



NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Advanced modeling and control of complex systems

Ph.D. candidate

Marco PERIN

Cycle

XXXVIII

Tutors

Angelo Cenedese

Luca Schenato

1. Description of the research program

The focus of the project is on robotic mobile platforms acting in unstructured and unknown environments both as independent platforms and as a single cooperative multi-agent system, to develop methodologies and strategies that can guarantee fail-safe operation in presence of failures and disturbances, allowing the fulfillment of complex tasks.

The fail-safe aspect would deal both with single-agent fail-safety, meaning a possible reduction of its actuation or manoeuvring capability, and with the whole formation fail-safety, meaning that in the case of agent failure, or even agent loss, the remainder of the formation must be able to deal with the scenario, and adapt accordingly. In particular, this study aims beyond the current state of the art that, for example in the case of a UAV multirotor platform, considers mainly the hovering/stabilization objective when dealing with the fail-safe study and does not account for maneuvering in unpaired conditions. The proposed research, indeed, would possibly enable performing homing or even trajectory tracking tasks, which would impose whole new challenges for agents with such limiting unmodeled constraints.

The complexity of the envisaged scenario appears in the considered platforms that, for the case of aerial robots, include generally tilted multirotors but also mobile robots with manipulators or other tactile sensors, leading on the one hand to a more complex dynamics and on the other to the need to devise contact-aware control strategies during the whole phase of the system-environment interaction.

On top of that, this interaction would have to account for the environment subject to possible changes, thus being strongly dynamic, and with the lack of prior knowledge of its mapping.

This would on the one hand expand the current studies on the topic in regard to the SLAM and SfM algorithms generalized to dynamic environments, while on the other it would drive the research on active sensing and or exploration/exploitation learning strategies.

Another related point of increasing interest in the research community is the energy-aware aspect, which generally trades off with the performance capabilities and can lead to more optimized controls able to cope with specific tasks.

All of these aspects would be studied by firstly considering a single-agent scenario, but most importantly it will be applied to a multi-agent formation, in order to maximize each agent's strengths and make possible to rapidly explore said environments. This would be applied, for example, by using switching formation control strategies with hierarchical control ones, using for example some agents as main nodes of the formation, functioning as coordinators for the others, enabling each smaller node to keep only local information, thus sparing effort and energy for their main task.

The whole formation would then be used by leveraging its whole combined computational power by efficiently distributing the computations, which would lead to less computational effort needed by the single agent and possibly offloading some of the calculations done by a central processing node.

This would be dealt with using parallel and distributed computation, exploiting the wireless interconnections among the agents in the formation, leading to novel approaches to the topic.

Another challenging aspect of the problem would be to break down the problem complexity by still being able to offload the heaviest computations to a processing unit, while keeping the actuation problem on board of the agent. This would lead to a control-by-wifi scenario, that poses its own problem to face with, for example real-time constraints that would be posed on the subject.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Literature review	Literature review on state of the art advanced control techniques, on fail-safety techniques and on distributed computation techniques	Nov 2022 - Jan 2023	NO
Supervision activity	Supervision of the Robotics Laboratory (20h) and Embedded Real-time control (20h) courses held at UniPD. My role will be in assisting the students during the laboratory sessions.	Jan 2023 - June 2023	NO
Research work	Individual research activity on the structural properties of robotic platforms and fail-safe robustness	Feb 2023 - Sept 2023	NO
Research work	Definition of simulation frameworks for preliminary validation and assessment of theoretical findings	Jan 2023 - June 2023	NO
Research work	Preparation and review of manuscripts	May 2023 - Sept 2023	NO
Research work	Summer school attendance	July 2023	NO

Second academic year (planned)

	Description	Period	Activity abroad
Supervision activity	Supervision of M.Sc. students' thesis projects	Oct 2023 - Sept 2024	YES/NO
Research work	Definition and study of novel frameworks for coordinate fail-safe maneuvering	Oct 2023 - Dec 2023	NO
Research work	Cooperative formation control for dynamic environments and evolution of mapping algorithms (at UCSB in collaboration with Professor Francesco Bullo).	Jan 2024 - Sept 2024	YES
Experimental activity	Design of experiments and laboratory activity in the SPARCS Lab (SPace Aerial and gRound Control Systems)	Oct 2023 - Dec 2023	NO
Research work	Preparation and review of manuscripts	Oct 2023 - Sept 2024	YES/NO
Research work	International conference and summer school attendance	Oct 2023 - Sept 2024	YES/NO

Third academic year (planned)

	Description	Period	Activity abroad
Research work	Individual research activity for the completion of the research program	Nov 2024 - May 2025	NO

	(methodologies for handling uncertain and complex scenarios)		
Experimental activity	Design of final demos for the methodologies assessment	Nov 2024 - Apr 2025	NO
Research work	Preparation and review of manuscripts	Oct 2024 - Sept 2025	NO
Research work	International conference attendance	Oct 2024 - Sept 2025	YES/NO
Preparation of final PhD thesis	Writing of the final dissertation	May 2025 - Sept 2025	NO

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Linear algebra for control applications	Spring 2023	Yes	2
	Analysis and control of cyber-physical systems	2023	Yes	3
	Navigation systems for autonomous systems	Jan-Feb, Oct-Nov 2023	Yes	1.5
	Duality-based decentralized and distributed optimization	June-July 2023	Yes	1
	Distributed Optimization and Applications (at UniPD)	May-June 2023	Yes	2
	Summer School		No	3
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Introduction to dynamic control allocation	Nov 2022 - Mar 2023		3
	Applied data-driven fault diagnosis	Feb - Mar 2023		1.5
	Introduction to fault diagnosis and fault prognosis	Mar-Apr 2023		1.5
	Virtual constraints for mechanical systems	June-July 2023		1.5
	Safety vs security in risk based vehicle routing	TBD		1.5
	Network dynamics and control	Jan-Feb or June 2023		3
	Linear matrix inequalities in systems and control	Apr/May/June 2023		3
	Complex Systems Modeling	TBD		1.5
	Theory and Applications of Contracting Dynamical Systems	Nov 2022		3
E. Participation to international congresses or workshops				
F. Presentation of research				

products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			32
G. Individual research activity	Individual study and research about advanced control techniques, fail-safety techniques and on distributed computation techniques. Definition of simulation frameworks for validations			24
H. Supervision of students				
I. Integrative teaching activities	Supervision of Master's Degree Laboratory courses (Robotics Laboratory and Embedded real time control)			1.6
J. Preparation of manuscripts for conferences or journals	Preparation and review of manuscripts			3
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			28.6
	TOTAL OF ECTS			60

Second academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Second year's courses, including summer school's courses		Yes	8
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Second year's seminars, offered both abroad and by the DAUSY program			8
E. Participation to international congresses or workshops	Participation to an international conferences			4
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			20
G. Individual research activity	Individual Research activity (Cooperative formation control for dynamic environments and evolution of mapping algorithms, design of experiments and laboratory activity in the SPARCS Lab)			30
H. Supervision of students	Supervision of M.Sc. students' thesis projects			2
I. Integrative teaching activities				
J. Preparation of manuscripts for	Preparation and review of manuscripts			8

conferences or journals				
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			40
	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 seminars offered during the third year			4
E. Participation to international congresses or workshops	Participation to an international conference			4
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			8
G. Individual research activity	Individual Research activity (methodologies for handling uncertain and complex scenarios) and preparation of the final dissertation			42
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation and review of manuscripts			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			52
	TOTAL OF ECTS			60

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

International Journal Articles

International Conference Proceedings

Marco Perin

Prof. Angelo Cenedese

Prof. Luca Schenato
