PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Massimo Rosamilia

Cycle: XXXV

Training and Research Activities Report

Academic year: 2020-21 - PhD Year: Second

Tutor: prof. Antonio De Maio

Date: October 21, 2021

1. Information:

- **PhD student: Massimo Rosamilia** **PhD Cycle: XXXV**
- **DR number: 993897**
- **Date of birth: 26/03/1994**
- **Master Science degree: Computer Engineering** **University: University of Salerno**
- **Scholarship type: UNINA**
- **Tutor: Prof. Antonio De Maio**
- **Co-tutor:**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Science, Reality and Credibility. Il ruolo del pensiero scientifico per contrastare la disinformazione e affrontare le grandi sfide del future	Seminar	1.5	0.3	24/11/2020	Fondazione Idis-Città della Scienza	N
AI4NETS – AI/ML for data communication Networks	Seminar	3	0.6	02/11/2020	Prof. Marco Mellia	Y
How to get published with the IEEE	Seminar	1.5	0.3	02/12/2020	Eszter Lukacs	Y
Subclonal reconstruction of tumor architectures by using machine learning and population genetics	Seminar	1.5	0.3	11/12/2020	Prof. Michele Ceccarelli	Y
1st International Virtual School on Radar Signal Processing (10 hours of lectures)	Seminar	10	2	22/12/20 - 23/12/20	University of Electronic Science and Technology of China (UESTC)	Y
Submission of the journal paper L.Lan, M. Rosamilia, A. Aubry, and A. De Maio, “Single-Snapshot Angle and Incremental Range Estimation for FDA-	Research		9	1/11/2020 – 31/122020		

MIMO Radar" to IEEE Transactions on Aerospace and Electronic Systems Preparation of the journal paper "Structured Covariance Matrix Estimation with Missing Data via Expectation–Maximization Algorithm" Submission of a clear and polished summary of the study and presentation of the work "*Simultaneous Radar Detection and Constrained Target Angle Estimation via Dinkelbach Algorithm*" to the student contest of The 1st International Virtual School on Radar Signal Processing.						
Msc course - Sistemi Radar	Courses	72	9	01/10/2020 – 18/12/2020	Prof. Antonio De Maio - DIETI	Y
Msc course - Radiolocalizzazione Terrestre e Satellitare	Courses	72	9	29/09/2020 – 18/12/2020	Prof. Augusto Aubry - DIETI	Y
From Photometric Redshifts to Improved Weather Forecasts an interdisciplinary view on machine learning	Seminar	1	0.2	13/01/2021	Kai Polsterer	Y
Tensor Completion from Regular Sub-Nyquist Samples	Seminar	1	0.2	20/01/2021	IEEE - Nikolaos D. Sidiropoulos and Charilaos I. Kanatsoulis	Y
AI: Artificial Intelligence for notary's sector - a case study	Seminar	1	0.2	21/01/2021	Salvatore Palange	Y

Advances in Machine Learning for Modelling and Understanding in Earth Sciences	Seminar	1	0.2	27/01/2021	IEEE Geoscience and Remote Sensing South Italy Chapter – Gustau Camps-Valls	N
Machine learning: Causality lost in translation	Seminar	1.5	0.3	10/02/2021	Edwin A. Valentijn	Y
Approaches to Graph Machine Learning	Seminar	1	0.2	17/02/2021	Miroslav Cepek	Y
Submission of the journal paper A. Aubry, A. De Maio, S. Marano, and M. Rosamilia, “Structured Covariance Matrix Estimation with Missing-Data for Radar Applications via Expectation–Maximization” to IEEE Transactions on Signal Processing	Research		9	1/01/2021-28/02/2021		
Cooperative and Non Cooperative Localization Systems	Courses	12	3	22/03/2021 - 09/04/2021	Proff. Antonio De Maio, Augusto Aubry, Dr. Vincenzo Carotenuto – DIETI	Y
Visual Interaction and Communication in Data Science	Seminar	2	0.4	03/03/2021	Dott. Marco Quartulli	Y
Robo Ludens: A game design taxonomy for human-robot interaction	Seminar	1	0.2	05/03/2021	Dr. John Edison Muñoz Cardona	Y
Dai mainframe all’IoT: una retrospettiva sull’evoluzione delle architetture di calcolo	Seminar	2	0.4	08/03/2021	prof. Antonino Mazzeo	N
Towards Neural Signal Processing and Imaging	Seminar	1	0.2	09/03/2021	Dr. Gordon Wetzstein - Signal Processing	N

