NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Title of the research:

Advanced control allocation techniques for large multi-agent systems and large sensors/actuators networks

Ph.D. candidate

Shima AKBARI

Cycle

XXXVIII

Tutors

Prof. Sergio Galeani

- # Description of the research program

The ever-increasing requests in terms of performance, flexibility and resilience both in autonomous production environments (under the Industry 4.0 paradigm) and in more general automation and robotics scenarios (such as search-and-rescue missions, renewable energy production involving micro-grids, precision agriculture, water distribution networks, and so on) have motivated a strong interest in the development of large-scale, multi-agent systems, as well as of large-scale networks of sensors and actuators. In many applications, the key element to achieve challenging objectives relies critically on the ability to coordinate such multi-agent systems in an optimal but flexible way. An additional ingredient adding complexity to the task is given by the fact that the operating environment is frequently unknown (at least up to some degree), and then the devised strategies must strike a balance between exploiting a priori given models and leveraging on data measured in real time. The goal of this project is to address the problems arising in large multi-agent systems and large sensor/actuator networks by developing innovative extensions of dynamic control allocation (DCA). Given an existing control loop equipped with a set of redundant actuators (that is, whose number exceeds the number of controlled outputs), DCA is an add-on compensation technique which can optimize the actuation demand without modifying the output response of the original control loop; the optimization criterion is usually in the form of a general Lagrange functional (and then tools from optimal control theory are involved) and can be changed in real time (thus providing flexibility in terms of goals). In order to address the considered applications, several challenging extensions have to be developed, including a dual theory for dealing with redundant sensors, and data-driven identification and optimization tools (requiring the use of machine and reinforcement learning). Cross-fertilization with the redundancy resolution literature in robotics will also be considered, which might also lead to novel ideas for the control of extremely over-actuated systems such as soft/flexible robots.

- # Schedule of the research activities

Insert the research activities that you plan, or you have completed for the three years, including any period abroad.

First academic year (planned)

	Description	Period	Activity abroad
State of the art review and writing up a research problems	Recognition of the state of the art in the control of redundant systems, including UAVs and redundant/soft robots; review of relevant Optimal Control literature and tools. Through bibliographic research and study of international projects, a set of specific and challenging open research problems will be rigorously defined, to be dealt with in the triennium.	November 2022 – October 2023	NO
Study and design of new techniques for DCA, with application to UAVs, redundant robots and Optimization in	Based on the devised open research problem, new approaches for DCA will be designed, and their applicability tested on preliminary, simplified scenarios in the fields of UAVs and redundant robots. At the same time, an effort wil be put on characterizing the proposed methods in terms of their main strengths and limitations.	November 2022 – October 2023	NO

Control			

Second academic year (planned)

	Description	Period	Activity abroad
Design and implementation of new DCA techniques, with application to UAVs, redundant robots and Optimization in Control. Cooperation with a foreign company or university	Definition and analysis of innovative scenarios and applications for the solutions developed during the first year. Development of tailored solutions for the considered scenarios, designed using mathematical models, simulation software and real testbeds.	November 2023 – October 2024	YES – Ohio State University
Development and analysis of new DCA techniques, with application to UAVs, redundant robots and Optimization in Control. Cooperation with a foreign company or university	Refinement of the solutions identified during the first year. Based on the formal results already obtained and on the challenges arising from the implementation in specific applications or scenarios, novel solutions will be developed and former solutions wil be generalized to address.	November 2023 – October 2024	YES – Ohio State University

Third academic year (planned)

	Description	Period	Activity abroad
Performance analysis and tool development	All the results and techniques developed during the three years will be put in perspective and assessed in terms of their strengths and weaknesses. The tools for the analysis and design of DCA solutions developed in the triennium based on the proposed solutions will be collected in a toolbox for easier implementation and dissemination.	November 2024 – October 2025	NO

Writing of the PhD Thesis	Writing of the PhD Thesis	November 2024 – October 2025	NO

