PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Emanuele Musicò

Cycle: XXXIX

Training and Research Activities Report

Academic year: 2023-2024
PhD Year: First

Tutor: prof. Francesco Lo Iudice 

Co-Tutor: prof. Mario di Bernardo

Date: October 31, 2024

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: **Author:**

1. Information:

- **PhD student: Emanuele Musicò**
- **PhD Cycle: XXXIX**
- **DR number: DR997210**
- **Date of birth: 25/03/1999**
- **Master Science degree: Ingegneria dell'Automazione e Robotica**
- **University: Università degli studi di Napoli Federico II**
- **Scholarship type: PNRR - DM 118/2023 Mis. 4.1: Dottorati Pubblica Amministrazione**
- **Tutor: prof. Francesco Lo Iudice**
- **Co-tutor: prof. Mario di Bernardo**
- **Period abroad:**
  Number of months to spend aroad: 6
  Number of Months spent abroad: 0
  Institution: Institute of Industrial and Control Engineering, Universitat Politecnica de Catalunya, Barcelona, Spain

  Number of months to spend in a public administration: 6
  Number of Months spent in a public administration: 2
  Public Administration : CNR Istituto Motori, Napoli, Italia

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Introduction to Complex Networks	Seminar	5	1	06-07/11/23	Scuola Superiore Meridionale: PhD Courses (Merc Area) – prof. Stefano Boccaletti	Y
La Scorciatoia: Come Le Macchine Sono Diventate Intelligenti Senza Pensare in Modo	Seminar	2	0.4	25/11/23	Città della Scienza – prof. Mario di Bernardo	Y

Umano						
Energy-Efficient Data Science	**Seminar**	**1**	**0.2**	**13/12/23**	**prof. Elio Masciari, DIETI - Unina**	**Y**
How to Boost Your PhD	**Courses**	**5**	**18**	**10-17-24-31/01/24 07/02/24**	**Prof. Antigone Marino**	**Y**
Using Deep Learning Properly	**Courses**	**4**	**12**	**23-25-30/01/24 01-06-08/02/24**	**Dr. Andrea Apicella**	**Y**
SINCRO Research Seminar Serie	**Seminar**	**15**	**3**	**14-28/02/24 06-13-20-27/03/24 03-10/04/24 10/07/24**	**Mario di Bernardo**	**N**
Invited Talk by Moshe Y.Vardi: Logical Algorithmics	**Seminar**	**1**	**0.2**	**23/02/24**	**32nd EACSL Annual Conference on Computer Science Logic 2024**	**Y**
Control Theory& Robust Distributed Optimization: Some Insight	**Seminar**	**1**	**0.2**	**21/03/24**	**Prof. Mario di Bernardo**	**N**
7th Advanced Course on Data Science & Machine Learning	**Doctoral School**	**37**	**8**	**10-11-12-13-14/06/24**	**Prof. Giuseppe Nicosia & Prof. Panos Pardalos**	**Y**

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	**0**	**1.6**	**8.4**	**0**	**10**
Bimonth 2	**9**	**1**	**0**	**0**	**10**
Bimonth 3	**0**	**2**	**8**	**0**	**10**

Bimonth 4	**8**	**0**	**2**	**0**	**10**
Bimonth 5	**0**	**0.4**	**9.6**	**0**	**10**
Bimonth 6	**0**	**0**	**10**	**0**	**10**
Total	**17**	**5**	**38**	**0**	**60**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

Title of the whole research activity: Investigating Application of Optimal Control and Reinforcement Learning tools to control complex systems

Description:
In my first year as an ITEE PhD student I mainly worked on the study of state-of-the-art for optimal control and reinforcement learning applications for complex systems control. I also have worked to improve my knowledge about reinforcement learning and machine learning methodologies.
Applications of interest for my research group are:

