Towards next generation of radar systems: Noise Radar Technology and Conformal Arrays for Multifunction Digital Radar

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1. Noise Radar Technology

1.1 Introduction to Noise Radar and its waveforms

The enormous scientific and technological effort in military electronics immediately before and during World War II [1] have paved, both to engineers and researchers, the way to greatly improve radar design and development, as well as new system concepts to be fully exploited in practice. An example is the Noise Radar Technology (NRT) that comes from the idea, conceived over half a century ago, to use noisy signals (random waveforms) for radar detection. The term Noise Radar traditionally designates systems that transmit waveforms generated by electronic noise, or by digitally generated pseudorandom noise. Horton [2] first proposed such a system in 1959.

Hence, those particular radar sets use noisy or pseudo-noise waveforms in place of the - widely studied and commonly used - deterministic radar signals [3-6]. Books [7], reports [8] and international Conferences have been fully dedicated to this topic, starting with the First International Workshop on Noise Radar Technology, NTRW'2002, Yalta, Ukraine [9] and its 2012 edition [10].

During the last decades the advancements in signal processing, together with the more and more powerful hardware, has allowed the scientists to implement this idea in practical systems, such as the radar demonstrators implemented - in an international effort - in the frame of the NATO Science and Technology Organization (STO), Sensors and Electronic Systems (SET) Groups: SET 184 and SET 225, [11-13].

In the frame of SET 225 Group, field trials of Noise Radar demonstrator (designed and built by the Fraunhofer FHR, Wachtberg) have been carried out from 25 to 28 June, 2018. Both static targets (Corner Reflectors) and moving targets (car, aircraft) have been used to check detection capabilities in the presence of clutter, multipath and antennas' coupling, as well as to test resolution. Ten different waveform types have been used, including both random and deterministic signals. The FHR demonstrator at the trials site is shown in Figure 1.1.

The photonic revolution in radars

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Abstract: *This chapter introduces the new generation of radars based on photonic technologies. The intrinsic characteristics of light provide radars with innovative features as frequency agility, performance independent on the RF carrier, precise and fast beamforming and easy RF signal distribution. Photonics also enable the development of coherent radar networks and ultra-wide band RF scanners. Finally photonics integration assures promising solutions on chip.*

1. Introduction

The next generation of microwave remote sensing systems will require innovative heterogeneous, distributed and miniaturized radars, for collecting complete information on the scene under observation, and being able to precisely detect, recognize and classify the different targets. They include:

1) Heterogeneous sensors, i.e., radars with different features and working in different radio spectral regions, permit to detect a wider range of properties of the targets and to be more robust to the environmental conditions, increasing the system detection capability and its reliability. Therefore, frequency flexibility and software-defined configurability will be largely desired. Frequency flexibility, besides permitting to differentiate the radar operating frequencies, also helps in developing sparse radars, i.e., radars having a total bandwidth defined as a sum of several narrower and sparse sub-bands. Since the range resolution in a radar depends on its total bandwidth, sparse radars will address the need of bandwidth by solving the problem of the spectrum erosion imposed by the communications field, exploiting the unregulated frequency regions. Coherent data fusion among the heterogeneous detections permits to exploit all the acquired information to increase the system resolution and accuracy. For this reason, coherence among bands will be largely sought. Unfortunately, conventional RF (radio frequency) electronics have an intrinsic narrow bandwidth; therefore multiband radars can be obtained only using several independent single-band apparatuses. In these cases, the coherence among data is usually reconstructed digitally through heavy synchronization algorithms that represent the main computational complexity in the radar processing.

Spectrum Sensing for Cognitive Radars

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Abstract: *Mobile radio communication systems are proliferating at increasing rates, resulting in spectrally dense environments and fierce competition for frequency bands that traditionally has been exclusively allocated to radar systems as primary users. To cope with the related issue of spectrum crowding, future radar systems should be able to coexist with radio frequency systems anticipating their behavior and properly reacting to avoid interference. To this end, radar designers need critical and new methodologies based upon cognition as an enabling technology. This work describes one of the main functions that a cognitive radar should be able to perform to cope with a spectrally dense environment: the spectrum sensing.*

