Cognitive Processing for Radar Systems: From Theory to Practice

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Abstract:
The tutorial provides an introduction to cognitive processing for radar systems. The emphasis is placed on how the emerging theories can be taken and applied in practice. Essentially, an attempt is made to answer the question: How does one build a cognitive radar?

The meaning of cognition, from an engineering perspective, is discussed and a case is made as to why future radar system need to be cognitive. From this base position, techniques by which cognitive-like algorithms can be developed are discussed and the role of bioinspired signal processing considered. A mathematically rigorous, generalized cognitive framework will be introduced and examples of its use in experimental tests given. Further examples will be provided of how cognition can be, and in some cases already is, used in radar processing. The tutorial will close with remarks on how the radar engineering community can move forwards with cognitive processing as a new part of its design toolkit.

Dr Smith has given half-day tutorials at the International Radar Conference and as part of The Ohio State University’s CERF activity. For the latter, he first gave the tutorial at OSU and was then invited to give it onsite at Raytheon Tucson, Az.

Dr Bell has given half-day tutorials on Bayesian Multiple Target Tracking at the 2015 FUSION and OCEANS conferences, and on Bayesian Bounds at the 2007 ICASSP Conference. Each of these tutorials had the highest registration numbers at their respective conferences.

Intended Audience:
The tutorial is intended for those with a basic understanding of radar. It assumes that the delegates understand radar principles such as Doppler processing, detection and tracking. The target audience would include: PhD students industry professionals in the earlier stages of their career and experienced industry professionals who are interested in how cognitive processing may be applied to radar.

Learning Outcome:
Attendees will leave the tutorial understanding the following:
- Why cognition is important for future radar systems.
- The meaning of cognition from an engineering perspective.
- The differences in signal processing between natural and man-made systems and how the natural approach supports cognition.
- How a generalized cognitive framework can be developed.
- The methods by which the generalized framework can be instantiated for specific applications.
- The way in which designing for cognition changes the requirements placed on the radar system.

Detailed Description:
This tutorial will cover the following areas:

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The Case for Cognition: A case will be made for why cognition is now essential for future radar development. This discussion will be based around three key areas: first, that all radar systems are inherently cognitive since the human operator provides the cognition; second, that multifunction AESA radars that can adapt on a pulse-by-pulse basis therefore work beyond the speeds of human operators and so have latent capacity that can only be accessed by making them cognitive; and third that the data rate arising from some radar systems, such as Earth imaging satellites, is so great that it is not feasible for a human operator to evaluate the data in real time.

What It Means to be Cognitive: The meaning of cognition will be defined. Models for cognition from neurology and neuropsychology will be presented. The key components of these models will be highlighted and connections made to radar engineering. The concept of the cognitive and hierarchical models for cognition will be discussed.

The Use of Bioinspired Signal Processing: There are many creatures that are known to use echolocation for their interaction with the environment. Typically, the biological radars used by these creatures are simple: one transmitter (the mouth) and two receivers (the ears). Despite this simplicity the abilities of the creatures far exceeds any man-made system suggesting that there is much to learn from them. The waveforms and possible signal processing of echo-locating creatures will be discussed.

Cognitive Radar Framework: Here we define the components of a cognitive sensor system that mimics the cognitive architectures taken from the neurology and psychology disciplines. At the heart of the architecture is the perception-action cycle in which the scene, sensor, processor, and cognitive controller interact in an unending cycle that works to continuously refine the system’s knowledge of the local environment. We develop a mathematical representation of the system and define key elements common to all cognitive radar systems.

Cognitive Radar Applications and Examples: Here we give examples from the literature of cognitive radar applications. These will include historical as well as emerging applications. We will show that there is a lot of previous work upon which cognitive radar is built and that many things that go by a different name can be considered cognitive radar. This will include waveform diversity, resource allocation in a multifunction radar, sensor management in a distributed sensor system, cognitive radar networks, knowledge-aided signal processing, etc. The examples will make the abstract components of the framework real, and further drive home the point that these problems all have some fundamental components in common but that they differ in model details and implementation. Recognizing this allows us to make use of work in diverse fields.

