the principles discussed within the book. This new edition incudes discussions of the most up-to-date topics to arise in the field of ISAR imaging and ISAR hardware design. The book provides a comprehensive analysis of advanced techniques like Fourier-based radar imaging algorithms, and motion compensation techniques along with radar fundamentals for readers new to the subject. The author covers a wide variety of topics, including: Radar fundamentals, including concepts like radar cross section, maximum detectable range, frequency modulated continuous wave, and doppler frequency and pulsed radar The theoretical and practical aspects of signal processing algorithms used in ISAR imaging The numeric implementation of all necessary algorithms in MATLAB ISAR hardware, emerging topics on SAR/ISAR focusing algorithms such as bistatic ISAR imaging, polarimetric ISAR imaging, and near-field ISAR imaging, Applications of SAR/ISAR imaging techniques to other radar imaging problems such as thru-the-wall radar imaging and ground-penetrating radar imaging Perfect for graduate students in the fields of electrical and electronics engineering, electromagnetism, imaging radar, and physics, Inverse Synthetic Aperture Radar Imaging With MATLAB Algorithms also belongs on the bookshelves of practicing researchers in the related areas looking for a useful resource to assist them in their day-to-day professional work.
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This paper reports on a study of ISAR imaging of a formation of two fighters. The observations are interpreted in terms of relative motions of the two aircraft by use of model study and computer simulation. This dissertation investigates in-situ, high-resolution radar imaging of dynamic targets using an ultra-wideband (UWB) radar. Three challenging classes of dynamic targets are investigated: wind turbines, vehicles, and small consumer drones. First, the measurement and processing methodologies are developed to capture the inverse synthetic aperture radar (ISAR) image of an operating horizontal-axis wind turbine. Measurement data of a small three-blade wind turbine are collected using a UWB radar, and the measured signatures are compared to simulation results based on physical optics. The backscattering phenomenology is examined in the sinogrom, spectrogram, and ISAR image domains. The same methodologies are then applied to generate the in-situ ISAR imagery of an 18-blade windmill and a 1.7 MW utility-class wind turbine. Next, the radar signatures of a vertical-axis wind turbine are studied. Measurement and simulation are carried out for a 1.5 m tall Darrieus-type turbine model. Interpretation of the dominant backscattering mechanisms is carried out. Subsequently, the radar signatures of a 112 m tall turbine are examined using simulation. Second, wide-angle ISAR imaging of vehicles is investigated. Measurement data of moving vehicles are collected using a stationary roadside UWB radar. The generated baseline ISAR images show a clear distinction between different-sized vehicles. The images are further focused through motion compensation using a p-norm minimization. The resulting images are well focused and correspond closely to the physical dimensions of the vehicles. Third, the ISAR imaging of small consumer drones is considered. Laboratory measurement is conducted first, where the drones are rotated on a turntable and the backscattered data are collected over a wide frequency band to form high-resolution images. The effects of frequency band, aspect, polarization, dynamic blade rotation, camera mount, and drone types are examined. Subsequently, ISAR imaging of in-flight drones, from data collected using a stationary UWB radar on the ground, is demonstrated. Finally, synthetic aperture radar (SAR) imaging using a small drone as the radar platform is explored. The entire system including a UWB radar, antennas, a camera, and a single-board computer fits on the small drone and is controlled through a Wi-Fi connection. Both the side-looking and downward-looking SAR scenarios are presented.

The thesis deals with the application of ISAR processing to obtain high resolution imaging of non-cooperative moving targets within a SAR scene. The research topic is of great interest nowadays. Modern SAR system can provide high resolution radar images of wide areas with reduced revisiting time. These features make them particularly suited for surveillance application. It is obvious that for these kind of applications the capability of imaging non-cooperative moving targets becomes fundamental. Since conventional SAR processing is unable to focus moving targets because of the lack of knowledge of the target motion a solution based on ISAR processing is proposed. In fact, ISAR systems, do not make any assumption about the target motion, but they exploit it to form the synthetic aperture and to obtain high resolution in the cross-range dimension. Since the ISAR processing must be applied to each target separately a detection step is fundamental. Although this detection step is not a problem when dealing with maritime targets, as the sea clutter return is usually much lower than the target return, it can be a challenge when dealing with ground target. Multichannel information provided by SAR systems with multiple receivers can be exploited to mitigate the return of the static scene. STAP processing is then combined with ISAR technique to produce high resolution images of non-cooperative moving targets after detection within SAR images. The multichannel version of Range Doppler image formation algorithm is derived and analyzed. Then, it is used to define a Space Doppler Adaptive processing to mitigate the strong clutter before the application of ISAR autofocus. Performance are evaluated on simulated data. Results on real data prove the effectiveness of the proposed processing and its applicability on actual systems.

Advanced spectral estimation methods are presented for radar imaging and target feature extraction. We study problems involved in inverse synthetic aperture radar (ISAR) autofocus and imaging, synthetic aperture radar (SAR) autofocus and motion compensation, superresolution SAR image formation, three-dimensional (3-D) target feature extraction via curvilinear SAR (CLSAR), and time delay estimation. For the ISAR imaging problem, we present a parametric AUTOCLEAN (AUTOfocus via CLEAN) algorithm, and two non-parametric algorithms including an adaptive Capon and a recursive APES (Amplitude and Phase ESTimation). For the problems related to SAR imaging, we propose a Semi-PARametric (SPAR) algorithm for target feature extraction and superresolution image formation, and two parametric methods, MCRELAX (Motion Compensation RELAX) and MCCLEAN (Motion Compensation CLEAN), for simultaneous target feature extraction and cross-range phase error compensation. For the 3-D target feature extraction problem, an AUTOfocus algorithm based on the RELAXation-based optimization approach (AUTORELAX) is proposed to compensate the aperture errors in CLSAR and to extract 3-D target features. For the time delay estimation problem, we first present a Weighted Fourier transform and RELAXation-based (WRELAX) approach. Then, a MODE-WRELAX (MODE (Method Of Direction Estimation) together with WRELAX) algorithm is proposed for the superresolution time delay estimation. An imaging radar, like ISAR, offers a combatant the capability to perform long range surveillance with high quality imagery for positive target identification. Extending this attractive feature to the battle damage assessment problem (BDA) gives the operator instant viewing of the target's behavior when it is hit. As a consequence, immediate and decisive action can be quickly taken (if required). However, the conventional Fourier processing adopted by most ISAR systems does not provide adequate time resolution to capture the target's dynamic responses during the hit. As a result, the radar image becomes distorted. To improve the time resolution, time-frequency transform (TFT) methods of ISAR imaging have been proposed. Unlike traditional Fourier-based processing, TFT's allows variable time resolution of the entire event that falls within the ISAR coherent integration period to be extracted as part of the imaging process. We have shown in this thesis that the use of linear Short Time-Frequency Transforms allows the translational response of the aircraft caused by a blast force to be clearly extracted. The TFT extracted images not only tell us how the aircraft responds to a blast effect but also provides additional information about the cause of image distortion in the traditional ISAR display.

Keywords: wavelet, image registration, shape analysis, ISAR.

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