Development of integrated methods across Control Theory and Artificial Intelligence

Context of the research activity

Development of integrated methods across Control Theory and Artificial Intelligence for optimal control and predictive maintenance in industrial automation

The research activity strategically lies at the intersection among two disciplines of great theoretical relevance and experimental impact: artificial intelligence and control theory. Both disciplines have been witnessing a rapid and outstanding development in the last decades. More recently, they shared a privileged role in a number of relevant domains, such as the estimation of dynamical models for the prediction of the behaviour of complex systems under the paradigm of the so-called Cyber-Physical Systems.

The interaction among artificial intelligence and control theory has been the object of a fruitful research activity initiated in 2015 under the INCIPICT project (http://incipict.univaq.it). Such activity has prosecuted within the aims of a number of other projects (such as EXEMERGE http://exemerge.disim.univaq.it, iRel4.0 https://irel40.mind-net.org, VALU3S https://valu3s.eu). The research focus has mainly addressed the integration among machine learning methodologies and two relevant fields of application: industrial automation and ICT technologies for the monitoring and supervision of complex systems.

One of the main problems to face under the “Industry 4.0” paradigm is surely the enabling of advanced optimal control and predictive maintenance strategies in complex large-scale systems. To reach this goal, one must be able to derive accurate mathematical models of complex systems, which is usually prohibitive in most real-life scenarios due to the lack of adequate physical modeling, or simply for cost and complexity reasons. Climate control systems (Heating, Ventilation and Air Conditioning - HVAC) of large smart buildings that are based on SCADA platforms constitute an ideal example of systems for which it is way more costly to derive a precise mathematical model, than the savings one is expected to obtain thanks to energy optimization based on such model. Structural health monitoring systems constitute another example: deriving precise mathematical models of any building, bridge, or general structure of interest is not achievable in practice.
The research will be conducted at the University of L'Aquila: the use of telematic co-working tools will allow to pursue the research objectives also in case of Covid related restrictions to physical presence in L'Aquila.

Moreover, the research activities will benefit of a long-term collaboration between the University of L'Aquila and the University of Pennsylvania, with exchange visiting periods foreseen, and a recently started collaboration with SIGIT S.p.a.

### Objectives

The objective of the whole research activity, and the core of this PhD project, is to develop novel theoretical algorithms at the intersection among control theory methodologies (such as Model Predictive Control, System Identification, Kalman Filtering, Fault Detection and Isolation) and machine learning (such as Regression Trees, Random Forests, Support Vector Machines, Kernel methods and Neural Networks).

The goal of such novel algorithms is to build accurate dynamical models of complex systems in the paradigm of industrial automation, which can be impossible in practice due to costs, complexity or limited knowledge of the actual system. The estimation is expected to be carried out leveraging historical data collected on ICT devices, mutually interconnected and monitored by data acquisition systems such as SCADAs. Such predictive models have to be built in order to favor the direct application of optimal control strategies and predictive maintenance, as well as allowing diagnostic methodologies for faults/attacks/non-nominal events.

An ongoing collaboration is envisioned with SIGIT S.p.a. for validating the methodologies developed during the PhD in a real industrial automation environment. In addition, past activities at UNIVAQ on those topics also allow the candidate to fully access experimental “Living Laboratory” structures, which consist of SCADA systems for data acquisition and supervision of climate control systems, photovoltaic and electric systems and a network of accelerometer sensors for structural monitoring in 4 buildings at the University of L'Aquila campus (“Dipartimento di Scienze Umane” building, “Renato Ricamo” building, “Casetta ESI", Palazzo Camponeschi), on which various experiments have been carried out in the last years, testified by a large number of scientific publications.

### Skills and competencies for the development of the activity

Due to the interdisciplinary nature of this PhD project, the ideal candidate should have a strong background in Mathematics and in at least one of the following disciplines:

1. Advanced techniques of Machine learning
2. Advanced methodologies of Control Theory

The ideal candidate is expected to have the willingness to improve her/his knowledge in the aforementioned disciplines.

A good knowledge of Python and/or MATLAB programming languages, along with the basics of coding, is also expected.

The activities of this research project, to some extent, can be adapted to the profile of the winning candidate, resulting in a more theoretically-focused project with validation on experimental datasets, or the development of new tools and algorithms with application to real industrial systems.