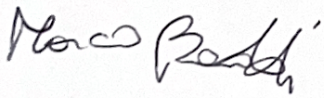
PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Marco Boddi

Cycle: XXXVII

Training and Research Activities Report

Year: First



Tutor: prof. Antonio De Maio

Date: October 31, 2022

1. Information:

- **PhD student: Marco Boddi**
- **DR number: 995996**
- **Date of birth: 03/04/1984**
- **Master Science degree: Telecommunications Engineering, University of Pise**
- **Doctoral Cycle: XXXVII**
- **Scholarship type: ad-hoc agreement between UniNa and the Presidency of the Council of Ministers**
- **Tutor: Prof. A. De Maio**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Software Defined Radio Applications for Radar and Localization Systems	Course	12	2	22, 23, 24, 25, 26, 29, 30 / 11 / 2021	UniNa / DIETI, lecturers: De Maio, Aubry, Carotenuto	Y
Study of the book “Detection, Estimation, and Modulation Theory. Part IV: Optimum Array Processing” (Van Trees). Study of the paper “Eigenstructure Techniques for 2-D Angle Estimation with Uniform Circular Arrays” (Mathews, Zoltowski).	Research		3	Nov-Dec. 2021		N
Radar Systems	Course	72	9	Nov.-Dec. 2021, exam taken on 18 / 02 / 2022	UniNa / DIETI, lecturer: De Maio	Y

Numerical methods and simulations for electromagnetic fields	Course	35	9	24 – 28 / 01 / 2022	Free Space S.r.l. / University of Pise, lecturer: Monorchio, Corucci	To be released
Intelligenza artificiale e sistema d'arma autonomi	Seminar	2	0.4	19 / 01 / 2022	CNR - Area della Ricerca di Pisa, lecturers Giannotti, Tamburrini	To be released
Matrix Analysis for Signal Processing with MATLAB Examples	Course	8	2	22, 23 / 03 / 2002, 5, 6, 7 / 04 / 2022 Exam taken on 26 / 04 / 2022	UniNa / DIETI, lecturers De Maio, Aubry, Carotenuto	Y
5G, Cloud and xHaul technologies	Seminar	35	7	14, 21, 24 / 03 / 2022, 4 - 7 / 04 / 2022	CNIT - Consorzio Nazionale Interuniversitario Telecomunicazioni / University of Rome Tor Vergata, lecturer Detti	Y
IEEE Authorship and Open Access Symposium: Tips and Best Practices to Get Published from IEEE	Seminar	3	0.3	30 / 03 / 2022	IEEE – the Institute of Electrical and Electronics Engineers, lecturers D.Abbott, P.Donato	Y

Study of the book "Classical and modern Direction-of-Arrival Estimation" (Tuncer, Friedlander). Review of algorithms and testing of Matlab software code for Direction of-Arrival estimation, front-backward averaging techniques and Akaike Information Criterion for model order selection.	Research		3	Mar.-Apr. 2022		N
"Electronic attack and antenna based countermeasures", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	15 / 06 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer De Maio	To be released at the end of the 2022 Lecturer Series
Study of the following papers and computer simulations with the methods therein suggested: • "Direction finding of coherent signals via spatial smoothing for uniform circular arrays" (Wax, Sheinvald). • "Analysis of spatial smoothing with uniform circular arrays" (Maheswara Reddy, Reddy) • "One- and two-dimensional direction-of-arrival estimation: An overview of search-free techniques" (Gershman, Rubsamen) • "An adaptive array utilizing an adaptive	Research		3	May-Jun. 2022		N

spatial averaging technique for multipath environments" (Takao, Kikuma)						
"Bayesian Quantum Mechanics", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	13 / 07 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Daum	To be released at the end of the 2022 Lecturer Series
"An Introduction to Non-linear State Estimation and Target Tracking Based on Tensor Decompositions", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	27 / 07 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Govaers	To be released at the end of the 2022 Lecturer Series
"Information Transfer Across Adjacent Cameras in a Network", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	09 / 08 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Y.Bar-Shalom	To be released at the end of the 2022 Lecturer Series
"Distributed Detection and Data Fusion", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	23 / 08 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Willett	To be released at the end of the 2022 Lecturer Series
Study of the following papers: • "A Clustering Approach for Jamming Environment Classification" (Carotenuto, De Maio);	Research		0.2	Jul.-Aug. 2022		N

