POLITECNICO DI MILANO

PhD in INGEGNERIA DELL'INFORMAZIONE / INFORMATION TECHNOLOGY - 39th cycle

Research Area n. 3 - Systems and Control

THEMATIC Research Field: LEARNING-BASED MODEL PREDICTIVE CONTROL BY EXPLORATION AND EXPLOITATION IN UNCERTAIN ENVIRONMENTS

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The research activity is part of the project LEPCO-EX2, financed by the call PRIN 2022 PNRR. Solving optimal control problems (OCP) is an effective tool for the design of operation policies for autonomous systems. In principle, OCPs are decision-making problems in dynamic environments, trading-off conflicting objectives and guaranteeing safety, intended as the satisfaction of hard constraints. However, their classical formulation is fully model-based, possibly handling process disturbances and measurement noise. When the process model is not fully known or its dynamics are too complex to be described adequately, uncertainty must be modeled and handled in the OCP. Learning-based techniques have emerged as a feasible approach for developing optimal controllers for unknown/uncertain systems. Advances in information and communication technology permit the collection of a large number of measurements from industrial plants. When enough plant data are available to develop autonomous control strategies, there exist two main approaches. In standard model-based design procedures, a model of the process is estimated or identified and then employed to design a control system in a two-step design. These approaches exhibit passive learning characteristics, since

	the uncertainty model is given a priori, possibly derived from the initial batch of data, and no new information is extracted during the system operation to improve the knowledge about the dynamics or the disturbances. Recent approaches to the OCP for uncertain systems consider the online update of the uncertainty model in an active learning MPC framework. These approaches use the feedback measurements to simultaneously learn the process dynamics and also to derive the optimal input signal. This project aims to formulate a framework for the simultaneous learning and control of dynamic systems, able to cope with uncertain and time-variant dynamics or environments, within a receding horizon control framework. The proposed strategies will integrate active learning actions to exploit information about the process generated online during optimal closed-loop operation, without artificially generating informative conditions and without performing independent/enforced system identification experiments during the operation. The proposed strategies will integrate active learning actions to exploit information about the process generated online during optimal closed-loop operation, without artificially generating informative conditions and without performing independent/enforced system identification experiments during the operation.
Methods and techniques that will be developed and used to carry out the research	The first element of the framework is the representation of the system evolution and the environment. Limited complexity models, such as nonlinear auto-regressive models, will be considered in a first attempt, in particular, set membership nonlinear systems, that are able to provide deterministic uncertainty bounds in the predictions and are easily adaptable as new data are produced. Alternative models, such as Gaussian Processes or Recurrent Neural Networks will be also evaluated. The dual-control approach for learning in control will be treated as an exploration-exploitation process. This method has already been employed by the team for solving black-box optimization algorithms by using set membership surrogate models to learn the cost function and the constraints of non-convex optimization problems. It can be noticed that the iterative test-and-learn approach of

	exploration-exploitation dual-control shares several features of Reinforcement Learning (RL) solutions in machine learning. The thesis project will propose alternative algorithms to incorporate active model learning within the optimal control policy of the MPC framework, i.e. the input sequence produced by the MPC will enforce both learning (exploration) and control (exploitation). The validity of the approaches will be evaluated on two different applications, namely an active noise control (ANC) system and an energy management system (EMC). Both real-time simulations and experiments will be used during the project development to assess the validity of the different building blocks of the learning-based control strategies.
Educational objectives	In addition to the training goals that are common to the whole curriculum in Systems and Control of the PhD in Information Technology, pertaining to advanced control, estimation and machine learning methods and transferable skills, this program will have a focus on system identification and optimization: the PhD candidate is expected to develop deep knowledge of advanced solutions to improve reliability and sustainability of complex and uncertain system.
Job opportunities	Upon completion of the three-years-long program, the Doctoral graduate will have strong theoretical and practical knowledge in the field of optimization-based control and estimation, which will allow her/him to pursue either a career in industry, with either a R&D or a project management role in fields like power and energy systems and more in general of control and automation for industrial systems, or in academia, deepening the fundamental research on uncertain and time-varying systems.
Composition of the research group	0 Full Professors 2 Associated Professors 1 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Fredy Orlando Ruiz Palacios

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information

The research team is composed by two research units: Politecnico di Milano (POLIMI) and Università di Genova (UNIGE). The POLIMI research team has strong expertise in the analysis, design, and implementation of learning-based control and optimization strategies, whereas the UNIGE team has excellent skills in the efficient implementation of real-time/embedded optimal control strategies. The doctoral student will interact with both units.

EDUCATIONAL ACTIVITIES (purchase of study books and material, including computers, funding for participation in courses, summer schools, workshops and conferences): financial aid per PhD student.

TEACHING ASSISTANTSHIP: (availability of funding in recognition of supporting teaching activities by the PhD student) There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.

COMPUTER AVAILABILITY: individual use

DESK AVAILABILITY: individual use