NATIONAL PH.D. PROGRAM IN AUTONOMOUS SYSTEMS

Reinforcement Learning Algorithms for Contact-Rich Manipulation Tasks

Ph.D. candidate

Mohamed Mahmoud Abdelwahab MOHAMED

Cycle

XXXIX

Tutors

Dr. ALBERTO DALLA LIBERA

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1. Description of the research program

Contact-rich manipulation, involving intricate interactions between a robot and its environment, demands precise control and adaptability. The challenges posed by this complex domain have been tackled through two main approaches: planning and reactive strategies.

Planning approaches employ meticulous off-line trajectory planning, leveraging deep geometric analysis and tolerance considerations. However, they struggle with uncertainties and lack generalization to variations in tasks and object shapes.

This project embraces Reinforcement Learning (RL) as a promising solution to derive reactive strategies. RL algorithms aim to derive robust and adaptive control strategies that autonomously adapt to complex environments. The integration of RL with Machine Learning (ML) enhances the project's scientific relevance.

The project delves into two distinct RL paradigms: Model-Free Reinforcement Learning (MFRL) and Model-Based Reinforcement Learning (MBRL). While MFRL shows promise, it demands extensive training iterations to converge to optimal solutions. In response, MBRL presents itself as a data-efficient alternative, building system evolution models based on collected data. By optimizing policies using these models, MBRL approaches offer significant advantages in terms of efficiency and adaptability.

This research primarily addresses two critical aspects that are pivotal for the advancement of MBRL algorithms. The first focus involves the development of hybrid models, integrating both physics-based and data-driven principles, enabling the accurate representation of complex dynamics inherent in manipulation tasks characterized by extensive contact interactions.

The second topic of emphasis pertains to policy optimization. In tasks of high complexity, the initialization of policies can have dramatic effects on temporal aspects and overall effectiveness. Notably, the process of policy optimization can leverage human demonstrations and optimal control techniques to augment the likelihood of convergence and reduce optimization time, thereby enhancing sampling efficiency. As an illustrative instance, we will study as an example the MBRL algorithm denoted as MC-PILCO, and investigate strategies to generalize the learned policies to different tasks and setups.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Literature review	Literature review on state of the art optimal control techniques, Model-based RL and learning from demonstration approaches.	Nov 2023 – Feb 2024	No
Supervision activity	Supervision of the Adversarial Machine Learning lab (25h) held at UniPD. My role will be in assisting the students during the laboratory sessions.	Nov 2023 – Jan 2024	No
Research work	Improving MC-PILCO implementation using optimal control methods as a guidance for the learning process.	Jan 2024 - Sept 2024	No
Research work	Summer school attendance	July 2024	No

Second academic year (planned)

	Description	Period	Activity abroad
Literature review	Literature review on state of the art system identification approaches specifically Gaussian Processes and Deep Lagrangian Neural Networks to build accurate models of the system and contact dynamics.	Oct 2024 - Jan 2025	Yes/No
Supervision activity	Supervision M.Sc. students' thesis projects.	Oct 2024 - Dec 2024	No
Research work	Model learning using the data coming from actual system and testing different contact dynamics.	Jan 2025 - Sept 2025	Yes
Research work	Model integration with MC-PILCO.	Jan 2025 - Sept 2025	Yes
Research work	International conference and summer school attendance	Oct 2025 - Sept 2025	Yes/No

Third academic year (planned)

	Description	Period	Activity abroad
Extensive tests	Design of final demos for the methodologies assessment	Nov 2025 - Apr 2026	No
Research work	Preparation and review of manuscripts	Oct 2025 - Sept 2026	No

Research work	International conference attendance	Oct 2025 - Sept 2026	Yes/No
Writing of the PhD thesis	Writing of the final dissertation	May 2026 - Sept 2026	No

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Applied Linear Algebra (Unipd)	November 2023	Yes	2
	Intelligent Control Systems	January 2024	Yes	2
	Elements of Deep Learning (Unipd)	January 2024	Yes	2
	Introduction to Optimal Linear Quadratic Control	February 2024	Yes	2
	Human autonomous systems interaction	May 2024	Yes	1
	Control of marine vehicles	June 2024	Yes	3
	Summer School Courses		Yes/No	3
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	First year's seminars, offered both abroad and by the DAUSY program			12
E. Participation to international congresses or workshops	To be defined			4
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**31**
G. Individual research activity				24
H. Supervision of students	- Supervision of the Adversarial Machine Learning lab (25h). - Supervision M.Sc. students' thesis projects.			2
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation and review of manuscripts.			3
	TOTAL OF ECTS FOR RESEARCH ACTIVITIES			**29**
	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	6
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			5
E. Participation to international congresses or workshops	Participation to an international conferences			5
F. Presentation of research products at international congresses or workshops				
				2
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**18**
G. Individual research activity				32
H. Supervision of students	- Supervision M.Sc. students' thesis projects.			2
I. Integrative teaching activities				
J. Preparation of manuscripts for conferences or journals	Preparation and review of manuscripts			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 seminars offered during the third year (To be defined)			4
E. Participation to international congresses or workshops	Participation to an international conference (To be defined)			4
F. Presentation of research products at international congresses or workshops				
	TOTAL OF ECTS FOR TRAINING ACTIVITIES			**8**

G.	**Individual research activity**	Methodologies for generalizing the learned polices 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

Mohamed Mahmoud Abdelwahab MOHAMED

Mohamed Abdelwahab

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Alberto Dalla Libera

Prof. Ruggero Carli

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