					And Computational Image formation	
Big data and Computational Linguistics	Seminar	2	0.4	10/03/2021	Prof. Francesco Cutugno	Y
6G: A New Frontier for the Design of NOMA	Seminar	1	0.2	15/03/2021	SPS Webinars	Y
Sensoria Health	Seminar	1	0.2	17/03/2021	Dr. Stefano Rossotti	Y
CFAR Techniques for Radar Detection	Seminar	1	0.2	06/04/2021	Dr. Antonio De Maio - 2021 IEEE AESS Virtual Distinguished Lecturer Webinar Series!	Y
The Role of Multitarget Tracking Radar in Surveillance Systems	Seminar	1	0.2	08/04/2021	Dr. Alfonso Farina - 2021 IEEE AESS Virtual Distinguished Lecturer Webinar Series!	Y
Submission of the conference paper M. Rosamilia, A. Aubry, V. Carotenuto, and A. De Maio, "Experimental Analysis of Structured Covariance Estimators with Missing data" to the 2021 IEEE International Workshop On Metrology For Aerospace. Submission of the conference paper A. Aubry, A. De Maio, and M. Rosamilia, "RIS-Aided Radar Sensing in	Research		9	1/03/2021 – 30/04/2021		

N-LOS Environment" to the 2021 IEEE International Workshop On Metrology For Aerospace. Submission of the journal paper A. Aubry, A. De Maio, and M. Rosamilia, "Reconfigurable Intelligent Surfaces for N-LOS Radar Surveillance" to the IEEE Transactions on Vehicular Technology.						
Advanced Topics in Radar Signal Processing	Seminar	8	1.6	18-19-25-26/05/2021	Dr. Alfonso Farina	Y
Submission of the journal paper A. Aubry, V. Carotenuto, A. De Maio, M. Rosamilia, and S. Marano "Adaptive Radar Detection in the Presence of Missing-Data" to IEEE Transactions on Aerospace and Electronic Systems. Presentation of the paper M. Rosamilia, A. Aubry, V. Carotenuto, and A. De Maio, "Experimental Analysis of Structured Covariance Estimators with Missing data" to 2021 IEEE International Workshop On Metrology For Aerospace. Presentation of the	Research		8	01/05/2021 – 30/06/2021		

paper A. Aubry, A. De Maio, and M. Rosamilia, “RIS-Aided Radar Sensing in N-LOS Environment” to 2021 IEEE International Workshop On Metrology For Aerospace. Preparation of the paper L. Lan, M. Rosamilia, A. Aubry, and A. De Maio, “Parameter Estimation for polarimetric FDA-MIMO”						
L’esposizione ai campi elettromagnetici generati dal sistema 5G - Metodologie scalari e vettoriali di misura dell'esposizione e tecniche di estrapolazione	Seminar	4	0.8	16/07/2021	Prof. N. Pasquino	Y
Submission of the conference paper M. Rosamilia, L. Lan, A. Aubry, A. De Maio, J. Xu, and G. Liao, “Adaptive Monopulse Based Estimation in FDA-MIMO radar” to 2021 CIE International Conference on Radar (Radar 2021) Preparation of the paper L. Lan, M. Rosamilia, A. Aubry, and A. De Maio, “Polarimetric FDA-MIMO Radar: Detection and Estimation Issues”	Research		4	01/07/2021 – 31/08/2021		
RCS measurements of drones Preparation of the	Research		6	01/09/2021 – 31/10/2021		

conference paper M. Rosamilia, L. Lan, A. Aubry, and A. De Maio, “Polarimetric FDA-MIMO Radar Detection” Preparation of the paper L. Lan, M. Rosamilia, A. Aubry, and A. De Maio, “Polarimetric FDA-MIMO Radar: Detection and Estimation Issues”						

