1

INTRODUCTION[1]

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The use of surveillance for a variety of applications in the dynamically changing civilian and military environments has led to a great demand for innovative sensors and sensing configurations based on cutting-edge technologies, such as knowledge-based (KB) signal and data processing, waveform diversity, wireless networking, robotics, advanced computer architectures, and supporting software languages [1]. Improved sensor signal and data processing performance will be gained from KB and a priori information, multiple processing paradigms, and sensor fusion. A knowledge-based system (KBS) uses a priori information to improve the performance of deterministic and adaptive systems. Although the exact form of this prior knowledge is problem-dependent, a KBS consists of a knowledge base containing information specific to a problem domain and an inference engine that employs reasoning to yield decisions.

With maturing electronics and radar hardware, advanced radar systems will use KB techniques to perform signal and data processing cooperatively within and between platforms of sensors and communication systems while exercising waveform diversity, as well as reconnaissance, surveillance, imaging and communications within the same sensor system. In addition, these sensors will cooperate with other users and sensors, sharing information and data. Sensor system performance can be enhanced by changing a sensor's algorithms as the environment changes. This is the fundamental concept underlying KB or cognitive radar, known to the radar community since the pioneering papers of Vannicola and colleagues [2, 3], Haykin [4], and Baldygo et al. [5]. The operational radar environment is subject to rapid spatio-temporal variation. Hence, the key to efficient adaptation is real-time

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exploitation of a priori knowledge pertaining to the operational environment. For example, if an airborne radar system is aware of certain features of the Earth and its surroundings, then it can significantly improve performance by exploiting degrees of freedom such as the transmit waveform, polarization, frequency, phase, power, modulation, and coding. The adaptive and optimal use of all available degrees of freedom is broadly termed "waveform diversity." Waveform diversity is the technology that will allow one or more sensors onboard a platform to automatically change operating parameters [e.g. frequency, gain pattern, pulse repetition frequency (PRF)] to meet the varying environments. Also, the system of sensors should operate with multiple goals managed by an intelligent platform network that can control the dynamics of each sensor to meet the common goals of the platform, rather than each sensor operate as an independent system. Intelligent software processing is required at all stages of signal, data, and system processing from the filtering, detection, tracking, imaging, and identification stages to the communications, command, and control (C3) stages. Examples of a priori knowledge are archival radar data, Geographic Information Systems (GISs), Digital Terrain Elevation Data (DTED), Land Cover Land Use (LCLU) data, information on the radar kinematical parameters, off-board sensor data, roadway maps, and background of air/surface traffic. Recent advances in environmental measurements, DTED, future information quality and accessibility, digital processing, mass and random-access memory technologies, have opened up many possibilities, unrealizable in the past, for radar systems to improve their on-line performance. New real-time processing techniques are required for [e.g. for the constant false alarm rate (CFAR) behavior of the radar system [6]] to take advantages of these advances to bring radar performance back to optimum under difficult operation conditions such as littorals that include mixed sea and variable terrain.

The great interest in the application of KB techniques to adaptive radar signal and data processing is evident from the following examples:

1. The Defence Advanced Research Projects Agency (DARPA) has been pioneering the development of the first ever real-time knowledge-aided adaptive radar architecture. In particular, the Knowledge Aided Sensor Signal Processing and Expert Reasoning (KASSPER) program has as its aim the development and application of a revolutionary new approach to demanding multidimensional adaptive sensor systems, with a near-term focus on military applications of Ground Moving Target Indicator (GMTI) radar and Synthetic Aperture Radar (SAR). Annual KASSPER workshops started in 2002 to allow the exchange of ideas across the spectrum of R&D activities, including knowledge-based space–time adaptive processing (KB-STAP), environmental knowledge-base generation and maintenance, and real-time KB embedded computing [7].
2. The US Air Force Research Laboratory's Sensors Directorate has been pursuing some of the most progressive work in employing KB techniques in the radar signal processing chain, specifically in the CFAR portion of the chain [5, 8].

3. The US Air Force (USAF) has an ongoing project called Autonomous Intelligent Radar System (AIRS) that is performing research in applying KB techniques to radar signal processing. The AIRS architecture design leverages advanced technologies developed by the World Wide Web Consortium (W3C) and the DARPA Agent Markup Language (DAML) program to define the next-generation Internet, also called the Semantic Web [9].
4. A series of lectures has been devoted to Knowledge-Based Radar Signal and Data Processing [10]. They were sponsored by the NATO Research and Technology Organization (RTO) with the following scope: promoting cooperative research and information exchange to support the development and effective use of national defense research and technology to meet the military needs of the alliance; maintaining a technological lead; and providing advice to NATO decision makers. This Lecture Series was held in Sweden, Hungary, and Italy in 2003; Poland and Spain in 2004; and in the Czech Republic, Belgium, and the UK in 2006.
5. A special section of the *IEEE Signal Processing Magazine* devoted to "Knowledge-Based Systems for Adaptive Radar: Detection, Tracking, and Classification," published in January 2006, edited by Fulvio Gini [11].
6. A special section of *IEEE Transactions on Aerospace and Electronic Systems* devoted to "Knowledge-Aided Sensor Signal and Data Processing," published in July 2006, co-edited by William Melvin and Joseph Guerci [12].