1. Introduction

Radar technology has recently been evolving towards higher resolution, high-precision multifunction systems with ever-increasing capabilities, all available simultaneously, such as surveillance, multi-target tracking, confirmation of alarms, clutter and interference estimation and rejection, and even more. These capabilities are traditionally associated with dedicated individual radars [1]. Hence, multifunctional radar systems should be able to work with frequency bands wider than traditional ones. Clearly, this is in conflict with the growth of activities in the area of radio and personal communications, where the emergence of new technologies and of new services having a high demand for spectrum allocation puts a very strong pressure upon the frequency bands currently allocated to radars. The allocation of the electromagnetic spectrum is regulated by the International Telecommunication Union (ITU) and is continually reviewed at the international level by the World Radiocommunications Conference (WRC) [2]. Some portions of the traditional radar bands have been recently allocated to communication services. For instance, in the US, the National Telecommunications and Information Administration (NTIA) [3] has recently devoted efforts to identifying frequency bands that could be made available for wireless broadband service provisioning. A total of 115 MHz of additional spectrum (1695-1710 MHz and 3550-3650 MHz bands) has been identified for wireless broadband systems [4]. Moreover, radar systems in the high part of the UHF band overlap with GSM communication systems and S-band radars already partially overlap with Long Term Evolution (LTE) and WiMax systems [5]. Some results on the impact of S-band radars on WiMax systems are shown in [5] and the impact of VHF/UHF radars on DVB-T and DVB-T2 systems has been studied in [6] as a function of the modulation scheme, the propagation environment, and the radar waveform type.
From the examples above, it is evident that the availability of frequency spectrum for multifunction radar systems has been severely compromised and the available frequency bands are increasingly shrinking. In the near future, radar systems will have to share their bandwidth with communications systems, where the latter are quite often the primary users. It is possible

New Frontiers in Radar imaging

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Abstract: *This article presents two emerging techniques on radar imaging of moving target, namely, Passive Bistatic Inverse Synthetic Aperture Radar (ISAR) and 3D Interferometric ISAR (InISAR). The former enables Passive Coherent Localization (PCL) system with imaging capabilities. The latter allows a 3D point-like model of a moving target to be reconstructed by exploiting an interferometric radar system. Both techniques provide conventional radar system (be it passive or active) with additional information on the detected moving target, and therefore may open the door to improved Automatic Target Recognition (ATR) capabilities.*

1. Introduction

Passive radars have a number of obvious advantages over active radar systems. Specifically, null electromagnetic pollution, low vulnerability to electronic countermeasures, and counter-stealth capabilities. Passive radars have gained a renewed interest from the scientific community, because the recent technological advances have made the realization of low-cost passive coherent radars and real-time processing feasible. Most of the current studies on passive radar involve target detection and tracking using different kind of broadcast signals, such as FM radio, wireless local area network signals, and digital broadcasting signals (DVB-T, DVB-S, DAB, UMTS). As research in this field progresses, more radar techniques are added to passive radar systems to make them able to handle several tasks and to be applied to different scenarios. One of the new passive radar capability is the radar imaging of non-cooperative targets, which in turn may open the door to ATR. Broadcast IOs (Illuminator of Opportunity) commonly operate at UHF/VHF band. The use of these digital broadcasting signals is attractive because they are transmitted in frequency bands typically not allocated for radar applications. However, operating at such low frequency bands (UHF/VHF band) implies narrow instantaneous bandwidth of the transmitted signals (limited to the bandwidth of the communication signals) and consequently a poor spatial resolution of the radar images. The use of multiple channels of the IOs signals can overcome the limit of the single channel narrow instantaneous bandwidth. In [1], [2], [3], the authors have demonstrated that it is possible to use a signal composed of frequency adjacent DVB-T channels to obtain a 2D-ISAR image with fine spatial resolutions, independently of the signal content.

2D ISAR techniques (both passive or active) generate a 2D image of the target, which represents a 2D projection of the true three-dimensional target reflectivity on an image plane, namely the Imaging Projection Plane (IPP). The orientation of such plane strongly depends on the radar-target geometry and on target motion, which is typically unknown. This complicates the interpretation of the ISAR images. The projected two-dimensional image can only provide

Spectrum Sharing between Radar and Communication Systems: a Multifaceted Challenge

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Abstract: *Radar signal design in a spectrally dense environment is a very challenging and topical problem due to the increasing demand of both defence surveillance/remote sensing capabilities and civilian wireless services. After a brief introduction on the key strategies for spectrum sharing between radar and communication systems, this Chapter mainly focuses on the description of optimization theory-based radar waveform design approaches to deal with the spectrum congestion problem. Cognition provided by a Radio Environmental Map (REM) paves the way for an intelligent dynamic spectrum allocation. It pushes for dynamic spectral constraints on the radar waveform which is thus the result of a constrained optimization process aimed at improving some radar performance (such as detection, low sidelobes level, resolution, tracking) while ensuring spectral compatibility with the surrounding Radio Frequency (RF) licensed systems. Finally, some spectrally crowded illustrative scenarios are analyzed to show the effectiveness of the considered optimization theory-based approach.*

1. Introduction & State of Art

The Radio Frequency (RF) electromagnetic spectrum is a limited natural resource necessary for an ever-growing number of services and systems. It is used in several applications, such as mobile communications, radio and television broadcasting, as well as remote sensing. Together with oil and water, nowadays the RF spectrum represents one of the most important, significant, crucial, and critical commodities due to the huge impact of radio services on the society. Both high-quality/high-rate wireless services (4G and 5G) as well as accurate and reliable remote-sensing capabilities (Air Traffic Control (ATC), geophysical monitoring of Earth, defense and security applications) call for increased amounts of bandwidth [1], [2]. Besides, basic electromagnetic considerations, such as good foliage penetration [3], low path loss attenuation, reduced size of the devices push some systems to coexist in the same frequency band [4], [5] (for instance HF, VHF, and UHF). As a result, the RF spectrum congestion problem has been attracting the interest of many scientists and engineers during the last few years and is currently becoming one among the hot topics in both regulation and research field [6], [7].