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	3.5	9	0	12.5
Bimonth 2	18	1.3	9	0	28.3
Bimonth 3	3	2.4	9	0	14.4
Bimonth 4	0	1.6	8	0	9.6
Bimonth 5	0	0.8	4	0	4.8
Bimonth 6	0	0	6	0	6
Total	21	9.6	45	0	75.6
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

3. Research activity:

a) Parameter Estimation for FDA-MIMO Radar

TOPIC

Estimation of target parameters is an enduring signal processing problem that has always raised persistent attention within the radar scientific community. The emergence of new threats call for stressing and stressing radar performance requirements as well as the development of advanced algorithms capable of providing reliable estimates of the target position, even at the expense of an increased computational complexity. It is worth pointing out that in a classic phased array radar system the beampattern is dependent only on the angular direction but it is not selective in the range domain. As a consequence, the range information is not directly embedded in the beamforming process. To overcome this drawback, a novel beam scanning array, referred to as frequency diverse array (FDA), has been proposed. Specifically, employing a small frequency increment across adjacent array elements, the FDA induces discrimination in both the angle and range domain. Once adequately exploited, it can allow to glean jointly range and angle information. Furthermore, FDA can be successfully twisted with a multiple-input multiple-output (MIMO) architecture leading to a FDA-MIMO radar. In literature, some techniques have been proposed to both estimate angle and range with FDA-MIMO, with the drawback of requiring a large number of snapshots. Despite its key role in many practical high-precision applications, the estimation of the incremental range (target displacement with respect to the center of the occupied range cell) has only received a limited attention.

Therefore, in this second PhD year, we investigated the problem of joint target angle and incremental range estimation using a FDA-MIMO radar in a background of Gaussian interference with known spectral properties.

METHODOLOGY

At the design stage, the target parameters, i.e., angle, incremental range, and echo-amplitude, are assumed unknown. Under the aforementioned setup, the estimation problem is formulated starting from a single data snapshot. Then the ML estimator is derived maximizing the likelihood function with respect to (w.r.t.) the unknown parameters.

At the analysis stage, CRBs for the angle and incremental range estimation via a FDA-MIMO radar are derived. The root mean square errors (RMSEs) of the estimates versus the input signal-to-interference-plus-noise ratio (SINR) are provided. Besides, an extensive bias and variance analysis is developed to show the effectiveness of the considered approximated estimation methods (including tapered and doublestep versions of the monopulse procedures).

RESULTS

Three adaptive estimators, with lower computational complexity than the 2-D search procedure required by the ML estimator, have been devised. Firstly, the coordinate descent algorithm has been perused, which reduces the 2-D search to a sequence of 1-D searches alternating between the optimization over each variable keeping the others constant. Then, the adaptive monopulse procedure has been considered, which is based on a reduced complexity approach than the 1-D searches involved in the coordinate descent algorithm. Finally, a more general method, i.e., adaptive generalized monopulse procedure has been developed with a complex slope and bias correction.

The results (for both white and colored interference) have pinpointed the effectiveness of the devised estimators to reliably estimate the angle and incremental range of the target in all the considered case studies. In particular, the CD method achieves a performance level very close to the theoretical CRBs when the SINR is sufficiently high.