- Energy Systems
- Autonomous Driving Systems
- Human – AI Interaction Systems

State of the Art:
The integration of optimal control and reinforcement learning (RL) has emerged as a beneficial approach in managing complex systems across various domains, including energy management, autonomous driving, and social applications such as crowd control. This synthesis of methodologies leverages the adaptability and learning capabilities of RL to optimize decision-making processes in dynamic environments and the solid guarantees provided by the optimal control theory.
For energy management systems, RL has been effectively applied to optimize the operation of complex systems such as tokamak plasmas. Degrave et al. demonstrated that deep reinforcement learning can achieve high performance and robustness in controlling plasma confinement, showcasing the method's versatility in handling uncertain operating conditions and its ability to specify intuitive targets [1]. This paradigm can be extended to energy systems, such as renewable energy communities, where RL can optimize energy distribution and consumption in real-time, adapting to fluctuating demands and supply conditions, while optimal control policies can optimize the use of energy storage systems [2],[3]. Zou proposed a real-time energy management strategy for hydrogen fuel cell hybrid electric vehicles that combines power following and fuzzy logic control, demonstrating the effectiveness of hybrid control strategies in optimizing energy distribution [4].

For autonomous driving applications, the complexity of interactions between autonomous and human-driven vehicles presents a unique challenge. Wang introduced a safe autonomous driving framework that incorporates latent dynamics and state-wise constraints, demonstrating how optimal control can enhance decision-making in complex driving scenarios [5]. Moreover, Gao et al. developed a driver-like decision-making method using deep reinforcement learning, which adapts to various driving conditions by learning optimal policies through interaction with the environment [6]. Traffic control, have instead benefited significantly from RL techniques. For instance, Liu et al. explored a multi-agent reinforcement learning framework to address lane-changing maneuvers in mixed traffic scenarios, allowing autonomous vehicles to learn strategies that maximize traffic throughput while adapting to human behaviors [7]. Similarly, Bouton et al. emphasized the importance of cooperation-aware RL in merging scenarios, where understanding the interaction dynamics among drivers is crucial for safe navigation [8]. These studies highlight the potential of optimal control and RL to enhance the decision-making capabilities of autonomous vehicles in real-world traffic conditions.
In social applications, particularly crowd control, RL has shown promise in enabling robots to navigate through dense crowds safely and efficiently. Research by Xu et al. focused on safety evaluations in robot crowd navigation, employing deep reinforcement learning to model social relationships and optimize actions in complex environments [9]. Furthermore, techniques such as the Socially Attentive Reinforcement Learning (SARL) have been developed to incorporate human-robot interactions into navigation strategies, enhancing the robots' ability to navigate crowded spaces without causing disturbances [10]. The application of RL in crowd navigation not only addresses the technical challenges of collision avoidance but also considers the social dynamics at play, making it a vital area of research for future autonomous systems.

Research Problem:
I have dealt with Energy Management Systems. The problem that I solved was about the control of the charging profile of a shared battery energy storage system (SBESS) owned by a renewable energy community (REC) with the goal of minimizing the average cumulative energy bill of the community over a time horizon of N days, while preserving fairness at an individual level. It was mathematically proved that minimizing the average cumulative energy bill of a REC over N days is equivalent to sequentially minimizing the average daily bill under mild assumptions. It was, also, proved that is possible to further reduce the number of the decision variables by taking advantage of the energy tariff scheme. The optimal control strategy developed was validated on an Australian case-study showing that a substantial reduction of the average cumulative daily energy bill at community level was achieved, and that the results is statistically significant respect the case where there is no SBESS, and the case were the SBESS is not endowed with an energy management system. Furthermore, it was also ensured fairness respect cost distribution at the individual level with a cost distribution policy proportional to individual energy demand and renewable generation profile. It resulted that each individual gets has a statistically significant beneficial in becoming part of a REC respect the case of not becoming part of it.

This work resulted in a paper named: "An optimal control approach for enhancing efficiency in renewable energy communities" that was submitted both for the American Control Conference 2025 and IEEE Letters on 16th September 2024.

