Università degli Studi di Napoli Federico II

Massimo Rosamilia

Antenna-Based Techniques for Modern Radars

Tutor: Prof. A. De Maio

Cycle: XXXV

Year: 3

My background

- **Master Science degree**: Computer Engineering at the University of Salerno
- **Research group/laboratory**: Radar Signal Processing and Electronic Defense Research Group (*RSPRG*)
- **PhD start date**: 01/11/2019
- **PhD end date**: 30/11/2022
- **Scholarship type**: UNINA
- **Periods abroad**: - Cranfield University, U.K., 23/09/2021 – 5/11/2021
  - University of Luxembourg, Luxembourg, 15/09/2022 – present

Summary of study activities

Study activities

- Spectral Analysis of Signals
- Detection, Estimation, and Modulation Theory
- Convex Optimization Theory
- Sparse representation and compressed sensing techniques
- Statistical Analysis of Measured Targets RCS
- Reconfigurable Intelligent Surfaces
- Exploitation of the polarimetric domain for adaptive radar detection task
- Mutual coupling phenomenon among the antenna array elements

Courses attended borrowed from MSc curricula

- Tecniche Di Elaborazione Dei Segnali Per la Bioingegneria
- Sistemi Radar
- Radiolocalizzazione Terrestre e Satellitare

Summary of study activities

Relevant attended ad hoc PhD courses / schools

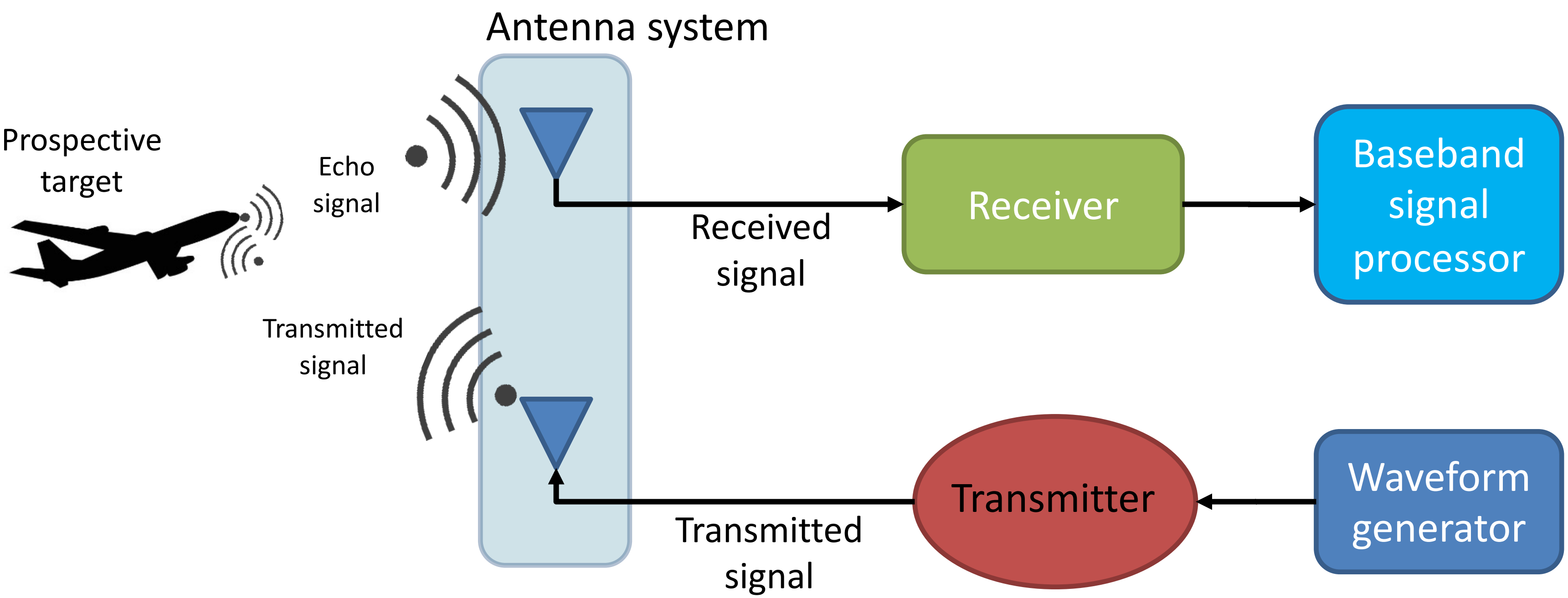
- Matlab Fundamentals
- Scientific Programming and Visualization with Python
- IEEE AESS Radar Summer School
- Cooperative and Non Cooperative Localization Systems
- 1st International Virtual School on Radar Signal Processing
- Software Defined Radio Applications for Radar and Localization Systems
- others…