Possible future research studies include the design of novel estimators exploiting other approximation approaches and accounting for the presence of some specific jammer or clutter scenarios. Analysis on real FDA-MIMO radar data is definitely another research topic of primary concern.

b) Structured Covariance Matrix Estimation with Missing Data via Expectation-Maximization Algorithm

TOPIC

In the last decades, phased array radar have become a standard in many radar applications. However, intermittent sensors failure can occur either in the form of impulsive noise burst in the received signal of failed sensors or intermittent failure - malfunctions of the ADC. A failure modes effects and criticality analysis (FMECA) on system level faults also reported cases of intermittent faults, probably caused by material-interaction (i.e., package moulding contamination, surface-state effects, etc.), stress (i.e., burnout, electro-migration, etc.), mechanical (i.e., solder joint failure, die fracture, etc.) and environmental induced (i.e., temperature, humidity and hydrogen effects).

As a consequence, in the presence of intermittent sensors failures, the sample covariance is no longer the maximum likelihood (ML) estimate of the spectral matrix. Therefore, many radar applications, i.e., robust beamforming, detection of number of sources, etc., must rely on a more robust estimation procedure, such as the Expectation-Maximization (EM) framework.

METHODOLOGY

In the presence of missing data, the constrained maximum likelihood (ML) estimation of the noise covariance matrix is, in general, a difficult problem to solve for which no analytic closed-form solution is known. In this regard, the Expectation-Maximization (EM) framework is able to provide a sub-optimal solution to the problem at hand, approximately computing ML estimates by directly maximizing the likelihood function of observed data. It is also worth pointing out that the algorithm can easily be tailored to any constraint on the structure of the covariance matrix.

The aim of this research work, conducted in this second year of the PhD, is to provide a general method to obtain a more robust estimate of the noise covariance matrix in the presence of missing data, exploiting some a-priori knowledge about the operating environment.

RESULTS

The theoretical results are capitalized for some specific structural covariance models with reference to two radar applications: adaptive beamforming and detection of the number of sources. General procedures are suggested to construct adaptive beamformers and to detect the number of active sources in a collection of snapshots when missing observations are present. At the analysis stage, extensive numerical results have been discussed to show the effectiveness of the bespoke strategies to handle missing-data scenarios. In conclusion, the main contributions of the paper can be summarized as followed:

a) the development of an EM-based technique for the estimation of a structured covariance matrix in the presence of missing-data;

b) the study of the convergence properties for the resulting iterative procedure according to B-stationarity as well as the computation of the rate of convergence;

c) the application of the methodology in the context of two fundamental radar problems: beamforming and detection of the number of sources;

d) the presentation of numerical results aimed at corroborating the theoretical achievements.

Moreover, a practical validation of the derived estimation technique has been carried on using snapshots from a four-channel receiver operating in a controlled electromagnetic environment. Performance results quantifying adaptive beamforming capabilities and spatial spectrum estimation quality have been illustrated and discussed. They corroborate the capability of the procedure to deal with missing data, providing a performance level very close to the ideal benchmark processor assuming the availability of the complete dataset. Besides, the conclusions are also consistent with those obtained via simulated data.

Possible future research avenues might include the assessment of the framework under different covariance structures, as well as a careful study on electronic protection techniques when some array elements (or sub-array) of the radar antenna are put in saturation by a strong interference source and, as a consequence, the data can be modeled as missing.

c) Adaptive Radar Detection in the Presence of Missing-Data

TOPIC

Adaptive radar detection has long been a popular and widely discussed topic in signal processing. Significant efforts have been made in the last decades to conceive practical detectors for point-like targets embedded in additive Gaussian interference (due to for instance thermal noise plus clutter and/or jammers) with unknown spectral properties. Most of the devised procedures have been designed under the ideal conditions that all the data at the output of the multi-channel sensor array would be available. Nevertheless, in practical radar systems, measurement errors due to acquisition equipment, random sensor failure caused by impulsive noises, 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. It becomes mandatory to address the design of adaptive detection architectures capable of operating is such non-ideal conditions accounting, at the synthesis stage, for the presence of missing-data.

