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A management framework for smart manufacturing applications in Industry 4.0

By

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The fourth industrial revolution, or Industry 4.0, began in 2011 at Hannover Fair with a focus on computerizing manufacturing. The combination of Internet of Things (IoT) and Machine Learning (ML) facilitated this revolution by enabling plants to connect to cloud services, collect previously unavailable data, and enhance production. The paradigm shift has transformed the manufacturing industry and has the potential to revolutionize other industries as well.
The emergence of Smart Manufacturing systems like Additive Manufacturing (AM) created new customer experiences and business models. However, Industry 4.0 requires appropriate management frameworks, new types of devices, and services, suitable communication, and energy efficiency. In the past years, huge amounts of data began to be produced by companies from industrial plants. However, in most cases, these data are only used for basic checks or disregarded entirely because a suitable platform to collect and analyze them is missing. In this context, researchers and companies concentrated on developing ad-hoc solutions for data collection and analysis based on the industrial use cases and machines they needed to analyze. Moreover, due to the complexity of industrial infrastructures, they mainly focused on a fast and simple collection of data without developing structured data management frameworks, as their main goal was only the analysis of data. By analyzing the current state-of-the-art, it is possible to observe that a management platform for heterogeneous industrial contexts is missing.
To address the problem of the lack of a general platform that could be applied in different industrial scenarios, my research activities focused on the development of an innovative microservices management framework to collect, manage, process, and analyze the data available in different smart manufacturing contexts, from Automotive to Aviation fields. The framework consists of several services with the objective to collect and manage the data provided by users and machines (Backend), visualize the data stored (dashboard and frontend), and provide an easy way to analyze them in order to improve the overall production line by exploiting AI and ML algorithms (e.g., defect detection algorithms, profile monitoring). I designed and validated the platform, IoT devices, and the data analysis methodologies proposed in different

Industry 4.0 scenarios: i) Smart Industry, ii) Smart Manufacturing, iii) Smart Sensors integration, and iv) Smart Energy.

In the industrial context, in order to store the data available, I integrated the platform developed in an AM production line. Then, I focused on the manufacturing process by analyzing the data collected, and I proposed several services for the framework to address most of the AM problems. I designed an in-situ monitoring system for the analysis of Laser Powder Bed Fusion (L-PBF) process, where I implemented ML algorithms based on images to detect typical defects on the powder bed and monitor the profile of the object during the printing process. Due to the small number of data available with defects, I also integrated a Generative Adversarial Network (GAN) to create synthetic images with defects from the images available.

Next, I moved towards Electron Beam Powder Bed Fusion (EB-PBF), another AM process, where I proposed a methodology for anomaly detection in order to predict in advance the success or failure of a printing job. Finally, I focused my research on the analysis of quality inspection procedures utilized for aircraft engine components with the aim of reducing the whole inspection time, ensuring higher quality, and guaranteeing standardization and process control.

In the context of smart sensors, I analyze the performances of several Artificial Intelligence (AI) algorithms and methods for the localization of industrial vehicles with IoT devices inside and outside a warehouse.

Regarding the smart energy context, I proposed an ML methodology for Global Horizontal Irradiance (GHI) predictions in short-, mid-, and long-term starting from exogenous inputs (i.e., physical factors related to the weather). The GHI is particularly important in the industrial context to forecast photovoltaic production and develop business models for energy efficiency.

In this thesis, a properly structured management framework suitable for data collection and analysis in different industrial contexts (e.g., automotive and aerospace production lines) is proposed and implemented. Besides, a set of ML and AI algorithms are presented and integrated into the platform in order to analyze the data collected from the different scenarios and provide insights to improve the overall processes (e.g., smart manufacturing, industrial localization, energy forecasting).