Conferences / events attended

- 2020 IEEE Radar Conference (Florence, Italy), Sept. 2020 (1 paper presented)
- 2020 1st International Virtual School on Radar Signal Processing (1 paper presented)
- 2021 IEEE 8th International Workshop on Metrology for AeroSpace, MetroAeroSpace (2 papers presented)
- 2022 IEEE Radar Conference (1 paper presented)
- 2022 IEEE 9th International Workshop on Metrology for AeroSpace, MetroAeroSpace (1 paper presented)
- Radar 2022 International Conference on Radar Systems (1 paper presented)

Research areas

Radar Signal Processing



Block diagram of a conventional radar system

Research areas

Radar Signal Processing

- Adaptive Target Detection
- Direction-of-arrival estimation
- Robust signal processing architectures
- Optimization theory applied to radar signal processing

Research results

In the context of **multichannel phased array radars**:

- *Development of a joint detection and estimation strategy with a single pulse spatial processing*
- *Derivation of robust detection and robust estimation signal processing architectures able to operate in the presence of missing data.*

In the context of **FDA-MIMO radars**:

- *Development of a tailored framework to simultaneously estimate the target angle and incremental range*
- *Design of adaptive radar detectors using a polarimetric FDA-MIMO radar*

In the context of **novel and promising technology**:

- *Usage of RIS to enhance the capabilities of a standard radar system to detect targets in N-LOS case, i.e., in the absence of a direct radar-target path.*

Research Products

Journal papers

[J1]	A. Aubry, A. De Maio, S. Marano, and M. Rosamilia, *“Single-Pulse Simultaneous Target Detection and Angle Estimation in a Multichannel Phased Array Radar,*" IEEE Transactions on Signal Processing, IEEE TSP, published, 2020.
[J2]	L. Lan, M. Rosamilia, A. Aubry, A. De Maio, and G. Liao, *“Single-Snapshot Angle and Incremental Range Estimation for FDA-MIMO Radar,”* in IEEE Transactions on Aerospace and Electronic Systems, IEEE TAES, published, 2021.
[J3]	A. Aubry, A. De Maio, and M. Rosamilia, "*Reconfigurable Intelligent Surfaces for N-LOS Radar Surveillance*," in IEEE Transactions on Vehicular Technology, IEEE TVT, published, 2021.
[J4]	A. Aubry, A. De Maio, S. Marano, and M. Rosamilia, "*Structured Covariance Matrix Estimation with Missing-(complex) Data for Radar Applications via Expectation-Maximization,*" IEEE Transactions on Signal Processing, IEEE TSP, published, 2021.

Research Products

Journal papers

[J5]	A. Aubry, V. Carotenuto, A. De Maio, M. Rosamilia, and S. Marano," *Adaptive Radar Detection in the Presence of Missing-Data*," IEEE Transactions on Aerospace and Electronic Systems, IEEE TAES, published, 2022.
[J6]	L. Lan, M. Rosamilia, A. Aubry, A. De Maio, G. Liao, and J. Xu, "*Adaptive Target Detection with Polarimetric FDA-MIMO Radar*," IEEE Transactions on Aerospace and Electronic Systems, IEEE TAES, published, 2022.
[J7]	M. Rosamilia, A. Balleri, A. De Maio, A. Aubry, and V. Carotenuto, "*Radar Detection Performance Prediction using Measured UAVs RCS Data*", IEEE Transactions on Aerospace and Electronic Systems, IEEE TAES, submitted.
[J8]	A. Aubry, A. De Maio, L. Lan, and M. Rosamilia, "*Adaptive Radar Detection and Bearing Estimation in the Presence of Unknown Mutual Coupling*", IEEE Transactions on Signal Processing, IEEE TSP, submitted.

Research Products

Conference papers

[C1]	M. Rosamilia, A. Aubry, A. De Maio, and S. Marano, *“Simultaneous radar detection and constrained target angle estimation via Dinkelbach algorithm,”* 2020 IEEE Radar Conference (Florence, Italy), Sept. 2020, RadarConf20. Published, 2020.
[C2]	M. Rosamilia, A. Aubry, V. Carotenuto, and A. De Maio, "*Experimental Analysis of Structured Covariance Estimators with Missing data*," 2021 IEEE 8th International Workshop on Metrology for AeroSpace, MetroAeroSpace, published, 2021
[C3]	A. Aubry, A. De Maio, and M. Rosamilia, "*RIS-Aided Radar Sensing in N-LOS Environment*," 2021 IEEE 8th International Workshop on Metrology for AeroSpace, MetroAeroSpace, published, 2021.
[C4]	M. Rosamilia, L. Lan, A. Aubry, and A. De Maio, *“Polarimetric FDA- MIMO Radar Detection,”* 2022 IEEE Radar Conference (RadarConf22), published, 2022.