METHODOLOGY

In this 2nd PhD year, we faced the problem of detecting a prospective target embedded in Gaussian interference with unknown (but possibly structured) covariance matrix in a context with missing-data. It is assumed the existence of a secondary data set, i.e., returns free of useful target echoes gathered from range cells spatially adjacent to that under test. The detection problem is formulated as a composite hypothesis test characterized by different unknowns under the two hypotheses. Since a uniformly most powerful (UMP) test does not exist for the aforementioned testing problem, the suboptimal generalized likelihood ratio test (GLRT) architecture, is designed. Besides, a variation of the conventional GLRT, known as the two-step GLRT, is also derived. The devised detectors demand the optimization of appropriate observed-data likelihood functions over the unknowns (under one or both the hypotheses), for which closed-form solutions could not exist. To this end, we resort on the expectation-maximization

(EM)-based iterative covariance estimator derived in the previous paper, which is also capable of managing diverse covariance structures. On the other hand, the alternative hypothesis (with reference to the GLRT receiver) involves the joint ML estimation of the complex target echo parameter and the covariance matrix. To handle this challenging task, an EM-based framework is proposed to determine optimized solutions, with some quality guarantees, to the maximization problem at hand.

RESULTS

At the analysis stage, the performance of the devised detectors is assessed in terms of probability of detection (PD) versus the signal-to-interference-plus-noise (SINR) ratio on both simulated and measured data. This last evaluation is critical for validating the robustness of the proposed detection strategies on real data including potential mismatches (due to hardware imperfections) that are not taken into account at the design stage. For comparison purposes, two counterpart detectors are considered. The former is a benchmark that assumes direct access to the complete-data set, whereas the latter replaces the missing values via linear interpolation.

The results have highlighted the potentialities of the proposed detectors showing a performance level comparable to the benchmarks, which assume access to the entire set of observables. Besides, the effectiveness of the detectors has been validated on measured data, collected in a controlled environment using an inexpensive four-channel receiver.

Future research studies might concern the extension of the framework to the case of distributed (range-spread) targets, the inclusion of other relevant covariance structures as well as the generalization of the devised architectures to the partially homogeneous and heterogeneous environment scenarios. Finally, it would be of great interest to consider the case of a multistatic radar where the different sensors observe the same scene but the missing data are diverse from sensor to sensor.

d) Reconfigurable Intelligent Surfaces for N-LOS Radar Surveillance

TOPIC

Reconfigurable Intelligent Surfaces (RISs) (also known in the open literature as intelligent reflecting surfaces, smart reflectarrays, large intelligent surfaces, metasurfaces, and so on) are a novel and promising technology which is receiving growing interest in recent years especially for next generation communication (e.g., beyond 5G and future 6G) and sensing systems. RISs are man-made digitally controllable meta-surfaces, composed of a very large number of low-cost passive programmable integrated electronic circuits, capable of varying the electric field distribution of the impinging signals, i.e., phase, amplitude, frequency, and polarization features, via appropriate electronic controls. Therefore, they pave the way to the "lifelong dream" of eliminating the Radio Frequency (RF) propagation medium randomness and avoiding the resulting deleterious effects, by means of a wisely designed electromagnetic waves interaction. Otherwise stated, they lay the ground to the paradigm of smart radio environments.

METHODOLOGY

In this second PhD year, we have explored the use of RIS technology to extend the coverage of a standard radar system whereby the direct LOS from a prospective target is missing. The basic idea is to place one or more RISs in suitable positions (fixed or possibly deployable on request together with a portable radar) within the operating environment such that there is always a direct path between the radar and each RIS. Besides, in each shadow region (where the direct radar-target path is absent), there is at least a RIS with a LOS toward the target. Thus, the region under test is scanned according to two different radar operative modes. The former is for the search in areas with a direct path radar-target and is nothing more than a classic radar modality. The latter, designed for operation in N-LOS areas, is based on the formation of a smart and controlled propagation environment where the radar focuses the radiation on a specific RIS. The RIS parameters are suitably set to perform scanning within its area of competence. Hence, after target backscattering and another programmed reflection of the RIS to the radar, a two-way double-hop channel is established which allows to accomplish the surveillance task. Alternation between the operative modes ensures the coverage of the entire region of interest.

