NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Safety-driven mixed model- and learning-based motion planning and control of autonomous systems

Ph.D. candidate

Mohammad Jeddi

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1. Description of the research program

This Ph.D. research project aims to make a contributions in the field of motion planning and control for autonomous systems, with a particular focus on vehicles and robots operating in crowded structured environments. By exploring a combination of mixed model-based and learning-based approaches, the project seeks to develop safe and adaptive algorithms that address the challenges and limitations currently faced in these complex scenarios. Through innovative methodologies and techniques, this research project aims to push the boundaries of the state of the art and contribute to the scientific community. The research project will focus on two key areas that are currently of great interest to the scientific community:

- Novel learning-based prediction tools
- Environment-aware planning and motion control algorithms

These areas hold significant potential for various applications beyond autonomous driving. They can be applied in domains such as assistive technologies, automatic warehouses, autonomous goods delivery systems, manufacturing robots, and agricultural automation, among others. The versatility and wide applicability of the proposed tools and technologies make this research highly relevant to current technological advancements.

The initial focus of the project will be on model-based methodologies, which rely on mathematical models, optimization tools, and algorithms. While optimization tools offer feasibility guarantees, they often come with significant computational demands. Moreover, creating, calibrating, and validating models for autonomous systems operating in highly complex environments is a formidable task that can be both costly and challenging. Therefore, the research project will explore innovative ways to optimize model-based methodologies and address their limitations when applied to safety-critical applications. In parallel, the project will investigate learning-based methods, which do not rely on explicit models but rather on data and experiments to learn how to handle complex situations. Learning-based algorithms have demonstrated success in non-safety-critical applications, showcasing their efficiency in adapting to various scenarios. However, their lack of interpretability poses challenges when it comes to ensuring performance guarantees, particularly in safety-critical domains such as self-driving vehicles. Hence, this research project will endeavor to overcome this limitation by exploring techniques to enhance the interpretability and reliability of learning-based approaches in safety-critical applications. The core innovation of this research lies in the integration of model-based and learning-based approaches. By combining the strengths of both methodologies, the project aims to harness the efficiency, adaptability, and performance guarantees of model-based methods while benefiting from the ability of learning-based methods to tackle complex scenarios effectively. This fusion of techniques will pave the way for groundbreaking advancements in motion planning and control for autonomous systems.

In summary, this Ph.D. research project focuses on the development of safety-driven mixed model- and learning-based motion planning and control algorithms for autonomous systems. Through the exploration of novel learning-based prediction tools and environment-aware planning algorithms, the research aims to overcome the limitations of current methodologies and achieve innovative solutions applicable to a wide range of domains. By combining the advantages of model-based and learning-based approaches, the project aims to enhance safety, adaptability, and performance in crowded structured environments, making significant contributions to the scientific community and the state of the art in autonomous systems.

2. Schedule of the research activities

First academic year (completed/planned)

	Description	Period	Activity abroad
Literature Review and Problem Definition	- Conduct an extensive literature review to understand the current state of the field. - Define the specific research problems that we will address in the project	01/11/2023-01/03/2024	NO
Data Collection and Preprocessing	- Begin collecting relevant data for model-based and learning-based approaches. - Develop data preprocessing pipelines to prepare the data for analysis.	01/03/2024-01/05/2024	NO
Model-Based Methodologies	- Start working on model-based methodologies, including mathematical models and optimization tools. - Explore the challenges and limitations faced in crowded structured environments.	01/05/2024-01/08/2024	NO
Learning-Based Approaches	- Begin exploring learning-based approaches for motion planning and control. - Investigate the interpretability and reliability challenges in safety-critical applications.	01/08/2024-01/01/2025	NO

Second academic year (completed/planned)

	Description	Period	Activity abroad
Model-Based Optimization	- Optimize model-based methodologies to reduce computational demands and improve efficiency. - Focus on addressing safety-critical application challenges.	01/01/2025-01/04/2025	NO
Enhancing Learning-Based Approaches	- Develop techniques to enhance the interpretability and reliability of learning-based methods. - Explore methods to ensure performance guarantees in safety-critical domains.	01/04/2025-01/07/2025	NO
Integration of Model-Based and Learning-Based Approaches	- Begin the core innovation phase by integrating model-based and learning-based approaches. - Focus on harnessing the strengths of both methodologies to tackle complex scenarios effectively.	01/07/2025-01/01/2026	NO

Third academic year (completed/planned)

	Description	Period	Activity abroad
Validation and Testing	- Validate and test the safety-driven mixed model- and learning-based motion planning and control algorithms. - Perform experiments and simulations in crowded structured environments.	01/01/2026-01/05/2026	YES
Performance Evaluation	- Evaluate the safety, adaptability, and performance of the developed algorithms. - Compare the results with existing methodologies and state-of-the-art approaches.	01/05/2026-01/09/2026	YES

Thesis Writing and Documentation	- Start writing Ph.D. thesis, incorporating the research findings, methodologies, and innovations.	01/09/2026-31/12/2026	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	16/02/2024-26/02/2024	Yes	2
	Control for Optimization	06/11/2023-09/11/2023	Yes	1
	Game Theory for Controlling Autonomous Systems	18/06/2024-19/07/2024	Yes	2
B. Master's degree courses	-			
	-			
C. Soft skill courses				
D. Participation to seminars	TBD			1.5
E. Participation to international congresses or workshops	TBD			
F. Presentation of research products at international congresses or workshops	TBD			5
	TBD			5
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			16.5
G. Individual research activity	Research activities mentioned in the first academic year.			23.5
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of manuscripts for conferences or journals			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			43.5
	TOTAL OF ECTS			**60**

Second 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	TBD			5

E. Participation to international congresses or workshops	TBD			5
F. Presentation of research products at international congresses or workshops	TBD			5
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			15
G. Individual research activity	Research activities mentioned in the second academic year.			35
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of manuscripts for conferences or journals			10
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			45
	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				
E. Participation to international congresses or workshops				
F. Presentation of research products at international congresses or workshops	TBD			5
	TBD			5
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			10
G. Individual research activity	Research activities mentioned in the last academic year.			30
H. Supervision of students				
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation of manuscripts for conferences or journals			20
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			50
	TOTAL OF ECTS			**60**

4. 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.).

Mohammad Jeddi

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Paolo Falcone

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