• "Expert System CFAR: Algorithm Development, Experimental Demonstration, and Transition to Airborne Radar Systems" (Wicks, Baldygo); • US Patent "Expert system constant false alarm rate (CFAR) Processor" (Wicks, Baldygo, Brown); • "Frequency diverse array radars" (Antonik, Wicks, Griffiths; Baker); • "The retrieval of harmonics by linear prediction", (Pisarenko). Software modelling and simulations for clustering solutions to radar jamming classification problems.						
Machine Learning for Science and Engineering Research*	Course	20	**5***	20, 21, 22, 23, 24, 27, 28, 29, 30 / 06 / 2022 – 01 / 07 / 2022 Exam taken on 27 / 10 / 2022	Dieti / UniNa, lecturers Corazza, Isgrò, Prevete, Sansone, Pezzulo	*To be released
"Tracking Maneuvering Targets in a World of Netted Sensors", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	07 / 09 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Blair	To be released at the end of the 2022 Lecturer Series

"Dual-Function Radar Communication System With Communication and Radar Performance Tradeoff", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	05 / 10 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Petropulu	To be released at the end of the 2022 Lecturer Series
"Radar Tomographic Imaging – Achieving High Resolution With Spatial Diversity", from the 2022 Radar Virtual Distinguished Lecturer Series	Seminar	1	0.2	19 / 10 / 2022	IEEE AESS (Aerospace and Electronic Systems Society), lecturer Sun	To be released at the end of the 2022 Lecturer Series
Study of the following papers: • "Model Order Selection Rules for Covariance Structure Classification in Radar" (Carotenuto, De Maio, Orlando, Stoica); • "Model Order Selection – A review of information criterion rules" (Stoica, Selén); • "Detection of Signals by Information Theoretic Criteria" (Wax, Kailath); • "Detection of Number of Sources via Exploitation of Centro Symmetry Property" (Xu, Roy, Kailath) Software modelling and simulations for testing model order selection criteria in direction finding problems.	Research			Sep.-Oct. 2022		N

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

*** Course completed and exam taken. Exam results not yet announced at the time of the TRAR submission.**

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	3	0	2	0	5
Bimonth 2	18	0.4	0	0	18.4
Bimonth 3	2	7.3	3	0	12.3
Bimonth 4	0	0.2	3	0	3.2
Bimonth 5	0	0.8	3	0	3.8
Bimonth 6	5*	0.6	2	0	7.6*
Total	28*	9.3	13	0	50.3*
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

*** Included 5 credits for the course "Machine Learning for Science and Engineering Research": course completed and exam taken, exam results not yet announced at the time of the TRAR submission.**

3. Research activity:

Novel algorithms for the Direction-of-Arrival (DoA) estimation in radar and communication problems

TOPIC

The main research topic for this PhD program is represented by the **estimation of the Direction-of-Arrival (DoA) of radio waves**, specifically in non-cooperative environments and when no or little information is available at a radio receiver about the incoming signals. In these conditions the task typically relies on **array processing**, through the observation of the signal samples obtained at each antenna element. Such an estimate can be important on its own (for instance in direction finding applications, whose ultimate goal is to support the localization of an emitter) or be a part of a more general process aimed at optimizing reception in communication systems and detection and tracking performances in radars.

Although this topic has a long history of research and relevant technological solutions, renewed interest and new trends have emerged in recent years, made possible by the diffusion of multi-channel **Software-Defined-Radios (SDR)** and by the development of **novel DoA estimation algorithms**. As for the latter, the effort of the research community is currently focused on the design of techniques (the majority belonging to the so-called family of **subspace fitting methods**) that can approach the statistical performances of the most complete parametric estimators, while maintaining a reduced computational complexity close to that of conventional spectral-based methods.