RESULTS

The use of RIS technology to address radar surveillance in N-LOS conditions demanded the development of new sensing mode via the formation of an artificial and favorable propagation environment established via the modulation of RIS parameters. For this operational regime the radar equation is laid down accounting for the artificially induced two-way and double-hop channel as well as the effects of the reflecting surface. Expressions for SNR and SCR (both for surface and volume clutter) are determined. Besides, the data acquisition procedure for N-LOS operation is discussed together with the resolution issues in the range, angle, and Doppler domains. A numerical analysis is carried on in terms of SNR, detection performance, and SNR loss with respect to a LOS monostatic geometry. The impact of the RIS size and system parameters is assessed corroborating the theoretical capability of the new framework to handle N-LOS short-range scenarios.

As future development, it is of interest to consider the joint use of natural multipath and the artificial (ad-hoc) multipath determined by the RIS to boost the performance of the "around the corner radar". Besides, RIS can also represent key elements for the cognitive radar architecture, i.e., another level of flexibility which can be adapted based on the perception-action cycle. In other words, by leveraging perception outputs, the radar can change the RIS parameters establishing a favorable propagation/sensing scenario via specific target-clutter illuminations both in terms of beam steering (size and direction) and polarization of the electromagnetic wave. Finally, the definition of RIS reflection coefficients selection strategies endowing robustness to the RIS-assisted radar with respect to unavoidable surface imperfections is, without doubt, a future research avenue worth of investigation.

4. Research products

Journal papers:

- 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. Indexed in both Scopus and ISI Web of Science.
- 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. Indexed in both Scopus and ISI Web of Science.
- A. Aubry, A. De Maio, S. Marano, and M. Rosamilia, "*Structured Covariance Matrix Estimation with Missing-(complex) Data for Radar Applications via Expectation-Maximization*," in IEEE Transactions on Signal Processing, IEEE TSP, published, 2021. Indexed in both Scopus and ISI Web of Science.
- A. Aubry, V. Carotenuto, A. De Maio, M. Rosamilia, and S. Marano," *Adaptive Radar Detection in the Presence of Missing-Data*," in IEEE Transactions on Aerospace and Electronic Systems, IEEE TAES, submitted. Indexed in both Scopus and ISI Web of Science.

Conference papers:

- 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. Indexed in both Scopus and ISI Web of Science.
- 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. Indexed in both Scopus and ISI Web of Science.
- M. Rosamilia, L. Lan, A. Aubry, A. De Maio, J. Xu, and G. Liao, "*Adaptive Monopulse Based Estimation in FDA-MIMO radar*", 2021 CIE International Conference on Radar (Radar 2021), submitted. Indexed in both Scopus and ISI Web of Science.

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

5. Conferences and seminars attended

2020 1st International Virtual School on Radar Signal Processing, IVSRSP, December 22-23, 2020 (1 paper presented)

2021 IEEE 8th International Workshop on Metrology for AeroSpace (MetroAeroSpace), Naples, June 22-25, 2021 (2 papers presented).

6. Periods abroad and/or in international research institutions

Description and activity carried out: Measurements of target (drones) RCS

Research period: 23 September 2021 - 05 November 2021

Hosting institution: Cranfield University, Shrivenham, SN6 8LA, United Kingdom

Supervisor: Dr Alessio Balleri

Framework: Visiting research student in Defence and Security

Total months spent abroad: 1.5

7. Tutorship

8. Plan for year three

Research activities: Adaptive radar detection with a polarimetric Frequency Diverse Array Multiple-Input Multiple-Output (FDA-MIMO) radar. RCS measurements of drones (experiment).

Research periods abroad: From February to April in Netherlands Organisation for Applied Scientific Research (TNO), Delft, Netherlands.

Draft topic or title of the thesis: Design of advanced algorithms for radar detection and target parameters estimation.