RF spectrum assignment and regulation is coordinated worldwide through the International Telecommunications Union (ITU) and it is reviewed every three-to-four years at the World

Monostatic & Bistatic Persistent Surveillance Radar

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Abstract: *Persistent surveillance is a key concept at the basis of different evolutions of the new generation digital radar systems. Having a region of the space continuously monitored by one or multiple staring antenna beams allows to operate with long observation times, thus allowing to collect enough power to detect dim targets, to identify flashing events, to provide a high Doppler frequency resolution useful for target recognition purposes. In the limit condition of a full cluster of persistent beams, the so-called "ubiquitous radar" operation is allowed. This paper is focused on the recent research activity on the persistent surveillance, which has been carried out by the Radar Remote Sensing & Navigation (RRSN) group at Sapienza University.*

1. Introduction

As an opposite to the use of the traditional rotating or scanning narrow antenna beams that are typically employed to provide surveillance of an assigned volume, a recent technological trend consists of using wide transmit beam patterns and clusters of staring beams. The availability of one or more staring beams potentially provides very long integration times compared to the rotating or scanning beams, which in turns enables, [1]:

(i) collecting enough power to detect dim targets,
(ii) providing the high Doppler frequency resolution useful for target recognition.
(iii) identifying flashing events,

Features (i) and (ii) require coherent integration performed on the large amount of data collected during the long observation times, while feature (iii) exploits the continuous monitoring to detect events that show up only for a small fraction of time and have short persistence. The capabilities provided by the three enabled features (i)-(iii) are especially valuable in the context of the asymmetric threat scenarios that largely characterize the present situation, where the detection and identification of the "low observable" targets, largely provides a significant advatage in the protection capabilities.

It is interesting to notice that a significant signal processing capability is typically required to fully exploit the long observation times, so that these operational modes are only applicable in the context of the new generation digital radar systems. In most of the cases, for the persistent surveillance increased computing capability is the price to be paid to exploit longer and longer observation times, thus improving both detection and identification capabilities. The staring beams imply a persistent surveillance of a specific volume, whose size and shape depends on the number of used beams and on their width. In the limit condition of a full cluster of persistent beams that covers all Direction of Arrivals (DoAs), the so called "ubiquitous radar" operation is obtained. In other cases, only specific sectors are persistently monitored. For an assigned volume to be monitored, a taxonomy of the

Microwave tomography for radar imaging in security applications

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Abstract: *This paper provides an overview of theoretical and practical aspects of radar imaging with a focus on security applications. Here, the emphasis is on the data processing involved in the image formation process, which is carried out by resorting to a microwave tomographic approach. A general mathematical model of the approach is presented and particularized to the specific radar configuration at hand. Conventional and emerging radars for security and monitoring such as ground penetrating radars, through-wall radars, and passive multistatic radars are discussed and relevant examples are reported to show their potentialities.*

1. Introduction

Radar imaging is a broad research topic at the basis of any operation regarding detection, localization and tracking of targets starting from the knowledge of their response to an incident microwave signal [1]. This topic has significant follow-ups in many applications such as surveillance, environmental monitoring, non-destructive diagnostics, border surveillance, security and crisis management, biomedical imaging and so on.

The basic goal of radar imaging is to localize and provide information about the geometry of a target by means of an aperture radar (either synthetic or physical), which illuminates the scene and collects the samples of the field scattered by the target. This goal is pursued by means of specific data processing algorithms, which take in input raw radar signals and provide a more easily interpretable image of the scene wherein the presence of the targets can be inferred.

The literature provides a lot of imaging algorithms, which have been developed in different areas such as Synthetic Aperture Radar (SAR) [2], Through-Wall Radar (TWR) [3], Ground Penetrating Radar (GPR) [4], biomedical imaging [5], etc.

As general scheme, imaging or focusing algorithms can be broadly classified as beamforming or matched filtering and inverse filtering methods [6]. Beamforming acts very similarly to seismic migration and achieves the imaging by compensating the phase of the scattered field with a proper spatially varying filter. Inverse filtering methods are based on the electromagnetic (EM) modeling of the sensing phenomenon and exploit inverse scattering-based procedures [7], [8] aimed at inverting a mathematical relationship between the scattered field and the EM properties of the target. This relationship depends on the target nature (dielectric, metallic), on the radar imaging configuration and the operating scenario. Sparse reconstruction approaches based on the compressive sensing paradigm have recently attracted considerable attention as well [9].

Most of above mentioned approaches are based on linearized models of the EM (EM) scattering phenomena. The choice to use a linear model allows bypassing typical issues of non-linear optimization methods such as false solutions and convergence problems [10], providing qualitative reconstructions of the targets with a computational effort complying with necessity to deal with real scenarios. On the other hand, linear models account only for the direct scattering events and neglect the target mutual interactions. In addition, if multipath is not