NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Advanced estimation methods via Kalman filters, resonator gyroscopes and machine learning

Ph.D. candidate

Giorgio MANCA

Cycle

XXXIX

Tutors

Prof. Mario SASSANO

Prof. Sergio GALEANI

1. Description of the research program

The fourth industrial revolution, characterized by the proliferation of automation systems, the Internet of Things (IoT), robotics, autonomous drones, and satellite swarms, necessitates precise and reliable position estimation of agents within these systems for safe and coordinated operations. This research program seeks to harness the potential of resonant gyroscopes and innovative inertial sensors in enhancing position estimation, since their proper usage promise to outclass more traditional sensors in terms accuracy and precision of the measurements.

However, the diffusion of this new family of devices is limited by conceptual and technological challenges concerning some control methods necessary for the operability of the measuring instrument and that defines the range of suitable operating conditions. Hence, the research's objective will have a dual focus.

Firstly, it aims to address the complexity of nonlinear, switching, and hybrid systems in both theoretical and practical aspects. This involves adapting existing tools, or creating new ones, to suit the specific context. Due to the inherent complexity of these systems and the limitations of current models, it is anticipated that Machine Learning (ML) and Artificial Intelligence (AI) methods will be crucial to enable, for example, systematic synthesis, autonomous calibration of control parameters, and context-specific optimization. Moreover, they can be extended to tackle the challenge of integrating data from diverse sensors for localization and navigation.

Secondly, the research program aims to study techniques related to the measurement filtering and estimation problem for sensor fusion and agents' localization. The purpose is to methodically revisit the use of the celebrated Kalman Filter and potentially improve its performance using ML/AI, establishing the groundwork for enhanced utilization across scientific and industrial sectors.

2. Schedule of the research activities

First academic year (planned)

	Description	**Period**	**Activity Abroad / At the Company**
Study of the functioning of resonant gyroscopes	Study of the basic physical phenomena that allow for an understanding of the functioning of resonant gyroscopes. The objective is to acquire the necessary knowledge to model the sensor dynamic.	November 2023 – April 2024	NO
Study and review of relevant literature	State of the art on control architectures and estimation methods for resonant gyroscopes. The main purpose is to detect the capabilities and the research opportunities offered by the considered sensor.	May 2023 – October 2024	NO

Second academic year (planned)

	Description	**Period**	**Activity Abroad / At the Company**
Design of control algorithms and sensor fusion strategies	Design and description of control algorithms from a mathematical point of view. The aim is to obtain acceptable performance that grants the operability of the measuring instrument in the widest possible range of operating conditions. Measurement estimation problems will be taken into consideration to simplify sensor integration within localization systems.	November 2024 – April 2025	YES, abroad (to be defined)

Implementation and simulation of designed control laws	Implement the designed control laws in a simulation environment to assess their performance and discover operational weakness/criticalities on all the relevant parts of the control architecture (the laws, the model, and the simulator itself).	May 2024 – October 2025	NO

Third academic year (planned)

	Description	**Period**	**Activity Abroad / At the Company**
Evaluation and refining of the proposed solutions	Deeper performance examination of the control architecture to highlight strengths and limitations of the proposed solution. A core activity will be the definition of optimization tools and strategies to tune the control parameters with respect to the sensor different use cases.	November 2025 – April 2026	YES, at the company (to be defined)
Deployment in a real-world context	Deploy and integration of the control architecture to verify its functioning and its performance in a real-world contest.	May 2025 – October 2026	NO

3. Training and research activities plan

First academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	Multi-agent and multi-object estimation (DAUSY COURSE)	16/02/2023 26/02/2023	YES	2
	Intelligent Control Systems (DAUSY COURSE)	10/01/2023 26/01/2023	YES	2
	Game Theory for Controlling Autonomous Systems (DAUSY COURSE)	18/06/2024 19/07/2024	YES	2
	Control of marine vehicles (DAUSY COURSE)	04/06/2024 27/06/2024	YES	3
	Data-driven fault diagnosis and fault prognosis (DAUSY COURSE)	19/06/2024 27/06/2024	YES	1
	Introduction to Optimal Linear Quadratic Control (DAUSY COURSE)	05/02/2024 22/02/2024	YES	2
	From Least Squares to Subspace Identification (DAUSY COURSE)	27/02/2024 08/03/2024	NO	2 → 1
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Participation to at least three seminars according to availability			9
E. Participation to international congresses or workshops	Participation to at least two workshops according to availability.			8
F. Presentation of research products at international congresses or workshops	Writing of conference/journal papers describing the obtained research results.			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			32

G. Individual research activity	Research activity in the topics of resonant gyroscopes and inertial sensor			20
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.			8
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			28
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses	Some courses to be defined according to the syllabus regarding academic year 2024/25		YES	6
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Participation to at least two seminars according to availability			6
E. Participation to international congresses or workshops	Participation to at least one workshops according to availability.			4
F. Presentation of research products at international congresses or workshops	Presentation of research products at one international congresses or workshops.			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			18
G. Individual research activity	Research activity in the topics of resonant gyroscopes and inertial sensor			28
H. Supervision of students	Some tutoring activity			6
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.			8
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			42
	TOTAL OF ECTS			**60**

Third academic year (planned)

	Description	**Period**	**Final Exam**	**ECTS**
A. Ph.D. courses				
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Participation to at least two seminars according to availability			3

E. Participation to international congresses or workshops	Participation to at least one workshop according to availability.			4
F. Presentation of research products at international congresses or workshops	Presentation of research products at international congresses or workshops			2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			9
G. Individual research activity	Research activity in the topics of resonant gyroscopes and inertial sensor. Writing of the PhD thesis.			37
H. Supervision of students	Some tutoring activity			6
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.			8
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			51
	TOTAL OF ECTS			**60**

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

International Journal Articles

International Conference Proceedings

Giorgio Manca

Giorgio Manca

Prof. Mario SASSANO

Mario Sassano

Prof. Sergio GALEANI

Sergio Galeani