Cognitive Radar Algorithm Development and Testing: Here we discuss the process of algorithm development and testing and how it differs from traditional feed-forward systems. (i) Simulation: designer has complete control over all aspects, (ii) testing on collected data – cognitive radar being in the loop presents a major challenge, can only be done in an artificial way on systems where the data can be “oversampled” in some manner. (iii) real-time experimentation in a laboratory setting, (iv) real-time experimentation in fielded system.

Design Requirements for an Experimental Cognitive Radar: This section will discuss what is needed to develop a cognitive radar. The relationship between common radar requirements, such as coherence or frequency agility, and cognition will be considered. Additional requirements that are necessary to enable cognitive processing will be presented. Finally, worked example will be given based on the development of the cognitive radar engineering workspace (the CREW) that is available at OSU.
Moving Forward with Cognitive Radar: The next steps for the emerging field of cognitive radar will be presented. Emphasis will be placed on two key areas. First, the changes that must come to radar engineering to allow the new field of cognitive radar flourish will be discussed. The new skillsets required by radar engineers will be considered. Second, the new opportunities that cognitive processing allows will be discussed through examples of where we may expect to see cognitive radars being used in the future.

Prior Presentations:
This tutorial will be prepared especially for the 2016 IEEE Radar Conference. It will be based upon the research effort of Dr. Bell and Dr. Smith into the development of a generalized cognitive framework for radar and their experimental validation. As part of the research, they have performed a comprehensive survey of the literature on cognitive radar processing. Additionally, they have given multiple briefings on cognition and its application to radar sensing to audiences ranging from NATO SET Panels to senior representatives from the Air Force Research Laboratory and Office of Naval Research. Material from those briefings will be included in the tutorial.

Bio-sketches:
Dr. Graeme E. Smith is a Research Scientist at The Ohio State University and is a visiting scholar at University College London. His pertinent research interests include: cognitive/fully adaptive radar processing the role of cognition in radar resources management echoic flow for radar and sonar passive bistatic and multistatic radar systems bistatic/MIMO clutter radar micro- Doppler signatures target recognition/classification and coherent on receive radars for sea surface monitoring. His primary focus is research into how radar processing can be improved through mankind’s understanding of cognitive processes. In essence he seeks to answer the question of how the abilities of natural, cognitive echolocating sensors, that can be so successful that certain species rely on them for their survival, can be achieved in man- made sensors. Before joining the team at The Ohio State University, Dr Smith worked at Villanova University where his research focused on through- the- wall radar imaging. Prior to this he completed his PhD and first post- doctoral position at University College London. Between 1999 and 2004 he worked as a lead systems engineer for BAE SYSTEM developing radar warning receivers. Dr Smith is a member of the IET and a Senior Member of the IEEE.

Dr. Kristine L. Bell is a Senior Scientist at Metron, Inc. and also holds an Affiliate Faculty position in the Statistics Department at George Mason University (GMU). From 1996- 2009, Dr. Bell was an Associate/Assistant Professor in the Statistics Department and C4I Center at GMU. During this time, she was also a visiting researcher at the Army Research Laboratory and the Naval Research Laboratory. She received the B.S. in Electrical Engineering from Rice University in 1985, and the M.S. in Electrical Engineering and Ph.D. in Information Technology from GMU in 1990 and 1995. Her technical expertise is in the area of statistical signal processing for source localization and tracking with applications in radar, sonar, aeroacoustics, and satellite communications. Her current research interests include cognitive sensing, processing, and sensor fusion. She is a co- author( with L. Stone, R. Streit, and T. Corwin) of the book Bayesian Multiple Target Tracking, 2nd edition, co- author (with H. Van Trees and Z. Tian) of the book Detection, Estimation, and Modulation Theory, Part I, 2nd edition, and co- editor (with H. VanTrees) of the book Bayesian Bounds for Parameter Estimation and Nonlinear Filtering/Tracking. In 2009, she received the George Mason University Volgenau School of Engineering Outstanding Alumnus Award. She is a Fellow of the IEEE.