NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Artificial Intelligence and Control Tools for Cognitive Satellite SAR Systems

Ph.D. candidate

Matteo SARTONI

Cycle

XXXVIII cycle

Tutors

Giuseppe Notarstefano

Andrea Pietropaolo

Carlo Ciancarelli

1. Description of the research program

Cognitive SAR systems, i.e. synthetic-aperture radars integrated with recent discoveries on human cognition, are a widely adopted technology in the Earth observation domain. Cognitive radars are based on the perception-action cycle of cognition, which sense the environment, learn from it information about both the target and the background, then adapt the radar sensors to optimally satisfy a desired goal.

The long term goal of this research project is to evaluate AI, control methods, optimization and signal processing techniques for SAR systems, aiming to optimize on-board data processing techniques. The topics that will be analyzed are:

- the increase of the level of adaptability and learning,
- the search for new ways to apply AI techniques to improve the decision-making quality,
- tasks state-space representation,
- on-board data processing for data reduction.

In order to solve the first two goals, different reinforcement learning techniques will be analyzed and tested, together with the principle of purposeful behavior of cognitive systems, a behavior oriented towards, or guided by, a goal.

SAR systems use tracking filters, whose output is defined by a posterior probability. The radar system can be made adaptive by adjusting some parameters in the transmitted signal, in response to the probabilistic decisions made by the bayesian tracker. In this way we can interpret the radar system as a stochastic control system, involving a state-space model governed by a posterior probability distribution. Therefore a research activity will be the formulation of the mathematical description of this model, to which optimal control techniques will be applied.

Lastly, different data processing techniques will be analyzed, such as on board Doppler filtering and Azimuth compression. The main goal is to reduce the amount of data to be sent to the ground stations. Thanks to this more data can be stored on-board and less ground stations are required, a processing and broadcasting facility at the ground station is not required as the satellite sends the end-product to Earth, and the image received by the ground station can be monitored and stored immediately.

The developed algorithms will be tested first on software like MATLAB and Simulink, and subsequently will be validated on physical devices like hardware with AI accelerators, since their computational speed comes in hand when running machine learning algorithms.

2. Schedule of the research activities

First academic year

	Description	Period	Activity abroad
Research on AI and optimization techniques	Study and analysis of the most used techniques in nonlinear optimization, reinforcement learning, gaussian mixtures. Study of the characteristics of a cognitive SAR system.	11/2022 - 02/2023	NO
Decision making improvement, increase of adaptability and learning	Application of the mentioned techniques to solve the perception-action cycle problem of cognitive SAR system and to increase the level of adaptability and learning.	03/2023 - 09/2023	NO

Second academic year

	Description	Period	Activity abroad
Research on filtering and optimal control techniques	Study and analysis of the state-of-the-art optimal control techniques and Kalman filtering.	10/2023 - 12/2023	NO
Tasks state-space representation	Application of the aforementioned techniques to define the tasks state-space representation.	01/2023 - 09/2024	NO

Third academic year

	Description	Period	Activity abroad
Research on data filtering techniques	Study and analysis of different data filtering and reduction techniques like on-board Doppler filtering and Azimuth compression.	05/2024 - 03/2025	NO
On-board data processing for data reduction	Application of the mentioned approaches to reduce the amount of data to be sent to ground stations.	04/2025 - 09/2025	YES

3. Training and research activities plan

First academic year

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Modeling, filtering and controlling aerospace systems	March-July 2023	Yes	2
	Numerical Methods for Big Data	To be defined	Yes	2
	Optimization and Control of Complex Systems	02/2023	Yes	2
	A system theoretical approach to the analysis of centralised and distributed algorithms for constrained and unconstrained optimisation	01-02/2023	Yes	1
	Extremum seeking	To be defined	Yes	1
	Duality-based decentralized and distributed optimization	June/July 2023	Yes	1
	Numerical Methods for Ordinary Differential Equations	To be defined	Yes	2
	Optimal control	To be defined	Yes	2
	SIDRA Summer School	July 2023	No	5
	Machine Learning	To be defined	Yes	2
B. Master's degree courses	-	-	-	-
C. Soft skill courses	-	-	-	-
D. Participation to seminars	-	-	-	-
E. Participation to international congresses or workshops	-	-	-	-
F. Presentation of research products at international	-	-	-	-

	congresses or workshops			
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			20
G. Individual research activity	Reinforcement learning techniques for cognitive SAR systems, decision making improvement and increase of level of adaptability and learning	11/2022 - 09/2023	No	35
H. Supervision of students	-	-	-	-
I. Integrative teaching activities	-	-	-	-
J. Preparation of manuscripts for conferences or journals	Publications on the researched topics	02/2023 - 09/2023	No	5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			40
	TOTAL OF ECTS			**60**

Second academic year

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Course(s) on Machine Learning (To be defined)	Autumn 2023	Yes	2
	Course(s) on control theory (To be defined)	Autumn 2023	Yes	3
	Course(s) on mathematical optimization (To be defined)	Spring 2024	Yes	2
B. Master's degree courses	-	-	-	-
C. Soft skill courses	-	-	-	-
D. Participation to seminars	-	-	-	-
E. Participation to international congresses or workshops	To be defined	Spring 2024	No	3
F. Presentation of research products at international congresses or workshops	To be defined	Spring 2024	No	2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			12
G. Individual research activity	Study on optimal control techniques and filtering for tasks state-space representation	Between 10/2023 - 09/2024	No	37
H. Supervision of students	To be defined	Between 10/2023 - 09/2024	No	3
I. Integrative teaching activities	To be defined	Between 10/2023 - 09/2024	No	3
J. Preparation of manuscripts for conferences or journals	Publications on the researched topics	Between 10/2023 - 09/2024	No	5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			48
	TOTAL OF ECTS			**60**

Third academic year

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	-	-	-	-
B. Master's degree courses	-	-	-	-
C. Soft skill courses	-	-	-	-
D. Participation to seminars	Seminar on control theory (To be defined)	Between 10/2024 - 09/2025	No	1.5
E. Participation to international congresses or workshops	To be defined	Between 10/2024 - 09/2025	No	5
F. Presentation of research products at international congresses or workshops	To be defined	Between 10/2024 - 09/2025	No	4
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			10.5
G. Individual research activity	Study on data filtering and data reduction techniques to reduce the amount of data to be sent to ground segments	Between 10/2024 - 09/2025	No	38.5
H. Supervision of students	To be defined	Between 10/2024 - 09/2025	No	3
I. Integrative teaching activities	To be defined	Between 10/2024 - 09/2025	No	3
J. Preparation of manuscripts for conferences or journals	Publications on the researched topics	Between 10/2024 - 09/2025	No	5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			49.5
	TOTAL OF ECTS			**60**

4. List of the publications written by the candidate in the triennium

No publications at the moment

Matteo Sartoni

Professor. Giuseppe Notarstefano

Dr. Andrea Pietropaolo

_____

Dr. Carlo Ciancarelli

_____