PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Francesco De Lellis

Cycle: XXXV

Training and Research Activities Report

Academic year: 2020-21 - PhD Year: Second

Tutor: prof. Mario di Bernardo

Co-Tutor: prof. Giovanni Russo

Date: 21/10/2021

1. Information:

- **PhD student: Francesco De Lellis** **PhD Cycle: XXXV Cycle**
- **DR number: DR993887**
- **Date of birth: 24/04/1993**
- **Master Science degree: Control Engineering** **University: University of Naples Federico II**
- **Scholarship type: UNINA**
- **Tutor: Mario di Bernardo**
- **Co Tutor: Giovanni Russo**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
At the Nexus of Big Data, Machine Intellignece, and Human Cognition	Seminar	1	0.2	21/12/2020	George S. Djorgovski	N
Learning-based Model Predictive Control	Seminar	1	0.2	30/11/2020	Melanie Zeilinger	N
SINCRO Research Seminar Series	Seminar	28	5.6	04/11/2020 11/11/2020 18/11/2020 25/11/2020 02/12/2020 09/12/2020 16/12/2020 13/01/2021 20/01/2021 27/01/2021 03/02/2021 10/02/2021 17/02/2021 24/02/2021	Mario di Bernardo	Y
AIRO PhD School 2021 and 5th AIRO-Young Workshop	PhD School	32	3.6	08/02/2021 09/02/2021 10/02/2021 12/02/2021	Antonio Sforza, Maurizio Boccia, Claudio Sterle, Adriano	Y

					Masone	
Reinforcement Learning Virtual School	**Seminar**	**9**	**1.8**	**25/03/2021**	**Toulouse AI institute ANITI**	**Y**
SINCRO Research Seminar Series	**Seminar**	**18**	**3.6**	**03/03/2021 10/03/2021 17/03/2021 24/03/2021 31/03/2021 07/04/2021 14/04/2021 21/04/2021 24/04/2021**	**Mario di Bernardo**	**Y**
IELTS course	**Course**	**24**	**5**	**15/04/2021 22/04/2021 29/04/2021 20/05/2021 27/05/2021 17/06/2021 24/06/2021 29/06/2021**	**CLA**	**Y**
The pandemic playbook, a physicist take	**Seminar**	**1**	**0.2**	**17/06/2021**	**Francesco Sannino**	**N**
SINCRO Research Seminar Series	**Seminar**	**26**	**5.2**	**04/05/2021 12/05/2021 19/05/2021 26/05/2021 02/06/2021 09/06/2021 16/06/2021 26/06/2021 31/06/2021 07/07/2021 14/07/2021 21/07/2021 28/07/2021**	**Mario di Bernardo**	**Y**
Strategic Orientation for STEM Research & Writing	**Course**	**18**	**4**	**15/06/2021 17/06/2021 22/06/2021 29/06/2021 06/07/2021 29/07/2021**	**Chie Shin Fraser**	**N**
SINCRO Research Seminar Series	**Seminar**	**12**	**2.4**	**15/09/2021 22/09/2021 29/09/2021**	**Mario di Bernardo**	**Y**

				06/10/2021 13/10/2021 20/10/2021		

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**	**3.2**	**8**	**0.24**	**11.44**
Bimonth 2	**3.6**	**2.8**	**8**	**0.24**	**14.64**
Bimonth 3	**0**	**5.4**	**5**	**0.16**	**10.56**
Bimonth 4	**5**	**3.8**	**6**	**0.32**	**15.12**
Bimonth 5	**0**	**1.6**	**6**	**0.28**	**7.88**
Bimonth 6	**4**	**2.4**	**8**	**0.1**	**14.5**
Total	**12.6**	**19.2**	**41**	**1.34**	**74.14**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

Title of the whole research activity*: Development and applications of nonlinear and distributed control strategies based on reinforcement learning for complex and multi-agent systems*

Title: Control-Tutored Q-learning

Description:

In the recent years, many efforts have been made to establish a unified framework to develop strategies that make use of Control Laws and Reinforcement Learning [1-2]. During my second year, I kept developing a strategy named Control-Tutored Q-learning [3-4-5] for the control of uncertain dynamical systems. The aim of this research is to find out if nonlinear control strategies can be used in combination with RL algorithms to improve data efficiency and increase the control performance and robustness. The CTQL algorithm makes use of a control policy to improve the learning phase of the Q-learning algorithm [6] by using a control law to recommended possible control actions using partial knowledge of the system dynamics encoded in a mathematical model. A new implementation of the CTQL has been developed and tested on the two representative control problems:

1. The multi-agent herding problem, where one or more agents have to collect and contain a group of target agents.
2. The classical benchmark of stabilizing an inverted pendulum.

In both cases, the new implementation CTQL showed its capability of reducing learning times, improving data efficiency and achieving satisfactory results with the use of only partial model knowledge. This further pushed my research towards the search of a unified framework for the control of dynamical systems that makes uses of state of the art Reinforcement Learning techniques in combination with nonlinear control laws to face the need of dealing with very uncertain modeling of the system dynamics.

Lastly, a study of the convergence properties of such strategy have been analyzed using results present in the literature [7-8] to link the classical tabular Q-learning proof of convergence with the tabular version of the CTQL algorithm.

Collaboration: Marco Coraggio, Shihao Xie*, Giovanni Russo** and Mario di Bernardo

*(University College of Dublin)

**(University of Salerno)

Title: Intermittent non-pharmaceutical strategies to mitigate the COVID-19epidemic in a network model of Italy via constrained optimization

Description:

The design of intermittent non-pharmaceutical strategies to mitigate the spread of the COVID-19 epidemic exploiting network epidemiological model is proposed in [9]. By studying a variational equation for the dynamics of the infected and by using contractivity arguments, we derived a condition that can be used to guarantee that the effective reproduction number is less than unity. Based on such analytical derivation, we developed a Model Predictive Control problem so as to mitigate (or suppress) the spread of the epidemic while minimizing the economic impact of the interventions. A data-driven model of Italy as a network of three macro-regions (North, Center, and South) is derived from [10]. Whose parameters are identified from real data and the simulation results are used to illustrate and evaluate the effectiveness of the proposed control strategy.