Research Products

Conference papers

[C5]	M. Rosamilia, A. Aubry, A. Balleri, V. Carotenuto and A. De Maio, “RCS Measurements of UAVs and Their Statistical Analysis,” 2022 IEEE 9th International Workshop on Metrology for AeroSpace (MetroAeroSpace), 2022, pp. 179-184.
[C6]	M. Rosamilia, A. Aubry, A. Balleri, V. Carotenuto and A. De Maio, “Performance Prediction of the Coherent Radar Detector on Measured UAVs Data”, Radar 2022 International Conference on Radar Systems, 2022.

Research Products

In December 2020 I ranked second in the Student Contest of the 1st International Virtual School on Radar Signal Processing, with the contribution “Simultaneous Radar Detection and Constrained Target Angle Estimation via Dinkelbach Algorithm”.

PhD thesis overview

- Problem statement

  *Design **antenna-based techniques** for modern radars capable of providing close-to-optimum detection and/or estimation performance while meeting the strict time constraints of standard multichannel systems.*

- Objective

  *Propose innovative solutions to solve such problem by means of **novel architectures** and **advanced optimization techniques**.*

- Methodology

  *The employed methodology is **model-based**. For a given operational scenario and specific radar system, the crucial point is the description of the received signal model:*

  - *Typically considered as the superposition of the target echo and the interference-plus-noise contribution.*
  - *The derived techniques fall within the framework of **statistical signal processing** applied to radar problems.*

PhD thesis

At the current state of the art, multichannel phased array radar systems must comply with very stressing operational requirements demanding for

- surveillance at specific ranges, sometimes with different update rates depending on the different elevation sectors
- tracking with variable update rates that can be different from those adopted in the search task
- 3-D target data measurements
- the capability to manage many tracks simultaneously without decreasing the search performance
- the capability to operate in clutter and jamming environments

At the root of all the mentioned processes, there is **target detection** and its **localization** within a 3-D coordinate system.

PhD thesis

In standar radar system, target detection and its angle estimation are typically addressed as two distinct signal processing tasks.

- First, detection of a mainbeam target is performed via an adaptive detector
- Then, if the presence of a target is declared within the antenna mainbeam, a specific angle estimation technique is initiated to localize the target within the antenna beam.

- A joint target detection and accurate angular estimation processing strategy could be advantageously implemented for every search beam of a multifunction phased array radar.

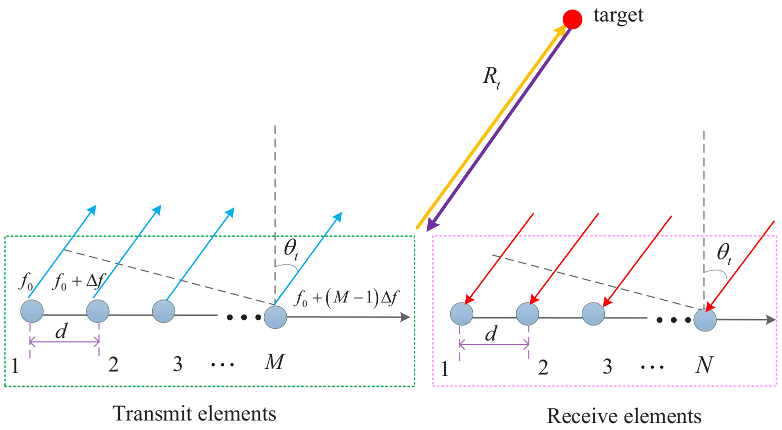
Main contributions

- Design of a signal processing architecture able to perform **simultaneous** target detection and angle estimation from the array pointing direction
- Optimal **ML estimates** of the unknown displacements provided via the Dinkelbach's algorithm or approximated through a Coordinate Descent algorithm
- **Close-to-optimum detection performance** and high-quality angular estimates in many scenarios of practical relevance for modern phased array radar

PhD thesis

Phased-array radar can achieve highly accurate angle estimation by precisely forming a beam in the desired direction.

