Title:

Waveform optimization techniques for radar systems

Presenter Information

Presenter 1
Name: Mohammad Alaee-Kerahroodi
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Short biography: Mohammad Alaee-Kerahroodi was born in City of Ray, IRAN. In 2007, he received the M.Sc. degree in communication engineering at the Electrical Engineering department of Amirkabir University of Technology (Tehran Polytechnic), Tehran, IRAN. After graduating from the university, he was a key engineer for the development of the different radar systems including meteorological, primary/secondary air traffic control radar systems, marine radar system, ground surveillance radar system, etc. In 2012, he started PhD study in communication engineering at the department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, IRAN. From February to August 2016, he was a Visiting Researcher with the University of Naples "Federico II", Naples, ITALY. In November 2017, he received the PhD degree and thereupon he joined to the Signal Processing and Satellite Communications group, SIGCOM, at the Interdisciplinary Centre for Security, Reliability and Trust (SnT), University of Luxembourg. Within this research tenure, he is currently working on innovative radar signal processing solutions for automotive MIMO radar systems as well as pursuing academic research in the area of radar waveform design and signal processing. In addition, he is participating in writing national and European projects to attract funding as well as supervising students. His research interests are related to waveform design for active sensing and communication systems, optimization theory applied to radar signal processing, design and optimization of MIMO radar systems and statistical/array signal processing. He also co-ordinates the Radar related activities at SIGCOM. Some of his academic activities can be found in https://radarmimo.com/ , in the website maintained along with colleague Dr. Bhavani Shankar.

Presenter 2
Name: Bhavani Shankar M. R.
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Short Biography: M. R. Bhavani Shankar (SM'15) received Masters and Ph. D in Electrical Communication Engineering from Indian Institute of Science, Bangalore in 2000 and 2007 respectively. He was a Post Doc at the ACCESS Linnaeus Centre, Signal Processing Lab, Royal Institute of Technology (KTH), Sweden from 2007 to September 2009. He joined SnT in October 2009 as a Research Associate and is currently a Research Scientist at SnT. He was with Beceem Communications, Bangalore from 2006 to 2007 as a Staff Design Engineer working on Physical Layer algorithms for WiMAX compliant chipsets. He was a visiting student at the Communication Theory Group, ETH Zurich, headed by Prof. Helmut Bölcskei during 2004. Prior to joining Ph. D, he worked on Audio Coding algorithms in Sasken Communications, Bangalore as a Design Engineer from 2000 to 2001. His research interests include Design and Optimization of MIMO Communication Systems, Radar and Array Processing, polynomial signal processing, Satellite communication systems, Resource Allocation, Game Theory and Fast Algorithms for Structured Matrices. He is currently on the Executive Committee of the IEEE Benelux joint chapter on communications and vehicular technology, member of the EURASIP Special Area Team (SAT) on Theoretical and Methodological Trends in Signal Processing and serves as handling editor for Elsevier Signal Processing. He was a co-recipient of the 2014 Distinguished Contributions to Satellite Communications Award, from the Satellite and Space Communications Technical Committee of the IEEE Communications Society. He has co-organized special sessions in ICASSP (2017, 18), SPAWC (2015, 16) and EUSIPCO (2015, 16). He also co-ordinates the Radar related activities at SIGCOM. Some of his academic activities can be found in https://radarmimo.com/, in the website maintained along with colleague Dr. Mohammad Alaee-Kerahroodi.

Abstract:

The main goal of the tutorial is to provide the audience with a bouquet of optimization techniques to address different challenging waveform design problems in classical and emerging Multiple Input Multiple Output (MIMO) radar systems, under practical constraints.

Waveform design plays a key role in enhancing classical radar tasks including target detection and parameter estimation. Further, waveform design is a key enabler of the emerging paradigm on joint radar-communications. Different applications warrant different performance metrics; this coupled with the advent of MIMO radar makes the waveform design more challenging. Particularly, in the emerging scenario of self-driving automotive applications, towards enhancing safety and comfort, high spatial resolution is achieved using the colocated MIMO virtual array by maintaining orthogonality between the transmit waveforms. Further, waveform diversity can also be used to obtain low-probability-of-intercept (LPI) radar properties. Nevertheless, the static use of a fixed waveform reduces efficiency due to limited or no adaptation to the dynamic environment as well as vulnerability to electronic attacks highlighting the need for multiple and diverse waveforms exhibiting specific features.

In this context, the tutorial focusses on key applications and highlights a variety of optimization approaches including coordinate descent (CD) and majorization minimization (MM), dealing with important applications in radar including 1) enhancing angular resolution using sets of orthogonal sequences, 2) SINR enhancement with joint design of space-time transmit and receive weights, 3) enabling a joint radar-communications paradigm through the transmit waveform design. To further bring the optimization closer to implementation and early adaptation in systems, practical constraints, such as finite energy, unimodularity (or being constant-modulus) and finite or discrete-phase alphabet are included in the optimization problem as constraints. The diversity of design metrics and signal constraints lays the groundwork for many interesting research projects in waveform optimization.