The aim of this book is to highlight recent advances in both knowledge-based systems and radar signal and data processing, in a common forum, in order to present a range of perspectives and innovative results with potential to enable practical adaptive radar systems design. The chapters of this book describe the current developments in the area and present examples of improved radar performance for augmented and upgraded systems, and project the impact of KB technology on future systems.

1.1 ORGANIZATION OF THE BOOK

The book is organized into ten chapters. This first chapter is the introduction to the concept of KB radar. The remaining nine chapters focus on the application of KB concepts to a specific radar function, that is, detection, tracking, or classification. Each of them is essentially self-contained, starting with introductory remarks, following with a discussion, and ending with a list of references. Their contribution is briefly summarized in the following.

Chapter 2, entitled "Cognitive Radar" (by Haykin), discusses the idea of cognitive radar. The radar environment is usually nonstationary, and adaptivity is the method implemented in modern radar systems for dealing with nonstationarity. In current designs of radar systems, adaptivity is usually confined to the receiver. In this chapter it is argued that for the radar to be cognitive, adaptivity has to be extended to the transmitter too. Three important conclusions are drawn:

1. Intelligence is a necessary requirement for the radar to be cognitive;
2. Feedback from the receiver to the transmitter is the facilitator of intelligent signal processing; and
3. The preservation of information in radar returns is of crucial importance to improved receiver performance.

Two potential applications of cognitive radars are finally presented, one dealing with multifunction radars and the other dealing with a network of noncoherent marine radars.

Chapter 3, entitled "Knowledge-Based Radar Signal and Data Processing: A Tutorial Overview" (by Capraro, Farina, Griffiths, and Wicks), describes the role of KB processing in exploiting available information such as positioning, waveform selection, and modes of operation to enhance radar performance. This chapter provides a brief overview of artificial intelligence (AI) and a rationale for knowledge bases and robotics, which are the two main areas of emphasis for bringing KB into fielded radar systems. Also, the role of Semantic Web technologies in KB radar systems is discussed. An end-to-end radar signal and data processing architecture for airborne surveillance radar and its over-arching KB processing and control are described in detail. The chapter ends with the authors' view of the future of KB radar research, including waveform diversity and intelligent sensor systems.

Chapter 4, entitled "An Overview of Knowledge-Aided Adaptive Radar at DARPA and Beyond" (by Guerci and Baranoski), provides a breezy tour of the KASSPER program, highlighting both the benefits of knowledge-aided (KA) adaptive radar, key algorithmic concepts, and a new "look-ahead" radar scheduling approach that is the cornerstone of High Performance Embedded Computing (HPEC) architectures. Methods in which prior knowledge can be incorporated into the space–time adaptive beamformer, which is the most demanding component of modern GMTI radar, are described in some detail. Finally, the chapter introduces the notion of extending KA processing to the adaptive MIMO (Multi-Input Multi-Output) radar problem. The methods described here are potentially applicable in many other adaptive sensor signal processing systems such as hyperspectral imaging, lidar, sonar, and other multidimensional sensor arrays where environmental disturbance is a dominant source of interference.

Chapter 5, entitled "Space–Time Adaptive Processing for Airborne Radar: A Knowledge-Based Perspective" (by Wicks, Rangaswamy, Adve, and Hale), provides an overview of radar STAP from its inception to state-of-the-art developments. The topic is treated with regard to both intuitive and theoretical aspects. A key requirement of space–time adaptive processing is knowledge of the spectral characteristics underlying the interference scenario of interest. However, these are seldom known in practice and must be estimated using training data. Two central problems arise in the application of STAP:

1. The homogeneity of the sample support needed to train the adaptive filter; and
2. The computational load of the algorithm. No algorithm is the best one and the only practical approach suggested in this article is to use a KB scheme that best matches the signal processing to the interference scenario at hand. The article illustrates the immense potential of KB approaches in solving these problems.

Chapter 6, entitled "CFAR Knowledge-Aided Detection and its Demonstration Using Measured Airborne Data" (by C. Capraro, G. Capraro, De Maio, Farina, and Wicks), addresses the design and analysis of a KA detector for airborne radar applications. The two building blocks of the proposed processor are the training data selector and the detector. The training data selector has the goal to choose the secondary cells that best represent the clutter statistics in the cell under test. It is a hybrid algorithm, which pre-screens training data through the use of terrain information from the United States Geological Survey (USGS). The second stage of processing is a data-driven selector, which attempts to eliminate residual training data heterogeneities. The performance of the proposed KA detector is analyzed using measured airborne radar data, obtained from the Multi-Channel Airborne Radar Measurements (MCARM) program, and is compared with alternative detectors proposed in the open literature.