The PhD research activity has thus the objective of refining and optimizing some of these novel estimation methods, in the following potential directions:

- extension of their theoretical framework in order to cope with multiple dimensions and unknowns (azimuth, angle, frequency, range, polarization, etc.);
- tailoring of the models for radio and radar applications of specific interest (e.g. direction finding in the HF spectrum);
- implementation through suitable commercial-grade SDR architectures.

METHODOLOGY

Most of the first year has been invested on the study of the large framework of technical literature related to the DoA estimation problem and other associated topics, such as:

- optimum array processing and beamforming;
- spectral-based (subspace and beamforming) estimators;
- parametric DoA estimators;
- model order selection criteria;
- new subspace-fitting and iterative methods;
- matrix analysis techniques and solving methods under matrix-sparsity representation conditions.

On this basis and with the objectives set forth above, the following methodology can be devised for the near future research activity:

- extend the theoretical framework of subspace fitting models and sparse matrix methodologies (starting from recent techniques such as SLIM, B-SLIM, etc.) to jointly deal with additional multiple dimensions of interest (range, azimuth, elevation, frequency, polarization, etc.);
- adapt the theoretical models to real-world radar and communication environments, and assess the feasibility and understand limits of a sparse representation of these scenarios;
- explore different array geometries in order to enforce, directly or through convenient transformations, favorable structures of the spatial spectrum and the related matrices emerging in the mathematical description of the problem (e.g. Vandermonde, Toeplitz, centro-Hermitian, etc.);
- assess performances through computer-based Monte-Carlo simulations;
- derive theoretical bounds for performances;
- compare (simulated or analytically derived) performances with known benchmarks (Maximum Likelihood estimators);
- implement algorithms on SDR platforms and test through on-field measurements.

RESULTS

Beyond achieving a deep understanding of the state-of-the-art and open points in the DoA estimation topic, the study and research activity performed during the first year (together with initial computer simulations and tests with algorithms) has provided the following guidelines and intermediate results useful to steer the future path:

- identified subspace fitting methods in general and SLIM and B-SLIM as suitable candidates for the DoA estimation under the constraints and objectives of interest (reduced complexity and cost, high statical efficiency);
- identified some room for improvement in conventional algorithms for joint azimuth and elevation estimation (for instance, in UCA (Uniform Circular Array) – ESPRIT method,

whose standard formulation suffers from errors in the elevation estimation in presence of noisy measurements);
- suggested the recourse to a multi-layer processing and estimation architecture, with consolidated spectral methods providing the baseline estimation, suitable for the general cases, and a second layer with iterative and subspace fitting methods, when super-resolution is needed or correlated signals exist.

4. Research products:

None

5. Conferences and seminars attended

- 2022 Radar Virtual Distinguished Lecturers Series, attended on line, arranged by IEEE (Institute of Electrical and Electronics Engineers) AESS (Aerospace and Electronic Systems Society), with the following seminars:
  - "Electronic Attack and Antenna Based Countermeasures", lecturer Prof. A. De Maio, 15/06/2022;
  - "Bayesian Quantum Mechanics", lecturer Dr. F. E. Daum, 13/07/2022;
  - "An Introduction to Non-linear State Estimation and Target Tracking Based on Tensor Decompositions", lecturer Dr. F. Govaers, 27/07/2022;
  - "Information Transfer Across Adjacent Cameras in a Network", lecturer Prof. Y. Bar-Shalom, 09/08/2022;
  - "Distributed Detection and Data Fusion", lecturer Prof. P. K. Willett, 23/08/2022;
  - "Tracking Maneuvering Targets in a World of Netted Sensors", lecturer W. D. Blair, 07/09/2022;
  - "Dual-Function Radar Communication System With Communication and Radar Performance Tradeoff", lecturer Prof. A. Petropulu, 05/10/2022;
  - "Radar Tomographic Imaging – Achieving High Resolution With Spatial Diversity", lecturer Dr. X. H. Sun, 19/10/2022.

6. Activity abroad:

None

7. Tutorship

None