While several seminal works have been published, a few previous “IRS” tutorials have focused on the optimization algorithms dealing with the various applications of active sensing. After attending the tutorial, participants will be able to understand:

- An overview of relevant theoretical bases and algorithms from optimization theory considered in the state-of-the-art waveform design.
- Current challenges and design criteria associated with waveform design in classical and emerging radar systems.
- Key hardware constraints of the practical radar systems and their consideration in the optimization formulation.
- An insight into formulation of waveform design optimization problems in modern radar systems and a few approaches towards finding a solution.

Tutorial outline:

We will present this tutorial in two slots and different parts as listed below:

1. **Slot 1 (1 hour and 40 minutes)**

    - **Part I: A brief review of optimization principles, active sensing scenarios and problem formulation (50 mins)**: This part begins by describing and illustrating principles of convex and non-convex optimization theory. Next, we consider casting various design problems in active sensing systems. More precisely, we address several scenarios like PSL/ISL minimization for classical radar systems, designing sets of orthogonal sequences for emerging MIMO radar systems, joint sensing and communications and so on. In this context, emphasis on the objective functions and constraint sets of the associated problems.
    - **Part II: CD optimization framework for transceiver design (50 mins)**: The CD based methods are intuitively appealing and simple to implement, yet they have shown powerful performance in emerging large-scale signal processing, machine-learning, regression, compressed sensing, and radar applications. The idea behind CD is not to tackle the original problem directly, but by iteratively optimizing it over a single coordinate, while keeping the other coordinates fixed. The most important advantage of the CD method is that the minimization of a multi-variable function can be achieved minimizing it along one

direction at a time, i.e., solving a set of potentially simpler uni-variate sub-problems in a loop. Using this framework, we illustrate how to apply CD method on the design problem introduced in the previous part.

2. **Slot 2 (1 hour and 40 minutes)**

- **Part III: Waveform optimization in mm-Wave sensing and communications (40 mins)**: In this part we introduce the driving factors for mm-Wave spectrum sharing, low-cost design and differences with respect to cm-Wave joint sensing-communications. The need for synergetic waveform design accomplishing radar and communication tasks will be highlighted. Focussing on the automotive scenario, different topologies and related challenges on waveform design will be presented. Waveform design based on aforementioned methodologies will be presented and the gains achieved will be discussed.
- **Part IV: MM optimization framework for waveform design (40 mins)**: The MM based methods introduced for various transceiver design problems in active sensing systems will be presented in this part. The idea is to address a difficult optimization problem indirectly, by finding a surrogate function that makes the optimization problem "easy" (or, in any case, easier than the directly solving the original problem). We illustrate tricks for finding surrogate functions and the key aspects in this framework through a variety number of examples.
- **Part V: Summary and open challenges (20 mins):** The aforementioned optimization methodologies have gained growing popularity in various applications. Some of these will be mentioned, and a summary of the introduced methods as well as the remaining challenges will be discussed in this part.

Relevant publications:

1- **M. Alaee-Kerahroodi**, M. Modarres-Hashemi, M.M. Naghsh, "Designing Binary Sequence Sets for MIMO Radar Systems", IEEE Transaction on Signal Processing, Volume : 67 , Issue : 13 , July1, 1 2019.

2- Kumar Vijay Mishra, **M. R. Bhavani Shankar**, Visa Koivunen, Björn Ottersten and Sergiy A. Vorobyov, "Toward millimeter wave joint radar-communications: A signal processing perspective," IEEE Signal Processing Magazine, vol. 36(5), pp. 100-114, 2019.

3- Sayed Hossein Dokhanchi, **M. R. Bhavani Shankar**, Kumar Vijay Mishra and Björn Ottersten, "A mmWave automotive joint radar-communications system," IEEE Transactions on Aerospace and Electronic Systems, vol. 55(3), pp. 1241-1260, 2019.

4- **M. Alaee-Kerahroodi**, A. Aubry, A. De-Maio, M.M. Naghsh and M. Modarres-Hashemi, "A CoordinateDescent Framework to Design Low PSL/ISL Sequences", IEEE Transactions on Signal Processing, Volume : 65 , Issue : 22, Nov.15, 2017.

5- M. M. Naghsh, M. Modarres-Hashemi, **M. Alaee-Kerahroodi**, and E. H. M. Aian, "An information theoreticapproach to robust constrained code design for MIMO radars," IEEE Transactions on Signal Processing,vol. 65, Issue 14, pp. 3647 - 3661. Year 2017.

You may refer to (https://wwwen.uni.lu/snt/people/mohammad_alaeekerahroodi, https://wwwen.uni.lu/snt/people/bhavani_shankar) for a full list of the publications.