- The resulting beampattern is dependent only on the angular direction but it is not selective in the range domain.
- However, by exploiting the characteristics of frequency diverse array, twisted with a MIMO architecture, realizing the so-called **FDA-MIMO radar**, the target angle and range can be simultaneously estimated.



Signal transmission and reception in FDA-MIMO radar.

Main contributions

– Design of a signal processing architecture able to **jointly estimate target angle** and **incremental range** using only a single data snapshot in a background of Gaussian interference with known spectral properties

– Devise of several adaptive and **computationally efficient estimators**

– Show the **effectiveness** of the devised estimators (in both white and colored interference scenario) to reliably estimate the unknown target parameters

PhD thesis

Multi-polarimetric measurements might enhance the detection performance of the conventional pulse-Doppler radars in challenging conditions where Doppler discrimination is problematic.

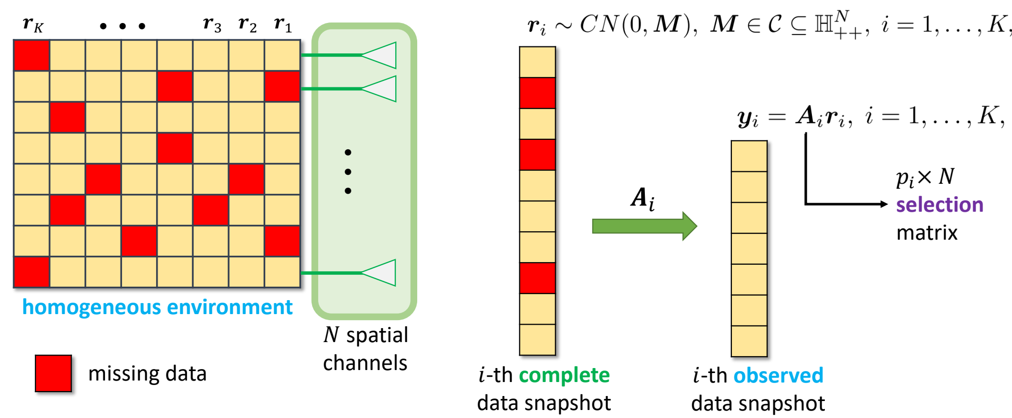
- In the open literature, some attempts to extend the plain FDA-MIMO architecture to incorporate polarimetric information have been pursued.
- However, the target detection problem with a polarimetric FDA-MIMO radar has only received a limited attention.

Main contributions

- Synthesis of **adaptive detectors** for a **polarimetric FDA-MIMO** radar accounting for a disturbance covariance matrix with unknown spectral characteristics
- Derivation of two sub-optimal detection architectures based on the GLRT and Two-Step GLRT criteria
- Design of three **solution strategies** to solve the resulting optimization problem: Linearized Array Manifold (LAM), Gradient Projection Method (GPM), Coordinate Descent (CD) procedure
- Assessment of the **detection performance** of the proposed strategies, also in comparison with both benchmark and mismatched receivers, in white noise and clutter (mixed or trees) environment

PhD thesis

Nevertheless, most of the procedures devised for multi-channel sensor arrays have been designed under the ideal conditions that all the data at the output of the array would be available.



- However, measurement errors due to acquisition equipment, random sensor failure caused by impulsive noise, range ambiguous echo returns affecting useful signal samples, as well as reception failures (e.g., in distributed radar architecture), can determine **the lack of some observations**
- Therefore, missing sensor measurements can arise in a variety of radar signal processing problems, for instance, beamforming, direction of arrival estimation, interference cancellation, covariance estimation, and target detection
- This demands the development of specific **procedures** in order **to keep contained the loss** with respect to the benchmark case where measurements are available from all the sensors

PhD thesis

Main contributions

- Provide a general method to obtain a more **robust estimate** of the noise covariance matrix in the presence of missing data…
- …possibly exploiting some a-priori knowledge about the operating environment
  - Theoretical results presented with reference to **two radar applications**: adaptive beamforming and detection of the number of sources
  - Investigation of the **convergence properties** of the resulting iterative procedure as well as the computation of the rate of convergence
  - Extensive numerical results to show the effectiveness of the bespoke estimation strategies to handle missing-data scenarios
- Design of **adaptive detection architectures**, based on the GLRT criterion, capable of operating in the presence of missing-data
  - Joint **ML estimation** of the complex target echo parameters and the interference covariance matrix in a scenario with missing-data
  - **Performance evaluation** of the devised detectors in terms of probability of detection (PD) versus the signal-to-interference-plus-noise (SINR)

Thanks for the kind attention!