Collaboration: Marco Coraggio, Shihao Xie*, Giovanni Russo** and Mario di Bernardo

*(University College of Dublin)

**(University of Salerno)

4. Research products:

- **Published conference paper:**
  - Francesco De Lellis, Giovanni Russo, and Mario di Bernardo. “Tutoring Reinforcement Learning via Feedback Control”, European Control Conference (ECC21), 2021.
  - Francesco De Lellis, Fabrizia Auletta, Giovanni Russo, Pietro De Lellis and Mario di Bernardo. “An Application of Control-Tutored Reinforcement Learning to the Herding Problem”, IEEE International Workshop on Cellular Nanoscale Networks and their Applications (CNNA212), 2021.
- **Accepted conference paper:**
  - Marco Coraggio, Shihao Xie, Francesco De Lellis, Giovanni Russo, Mario di Bernardo. “Intermittent non-pharmaceutical strategies to mitigate the COVID-19 epidemic in a network model of Italy via constrained optimization”, Conference of Decision and Control (CDC21), 2021.

5. Conferences and seminars attended

- **SIAM Conference on Applications of Dynamical Systems (DS21):**
  - Dates: 23 - 27/05/2021
  - Location: Virtual Conference
  - Gave the talk "Tutoring Reinforcement Learning via Feedback Control"
  - Website: https://www.siam.org/conferences/cm/conference/ds21

- **European Control Conference (ECC21):**
  - Dates: 29/06/2021 – 02/07/2021
  - Location: Rotterdam (hosted online)
  - Paper presented: Francesco De Lellis, Giovanni Russo, and Mario di Bernardo. "Tutoring Reinforcement Learning via Feedback Control", European Control Conference (ECC21), 2021
  - Website: https://ecc21.euca-ecc.org/

- **IEEE International Workshop on Cellular Nanoscale Networks and their Applications (CNNA21):**
  - Dates: 29/09/2021 – 01/10/2021
  - Location: University of Catania
  - Paper presented: Francesco De Lellis, Fabrizia Auletta, Giovanni Russo, Pietro De Lellis and Mario di Bernardo. "An Application of Control-Tutored Reinforcement Learning to the Herding Problem", IEEE International Workshop on Cellular Nanoscale Networks and their Applications (CNNA212), 2021
  - Website: http://cnna2021.unict.it/

7. Tutorship

- Co-supervisor of the thesis of 2 master students in Ingegneria dell'Automazione
- Weekly 2 hours tutorship ("ricevimento") for the course of Dinamica e Controllo Non Lineare in Ingegneria dell'Automazione

8. Plan for year three

In the next year, I plan to:

- Test the Control-Tutored strategies developed to more control application like the control of synthetic biology systems as well as environments from the OpenAI gym framework.
- Extend the Control-Tutored Reinforcement Learning to other RL algorithms present in the literature for the control of nonlinear dynamical systems
- Spend a period of 3 months at the University College of London under the supervision of professor Mirco Musolesi to finish the development of Control-Tutored strategies and their application
- Cosupervise master students and keep the tutorship for the course of Dinamica and Controllo Non Lineare
- Write my thesis on an unified framework for the development of Control-Tutored Reinforcement Learning strategies for the control of uncertain nonlinear dynamical systems a

possible title is: “Tutoring Reinforcement Learning via Feedback Control to deal with uncertain dynamics”

9. References

[1] N. Matni, et al. "From self-tuning regulators to reinforcement learning and back again." IEEE 58th Conference on Decision and Control (CDC), p. 3724-3740 ,2019.
[2] B. Recht, "A tour of reinforcement learning: The view from continuous control." Annual Review of Control, Robotics, and Autonomous Systems 2, p. 253-279, 2019.
[3] F. De Lellis, F. Auletta, G. Russo, P. De Lellis, M. di Bernardo. "Control-Tutored Reinforcement Learning", arXiv:1912.06085, 2019.
[4] F. De Lellis, F. Auletta, G. Russo, P. De Lellis, M. di Bernardo. "Control-Tutored Reinforcement Learning: an application to the Herding Problem", CNNA21, 2021.
[5] F. De Lellis, G. Russo, M. di Bernardo. "Tutoring Reinforcement Learning via Feedback Control", ECC21, 2021.
[6] C. Watkins, P. Dayan, “Q-learning.” Machine learning, p.279-292, 1992.
[7] D. P. Bertsekas, and J. N. Tsitsiklis, “Neuro-dynamic programming.” Athena Scientific, 1996.
[8] R. S. Sutton and A. G. Barto, “Reinforcement learning: An introduction.” MIT press, 2018.
[9] M. Coraggio, S. Xie, F. De Lellis, G. Russo, M. di Bernardo, “Intermittent non-pharmaceutical strategies to mitigate the COVID-19 epidemic in a network model of Italy via constrained optimization”, accepted by Conference on Decision and Control (CDC), 2021
[10] F. Della Rossa, D. Salzano, A. Di Meglio, F. De Lellis, M. Coraggio, C. Calabrese, A. Guarino, R. Cardona-Rivera, P. De Lellis, D. Liuzza, F. Lo Iudice, G. Russo, M. di Bernardo. “A network model of Italy shows that intermittent regional strategies can alleviate the COVID-19 epidemic”, Nature communications, 11(1), 1-9, 2020