Doctoral Dissertation
Doctoral Program in Computer and Control Engineering (35^{th}cycle)

Investigation of innovative IoT technologies for complex manufacturing process modelling and optimization

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Abstract

The aim of this Doctoral research is to investigate innovative solutions aiming to leverage the potential of Internet of Things (IoT) technologies within the manufacturing environment, especially focusing on complex industrial processes. The research can therefore be considered to fall into the realm of Industry 4.0 (I4.0) and, within this framework, if one looks at the I4.0 clusters which were identified by the Italian Government's "Piano Nazionale Industria 4.0" in 2016, it would aim to focus on the "Big Data & Analytics" cluster.

In order to strengthen the link between academic research and industrial applicability, the research focuses on industrial areas which are considered critical for their impact on manufacturing performance (cost, quality, delivery), taking into consideration also aspects such as readiness, cost, robustness, reliability and flexibility during the investigation. If the costs and, especially, losses of an average industrial company are stratified, for example, the main priorities are usually related to manpower. However, if the affinity with the cluster "Big Data & Analytics" is also considered, Energy results being the main priority. Following this prioritization, the research has focused on highly energy consuming processes, because of the weight of the cost of energy in manufacturing systems.

When integrating the energy topic with the I4.0 cluster of Big Data & Analytics, the research naturally falls under the realm of Smart Grids. Within this realm, better coordination between power demand and supply can be achieved by implementing innovative applications, for example real time forecasting or demand response. For such applications to work effectively though, the ability to effectively forecast both power demand and supply with different forecast horizon has become increasingly important. When looking at innovative solutions for forecasting, with the support of Big Data & Analytics, one enters the Machine Learning (ML) realm: ML methods have gaining significant popularity in the forecasting field, particularly those based on

Artificial Neural Network (ANN) models, which present substantial improvements in forecasting modelling compared to benchmarks. The research therefore focuses on developing innovative solutions for the effective forecasting of both power demand and supply, leveraging ML methods and particularly those based on ANN.

The investigation was originally supposed to be carried out on an industrial building case-study, however due to the Covid-19 emergency access to the site was restricted and the research activities were significantly slowed down. Alternative case-studies were therefore identified, which could easily be replicated in the industrial reality.

In terms of forecasting power demand, the research focuses on energy consumption in buildings due to Heating, Ventilation and Air Conditioning (HVAC) systems, and on their relation to in-door air temperature, developing an innovative solution for the effective forecasting of building in-door air temperature and, as a consequence, of power demand. In terms of forecasting power supply, considering current soaring investments in clean electricity and electrification, particularly solar photovoltaic (PV), the research focuses on developing an innovative solution for effective forecasting of photovoltaic power generation. Both solutions are tested and validated on two different real-life case studies. A common methodology applicable to both case studies is developed, leveraging IoT sensors to collect real, but limited, data, and simulators to generate artificial, but accurate and realistic, datasets large enough to effectively train and test different ANNs. The methodology also includes Transfer Learning (TL) to further improve forecasting accuracy.