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A LABORATORY DEMONSTRATOR OF SIMULATION-BASED DIGITAL TWINS FOR SMART MANUFACTURING

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ABSTRACT

To benefit from the functionalities of digital twins (DTs), it is essential to guarantee a correct alignment between a manufacturing system and the associated digital model along the whole system life cycle. This work presents a case study that serves as proof-of-concept of the operational phase of a DT. The demonstrator exploits a lab-scale manufacturing system as physical twin and concentrates on the development of two main components of the DT architecture: (1) synchronization and (2) validation. The results confirm the applicability of the proposed DT architecture to enhance the performance of a manufacturing system.

1 INTRODUCTION

The digitization of processes within the context of Industry 4.0 has sparked an interest toward research on Digital Twin (DT) (Tao et al. 2019). In manufacturing, the DT is defined as: *"a virtual representation of a production system that is able to run on different simulation disciplines that is characterized by the synchronization between the virtual and the real system"* (Negri et al. 2017). To develop a DT, a bi-directional communication capability between the system and its digital counterpart is needed. Within a production planning and control scope, the digital counterpart of a manufacturing system can be a Discrete Event Simulation (DES) model, given the capabilities of this technology in analysing complex and dynamic systems. In addition, the DT has to be able to represent in real-time the behaviour of the physical system and to adapt in case of disruptions and changes in the shop-floor configuration (Lugaresi and Matta 2018).

2 DIGITAL TWIN ARCHITECTURE

This work develops the high-level DT architecture depicted in Figure 1a. Exploiting the sensors of the manufacturing system, it is possible to collect and store field data in real-time. The presence of a bi-directional flow of information enables to automatically feedback actions to the physical system. In order to provide the aforementioned DT functionalities and support short-term decision making, the digital model must be capable of adequately reproducing the dynamic behaviour of the system. This condition is done by two main procedures, namely (1) synchronization, and (2) validation. Each is implemented within a dedicated software component in the DT architecture. The validation component checks in real-time whether the model is correctly built by comparing a set of real and digital data and measuring their similarity level (Lugaresi et al. 2022). This component is able to validate both the model logic and its input data

a) b)

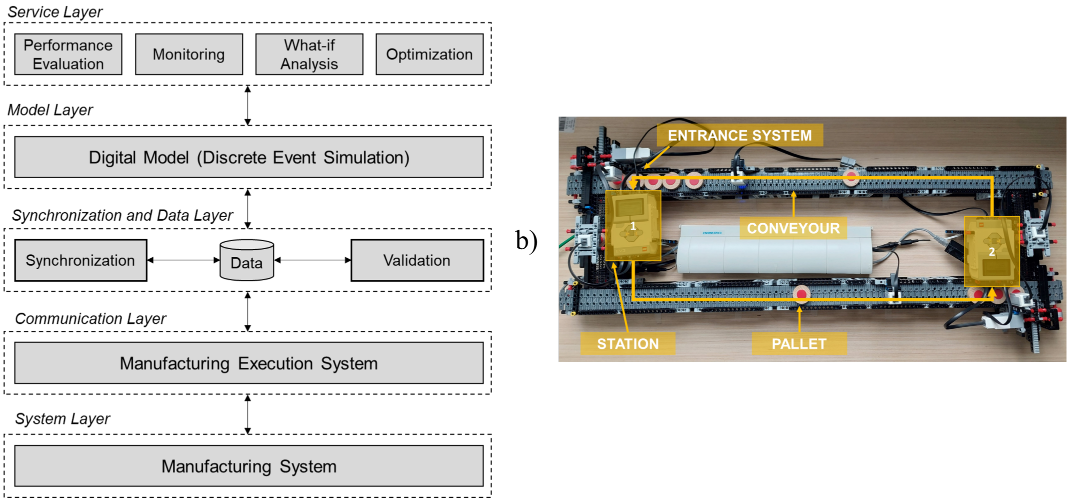

Figure 1: a) Digital twin architecture used as reference in this work; b) lab-scale two-station closed-loop manufacturing system used for the case study.

distributions. The synchronization component consists of a control which, based on the validation results, manages and deploys aligning actions to ensure that the simulation model correctly reflects the state of the physical system at any time. Once the digital model is properly validated and synchronized, the DT can be used to provide services such as monitoring, performance evaluation, what-if analysis, and optimization.

3 CASE STUDY

The DT architecture is implemented in a demonstration exploiting a two-station closed-loop lab-scale manufacturing system (Lugaresi et al. 2021), shown in Figure 1b. As production starts, field data is collected and stored into a time-series database. The simulation model is automatically generated and synchronized. The online validation procedure checks if the digital model reflects the behaviour of the real system in terms of logic and input. In order to validate the operational capability of the DT, a disruptive event is initiated on the manufacturing line. Specifically, a sudden degradation on one of the stations occurs while the production is still in progress. The result is a change in the physical system configuration, which is initially not reflected in the digital model. The DT is able to detect the disruption through the input validation procedure, then respond by synchronizing the model to the new conditions. This physical-digital alignment allows to use the DT to provide a smart manufacturing service :a what-if analysis is performed to decide among two alternatives, and the best one in terms of expected throughput is automatically implemented.

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