- **Training and research activities plan**

First academic year (planned)

	Description	Period	Final Exam	ECTS
• Ph.D. courses	Control of soft and articulated elastic robots **(EECI course)**	22/05/2023-26/05/2023	No	3-->1.5
	Duality-based decentralized and distributed optimization **(DAUSY course)**	June/July 2023	Yes	1
	Introduction to modeling, analysis and control of complex systems **(DAUSY course)**	January-February or June 2023	Yes	1
	Linear and nonlinear Kalman filtering: theory and applications **(DAUSY course)**	January-February 2023	No	1.5 -->0.75
	Modeling, filtering and controlling aerospace systems **(DAUSY course)**	March-July 2023	No	2-->1
	APPLICATIONS OF MATLAB **(Poliba Course)**	26,27,28, 29,30 june and 3, 4, 5, 6, 7 july	Yes	2
	OPTIMIZATION AND CONTROL OF COMPLEX SYSTEMS **(Poliba Course)**	6, 7, 9, 10, 13,14, 16, 17 February	No	2-->1
	Navigation systems for autonomous systems **(DAUSY course)**	January-February, Oct/Nov 2023	No	1.5 -->0.75
• Master's degree courses	Robust And Adaptive Control **(Tor Vergata Course)**	February 2023– June 2023	No	6 -->3
• Foreign Language courses	Italian Language self-study/courses	November 2022 – October 2023		3
• Participation to seminars	Introduction to dynamic control allocation (**DAUSY**)	November 2022-March 2023		3

	Learning influences in large scale dynamical social networks - a systems and control approach (**DAUSY**)	March-July 2023		1.5
	Human-Machine Collaboration 2022 **(HIMC22)**	December 1 & 2		3
• Participation to international congresses or workshops	2022 International Autumn School on Autonomous and Connected Driving for Future Mobility	November 18 – 21		4
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**26.5**
• Individual research activity	Research activity in the topics of DCA, UAVs, redundant/soft robots and Optimal Control	November 2022 – October 2023		22
• Integrative teaching activities	Integrative didactic activities will be carried out under the supervision of the tutor	November 2022 – October 2023		3
• Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.	November 2022 – October 2023		8.5
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			33.5
	TOTAL OF ECTS			**60**

Second academic year (planned)

	Description	Period	Final Exam	ECTS
• Ph.D. courses	Some courses to be defined according to them syllabus regarding academic year 2023/24		Yes	14
• Foreign Language Courses	Italian Language self-study/courses			3
• Participation to seminars	Participation to at least two seminars/workshops according to availability.			
• Participation to international congresses or workshops	Participation to at least two seminars/workshops according to availability.			4

• 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			23
• Individual research activity	Research activity in the topics of DCA, UAVs, redundant/soft robots and Optimal Control. Writing of the PhD thesis.			26
• Integrative teaching activities	Integrative didactic activities will be carried out under the supervision of the tutor			3
• Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.			8
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			40
	TOTAL OF ECTS			**60**

Third academic year (planned)

	Description	Period	Final Exam	ECTS
• Ph.D. courses	Some courses to be defined according to them syllabus regarding academic year 2024/25		Yes	4
• Participation to seminars	Participation to at least two seminars/workshops according to availability.			4
• 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			10
• Individual research activity	Research activity in the topics of UAVs, redundant robots and Optimal Control. And writing the PhD thesis			35

• Integrative teaching activities	Integrative didactive activities will be carried out under the supervision of the tutor			5
• Preparation of manuscripts for conferences or journals	Writing of conference/journal papers describing the obtained research results.			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			50
	TOTAL OF ECTS			**60**

- **List of the publications written by the candidate in the triennium**

Insert the list of papers written during the Ph.D. program. If the paper is still not published indicate its status (e.g., submitted, under review, under 2nd review round, accepted to appear, etc.).

International Journal Articles

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International Conference Proceedings

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Ph.D. student name:

Shima Akbari

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Tutor name and title:

Prof. Sergio Galeani

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