Emanuele Musicò

Application of Optimal Control and Reinforcement Learning tools to control complex/distributed systems

Tutor: Francesco Lo Iudice co-Tutor: Mario di Bernardo

Cycle: XXXIX Year: 2025

Candidate's information

- MSc degree: Automation and Robotics Engineering
- DIETI Research group: SINCRO – Sincronizzazione e Controllo di Reti e Processi
- PhD start date: 01/11/23 – PhD end date: 31/10/26
- Scholarship type: PNRR - DM 118/2023 Mis. 4.1: Dottorati Pubblica Amministrazione
- Periods abroad: 6/6 month
  Institute of Industrial and Control Engineering, Universitat Politecnica de Catalunya, Barcelona, Spain
- Periods in company 6/6 month
  CNR STEMS, Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibile, Napoli, Italia

Summary of study activities

- Ad Hoc PhD Courses / Schools
  - I Pilastri della Trasfomrazione Digitale by dr. Francesco Tortorelli;
  - Methodologies and Tools for conducting Systematic Literature Reviews and Systematic Mapping Studies by prof. Domenico Amalfitano;
  - AI Code Generation: Foundations, Evaluation, and Security by Wendy Luiten and John H. J. Janssen.
- Conference Attended
  - 2024 Conference on Decision and Control.
- Research Study
  - Multi-Agent Proximal Policy Optimization Algorithm;
  - Urban Traffic Models;
  - Continuification methods for ODEs to PDEs.

Research area(s)

- Optimal control and Reinforcement Learning applications for complex/distributed systems control
  - Energy Systems with Renewable Penetration: Microgrids and Renewable Energy Communities
  - Autonomous Driving Systems: AGVs and Urban Traffic

Research Description

- The overarching goal of my research is to investigate application of both optimal control and reinforcement learning analysing how to exploit and possibly combines the optimal control theory guarantees and the efficiency of deep reinforcement learning tools.

- Methodology:
  - Searching gaps in the current state-of-art of control theory and RL literature;
  - Formalize a control-problem in different real-world scenarios;
  - Propose an original application-specific control strategy;
  - Investigate both analytically and numerically its performance.

Second Year Research Activity

- Research Problem I: Control of the charging profile of a shared battery energy storage system (SBESS) owned by a renewable energy community (REC)
- Goal: Minimizing the cumulative hourly energy bill of the community over an horizon of N days
- Results:
  - Developed an Optimal Control Strategy that showed statistical significant reduction in the reduction of the cumulative hourly energy bill [P1];
  - Proved theoretically that solving N optimization problems is equivalent to solve the original single optimization problem over N days;
  - Proved theoretically that by making advantage of the energy tariff some decision variables of the problem can be set to 0 a priori, hence reducing the number of variables.

Second Year Research Activity

- Research Problem I: Control of the charging profile of a shared battery energy storage system (SBESS) owned by a renewable energy community (REC)
- Goal: Minimizing the cumulative hourly energy bill of the community over an horizon of N days
- Results:
  - Reformulated the problem in a convex way demonstrating that our strategy reaches the global optimal solution;
- Currently:
  - We want to reformulate the problem in a distributed way so that each community member has its own Energy Management System enhancing privacy among members;

Second Year Research Activity

- Research Problem II: Optimizing Task Allocation for a Multi AGVs System in a warehouse working under Improved Dynamic Resource Reservation
- Goal: Maximizing Productivity while minimizing the total travel distace of each AGV and minimizing conflict resolution maneuvers.
- Methodology:
  - Developed a MATLAB simulator of the warehouse working under IDRR;
  - Desing of a Multi-Agent Proximal Policy Optimization Agent and exploiting centralized training and decentralized executing;
  - Fully Distributing the task allocation so that each AGVs can autonomously select the best available task depending on its and the environment state.

Second Year Research Activity

- Research Problem II: Optimizing Task Allocation for a Multi AGVs System in a warehouse working under Improved Dynamic Resource Reservation
- Goal: Maximizing Productivity while minimizing the total travel distace of each AGV and minimizing conflict resolution maneuvers.
- Currently with 7 AGVs and a total of 21 Task to complete:

📊 ANALISI STATISTICA RISULTATI

METRICA	IDRR	RL	Δ	p-value	
Produttività [task/h]	49.52	51.22	+3.43%	0.0122	✅
Distanza Media AGV [m]	977.44	922.84	-5.59%	0.0000	✅
Tempo Waiting Medio [s]	228.92	219.50	-4.11%	0.3080	⚪
Tempo Resolving Medio [s]	0.96	1.08	+12.38%	0.5013	⚪
Conflitti Totali	57.16	54.68	-4.34%	0.1222	⚪
Manovre Totali	33.58	32.34	-3.69%	0.2759	⚪
Tempo Esecuzione Task [s]	371.85	341.13	-8.26%	0.0000	✅
Tempo Idle Medio [s]	268.55	288.34	+7.37%	0.1165	⚪

Research products

[P1]	E. Musicò, C. Ancona, F. Lo Iudice and L. Glielmo, "An Optimal Control Approach for Enhancing Efficiency in Renewable Energy Communities," in *IEEE Control Systems Letters*, vol. 8, pp. 3039-3044, 2024, doi: 10.1109/LCSYS.2024.3521193.

First Year CFU

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	1.6	8.4	0	10
Bimonth 2	0	2.6	7.4	0	10
Bimonth 3	3	0.8	6.2	0	10
Bimonth 4	3	0	7	0	10
Bimonth 5	0	0	10	0	10
Bimonth 6	3	0	7	0	10
Total	9	5	46	0	60
Expected	10-20	5-10	30-45	0-1.6	45-76.6

Next Year Plan

	Courses	Seminars	Research	Tutorship	Total
Prevision	4	0	56	0	60
Expected	10-20	0-10	40-60	0-1.6	50-91.6