BORSA N. 9

DAUSY

D.M. 351/2022

Ambito: PNRR

Tematica: “Machine learning paradigms for fast and faithful approximations of model predictive controllers”

Research theme title:

Machine learning paradigms for fast and faithful approximations of model predictive controllers

Contacts:

Prof. Alberto Bemporad

e-mail: alberto.bemporad@imtlucca.it

Curriculum of DAUSY:

C2 AS for Smart Environments

Hosting University/Research Centre

IMT School for Advanced Studies Lucca, Italy

Department:

IMT School for Advanced Studies

Piazza S. Francesco 19, 55100, Lucca, Italy

https://www.imtlucca.it/

Prospective Supervisors:

Prof. Alberto Bemporad (http://cse.lab.imtlucca.it/~bemporad/)

Dr. Filippo Fabiani (filippo.fabiani@eng.ox.ac.uk)

Description:

The contemporary quest for easily embeddable control systems with increasing efficiency is shedding light on the impressive potential of machine learning approaches to design proxies for traditional, possibly model-based, control techniques. Among them, model predictive control (MPC) has been shown to benefit the most since surrogate MPC-based policies synthesized through machine learning paradigms typically feature almost inexpensive online evaluation while retaining some flavour of optimality.

Nevertheless, accompanying those learning-based controllers with rigorous certificates demonstrating their reliability in terms of stability and performance of the closed-loop system when called to replace the original MPC law based on online optimization denotes a key challenge. Therefore, the PhD student will investigate a combination of machine learning and control theoretical methods to approximate MPC laws outperforming the original policy from a computational perspective, while retaining rigorously-proven stability properties. Relevant approaches may hence look in several directions, including for instance active learning to reduce the number of samples and the corresponding computational effort required to learn the approximate MPC law; supervised/unsupervised learning with possible dual-mode implementation to safely merge optimal explicit solutions and deep neural approximations; learning dynamic output-feedback MPC laws by using recurrent neural networks. The thesis will thus focus on the theoretical soundness of the proposed approaches to learning-based controller approximation, algorithmic aspects, and on testing the effectiveness of the developed methods on case-studies of practical relevance spanning from automotive and aerospace applications to industrial process and energy dispatch control.

Specific Information:

We are looking for a motivated and talented PhD student with strong mathematical background in systems and control, numerical optimization, and machine learning. Coding skills, as well as proficiency in both spoken and written English, are required.

*Note that IMT offers free board and lodging for Ph.D. students during the course.

References:

[1]. Bemporad, A. (2022). A piecewise linear regression and classification algorithm with application to learning and model predictive control of hybrid systems. *IEEE Transactions on Automatic Control* (conditionally accepted for publication).
[2]. Bemporad, A. (2021). Training recurrent neural networks by sequential least squares and the alternating direction method of multipliers. *arXiv preprint arXiv:2112.15348*.
[3]. Bemporad, A., Morari, M., Dua, V., & Pistikopoulos, E. N. (2002). The explicit linear quadratic regulator for constrained systems. *Automatica*, *38*(1), 3-20.
[4]. Breschi, V., Piga, D., & Bemporad, A. (2016). Piecewise affine regression via recursive multiple least squares and multicategory discrimination. *Automatica*, *73*, 155-162.
[5]. Fabiani, F., & Goulart, P. J. (2021). Reliably-stabilizing piecewise-affine neural network controllers. *arXiv preprint arXiv:2111.07183*.
[6]. Fabiani, F., & Goulart, P. J. (2022). Neural network controllers for uncertain linear systems. *arXiv preprint arXiv:2204.13209*.
[7]. Hewing, L., Wabersich, K. P., Menner, M., & Zeilinger, M. N. (2020). Learning-based model predictive control: Toward safe learning in control. *Annual Review of Control, Robotics, and Autonomous Systems*, *3*, 269-296.
[8]. Karg, B., & Lucia, S. (2020). Efficient representation and approximation of model predictive control laws via deep learning. *IEEE Transactions on Cybernetics*, *50*(9), 3866-3878.

[9]. Maddalena, E. T., Moraes, C. D. S., Waltrich, G., & Jones, C. N. (2020). A neural network architecture to learn explicit MPC controllers from data. *IFAC-PapersOnLine*, *53*(2), 11362-11367.
[10]. Mayne, D. Q., Rawlings, J. B., Rao, C. V., & Scokaert, P. O. (2000). Constrained model predictive control: Stability and optimality. *Automatica*, *36*(6), 789-814.

Type of scholarship:

DM 351/2022 – Project on PNRR (Italy's Recovery and Resilience Plan)

Study and research period outside the Hosting Institution:

- Period length: 6 months;
- Hosting institution:
  - University of Oxford - Department of Engineering Science
  - Parks road OX1 3PJ, Oxford - United Kingdom
  - https://www.ox.ac.uk/ - https://eng.ox.ac.uk/