Chapter 7, entitled "STAP via Knowledge-Aided Covariance Estimation and the FRACTA Meta-Algorithm" (by Blunt, Gerlach, Rangaswamy, and Shackelford), describes the development of a KB approach to airborne/space-based radar for GMTI in the presence of severely heterogeneous training data. In particular it addresses the benefit provided by model-based prior knowledge when used to supplement the FRACTA meta-algorithm, a multistage/multimetric approach that is robust to training data heterogeneity. The FRACTA meta-algorithm utilizes three stages of detection, which, individually, systematically identify potential targets while eliminating data contamination (censoring), detect targets within the clutter-suppressed environment (cell-averaging CFAR), and eliminate false alarms that may arise due to undernulled clutter and/or space–time filter sidelobes (Adaptive Coherence Estimator (ACE) detector). In the chapter it is demonstrated how approximate prior knowledge in the form knowledge-aided covariance estimation (KACE) further improves the robustness of the detector by supplementing interference covariance estimation in scenarios with insufficient sample support that would otherwise lead to "sample starvation" problems.

Chapter 8, entitled "Knowledge-Based Radar Tracking" (Benavoli, Chisci, Farina, Immediata, and Timmoneri), describes how to efficiently exploit a priori knowledge in the tracking of multiple radar targets. In many scenarios, heterogeneity of the surveillance region makes conventional tracking systems (not using the KB) very sensitive to false alarms and/or missed detections. In this chapter it is demonstrated that an effective use of a priori knowledge at various levels of the tracking algorithms significantly reduces the number of false alarms, missed detections, false tracks, and improves true target track life The main ingredients of the tracker are (1) Extended Kalman filtering to take into account nonlinearities; (2) Interacting Multiple Model for managing the target maneuvers; (3) Nearest Neighbour Cheap Joint Probabilistic Data Association for robust plot–track association; (4) M out of N logic for track initiation; (5) use of the Knowledge Base (geographical maps and targets characteristics) and of Amplitude Information; (6) use of fuzzy logic for classification of the surveillance region. The proposed algorithm is tested against simulated and live data pertaining from a SELEX-SI naval surveillance radar. The results demonstrate that the KB approach provides meaningful advantages, allowing for the reduction of false and tentative tracks while permitting the continuous track of useful targets.

Chapter 9, entitled "Knowledge-Based Radar Target Classification" (by Bilik and Tabrikian), addresses the problem of automatic target recognition by means of ground surveillance Doppler, in particular, the classification between a walking person, a pair of walking persons, and a slowly moving vehicle. The maximum likelihood (ML) and the "majority voting" decision rules were applied to the proposed classification problem. Two sources of knowledge were considered for target classification: statistical and physical. Statistical knowledge is obtained from a training database of recorded target echos, and physical knowledge is available by developing locomotion models for the different targets. The statistical classifier was applied to a seven-class problem of radar targets such as walking person, group of walking persons, tracked vehicle, wheeled vehicle, animals, and clutter. The human operator's performance has also been evaluated. In many cases, a training database may not be available, and in some cases, it may be insufficient to represent the different classes. On the other hand, the inaccuracy in the locomotion models results in limited classification performance. In the chapter it is shown that the best performance is achieved via a combined approach, which incorporates both the statistical and physical knowledge sources. The performances of the physical, statistical, and combined knowledge-based algorithms are tested using real data records from three classes: one person, two persons, and vehicle.

The final chapter, entitled "Knowledge-Based Resource Management for Multifunction Radar" (Miranda, Baker, Woodbridge, and Griffiths), focuses on the multifunction radar (MFR) resource management problem, that is, the allocation of finite resources in an optimal and intelligent way. The dynamic and interactive interplay between the setting of radar parameters to optimize the tasks to be carried out and perception of environment motivates the centrality of knowledge-based data processing in determining MFR performance. The chapter focuses on two related aspects of radar resource management: scheduling and task prioritization. Two different methods of scheduling are examined and compared, and their differences and similarities highlighted. The analysis indicates that prioritization is a key component to determining overall performance. A fuzzy logic approach for prioritizing radar tasks in changing environment conditions is described. By assessing the priorities of targets and sectors of surveillance according to a set of rules, an attempt is made to imitate the human decision-making process such that the resource manager can distribute the radar resources in a more effective way. Results suggest that the fuzzy approach is a valid means of evaluating the relative importance of the radar tasks; the resulting priorities are adapted by the fuzzy logic prioritization method, according to how the radar system perceives the surrounding environment.

We hope that this book will stimulate the interest of the scientific community in this new and exciting field of research, which offers a rich set of challenges and problems spanning a broad spectrum of basic and applied research.

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