Collaboration: Luigi Glielmo*,Francesco Lo Iudice*, Camilla Ancona*.

*(University of Naples Federico II)

References:

[1] Degrave, J., Felici, F., Buchli, J., Neunert, M., Tracey, B., Carpanese, F., … & Riedmiller, M. (2022). Magnetic control of tokamak plasmas through deep reinforcement learning. Nature, 602(7897), 414-419. https://doi.org/10.1038/s41586-021-04301-9

[2] Talluri, G., Lozito, G. M., Grasso, F., Iturrino Garcia, C., & Luchetta, A. (2021). Optimal battery energy storage system scheduling within renewable energy communities. *Energies*, *14*(24), 8480. https://doi.org/10.3390/en14248480

[3] L. Guiducci, G. Palma, M. Stentati, A. Rizzo and S. Paoletti. (2023). A Reinforcement Learning approach to the management of Renewable Energy Communities. *12th Mediterranean Conference on Embedded Computing (MECO)*, Budva, Montenegro, 2023, pp. 1-8. https://doi.org/10.1109/MECO58584.2023.10154979

[4] Zou, K. (2023). Real-time energy management strategy of hydrogen fuel cell hybrid electric vehicles based on power following strategy–fuzzy logic control strategy hybrid control. World Electric Vehicle Journal, 14(11), 315. https://doi.org/10.3390/wevj14110315

[5] Wang, C. (2024). Safe autonomous driving with latent dynamics and state-wise constraints. Sensors, 24(10), 3139. https://doi.org/10.3390/s24103139

[6] Gao, Z., Yan, X., Gao, F., & He, L. (2021). Driver-like decision-making method for vehicle longitudinal autonomous driving based on deep reinforcement learning. Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering, 236(13), 3060-3070. https://doi.org/10.1177/09544070211063081

[7] Liu, Q., Hu, X., & Li, S. (2023). Research on automatic vehicle lane changing model based on masac-discrete algorithm.. https://doi.org/10.1117/12.3004627

[8] Bouton, M., Nakhaei, A., Fujimura, K., & Kochenderfer, M. (2019). Cooperation-aware reinforcement learning for merging in dense traffic.. https://doi.org/10.1109/itsc.2019.8916924

[9] Xu, J. (2023). Safecrowdnav: safety evaluation of robot crowd navigation in complex scenes. Frontiers in Neurorobotics, 17. https://doi.org/10.3389/fnbot.2023.1276519

[10] Seghiri, S., Mansouri, N., & Chemori, A. (2022). Implementation of sarl* algorithm for a differential drive robot in a gazebo crowded simulation environment.. https://doi.org/10.1109/icaee53772.2022.9962010

Research products:

- **Submitted Papers**
  - Musicò, E., Ancona, C., Lo Iudice, F., & Glielmo, L. (2023). An optimal control approach for enhancing efficiency in renewable energy communities (Submitted to the IEEE Control Systems Letters).

5. Conferences and seminars attended

- **32nd EACSL Annual Conference on Computer Science Logic 2024**
  - Dates: 23/02/2024
  - Location: Naples, Italy

6. Periods abroad and/or in international research institutions

Number of months to spend abroad: 6
Number of Months spent abroad: 0
Institution: Institute of Industrial and Control Engineering, Universitat Politecnica de Catalunya, Barcelona, Spain

Number of months to spend in a public administration: 6
Number of Months spent in a public administration: 2
Public Administration: CNR Istituto Motori, Napoli, Italia

7. Tutorship

8. Plan for year two

- Research activities:
  Application of Reinforcement Learning for crowd control;
  Application of Multi-Agent Reinforcement Learning to control the traffic jam;
  Application of Rinforcement Learning to the problem of Zone Partitioning in a Warehouse

for AGV Navigation

- Research periods abroad - Universitat Politecnica de Catalunya, Barcelona, Spain
- Collaboration with public administration - CNR: Istituto Motori