THE ROLE OF DIGITAL TWIN IN A CYBER-PHYSICAL PRODUCTION ENVIRONMENT WITH PRESCRIPTIVE LEARNING

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ABSTRACT
In this paper, we introduce the establishing of digital twins for cyber-physical production systems. Using industrial PLC network and a discrete event simulation tool a live and interactive connection is made between the physical and cyber world. Based on this achievement a modified proactive framework with prescriptive simulation will be presented.

Keywords: cyber-physical production system, digital twin, proactive and prospective planning

1. INTRODUCTION

In the last years Industry 4.0 has got an increasing role within production environments. It is based on cyber-physical systems (CPS), where the physical and cyber (virtual) elements are in close interaction with each other. In such environments, the data collection and analysis is made in a networked structure. In production environments, cyber-physical production systems (CPPS) are evolving. This progress is based on three main science fields: computer science (CS), info communication technologies (ICT) and manufacturing science technologies (Monostori et al. 2016)(Schleich et al. 2017)(Enke et al. 2018).
Cyber-physical production systems are horizontally and vertically integrated environments, where the planning processes of products, technology, production and logistical system are digitally interconnected and permeable (Ochs and Riemann 2018)(Vogel-Heuser, Bauernhansl, and Ten Hompel 2017)(Ustundag and Cevikcan 2018, 4).
One of the main features of cyber-physical production systems is the Digital Twin model. These virtual models are mirroring the real world into the cyber space with the appropriate level of detail (Deloitte 2017)(Negri, Fumagalli, and Macchi 2017)(Post, Groen, and Klaseboer 2017).
Through the digitalisation of production, the Digital Twins can have a live connection to the real world, bringing its physical state changes directly into the virtual world. This enables a reactive or proactive planning using simulation as well (Dr. Pfeiffer 2017)(Stark, Kind, and Neumeyer 2017)(Uhlemann et al. 2017).
Figure 1. presents a simulation-based prediction framework. In Figure 1, Plant represents the underlying production system, which is generally controlled through the MES. Thus, green arrows represent production related data provided by the plant (e.g., resource status, job completion, or, the performance measure of interest KPI in the current case), either gathered by the MES and stored as log data, or, monitored on-line by, i.e. the simulation framework. Contrary, grey arrows represent an interaction or information exchange, e.g., the Decision-maker might control the process of the production (highlighted as Reaction) of the plant by the MES system.

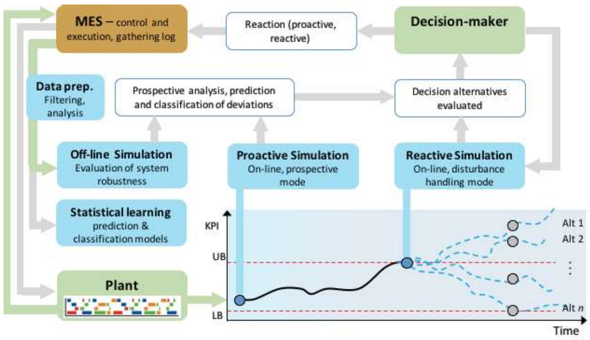

Figure 1: Simulation-based prediction framework (Dr. Pfeiffer 2017)

In a real-world application, three main distinct operation modes follow each other during operation.

- Off-line validation, sensitivity analysis and statistical modelling of the system. Evaluation of the robustness of the system against uncertainties (e.g., different control settings, thresholds and system load levels). Consequently, this scenario analysis might point out the resources or settings which can endanger the normal operation conditions. In Figure 1 off-line simulation represents the comprehensive model of the plant.

- On-line, anticipatory recognition of deviations from the planned operation conditions by running the simulation parallel to the plant activities; and by using a look ahead function, support of situation recognition (proactive operation mode, Fig. 1).
- On-line analysis of the possible actions and minimization of the losses after a disturbance already occurred (reactive operation mode, Fig. 1), e.g., what-if scenario analysis.

In this paper, we would like to present how a real-world application and a simulation-based predictive and prescriptive framework can be connected.

2. DECRIPTION OF THE CYBER PHYSICAL SYSTEM

The laboratory of the Department of Automobile Production Technologies at the Széchenyi István University has a FESTO Didactic System with modular elements. Figure 2. represents the 3D digital model examples of those elements.

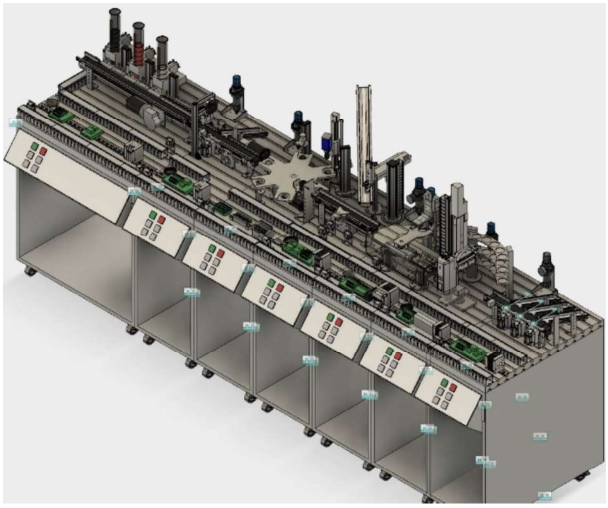

Figure 2: FESTO Didactic System 3D digital model

The modular FESTO Didactic line components of this system are controlled by Siemens S7-300 PLCs. These are linked through a switch and then a main central control is delivered by an S7-1500.

The physical connection between the computer and the system is provided by the S7-1500 PLC. The data communication between machine-to-machine is realized by the currently available most modern communication protocol OPC UA. As the OPC UA server S7-1500 PLC provides the central control.

Two example system components are shown by Figure 3. The first one is the starting station; this unit delivers the basic parts for the small production process. The delivery sequence can be predefined using the systems own control mechanism, or through the later described network architecture. The second example on the same figure is a machining station with a rotation table for different operations. It is planned to change the operation sequence depending on the parameters of the arriving part. The goal is to achieve a lot size 1 automated production environment without interruptions.

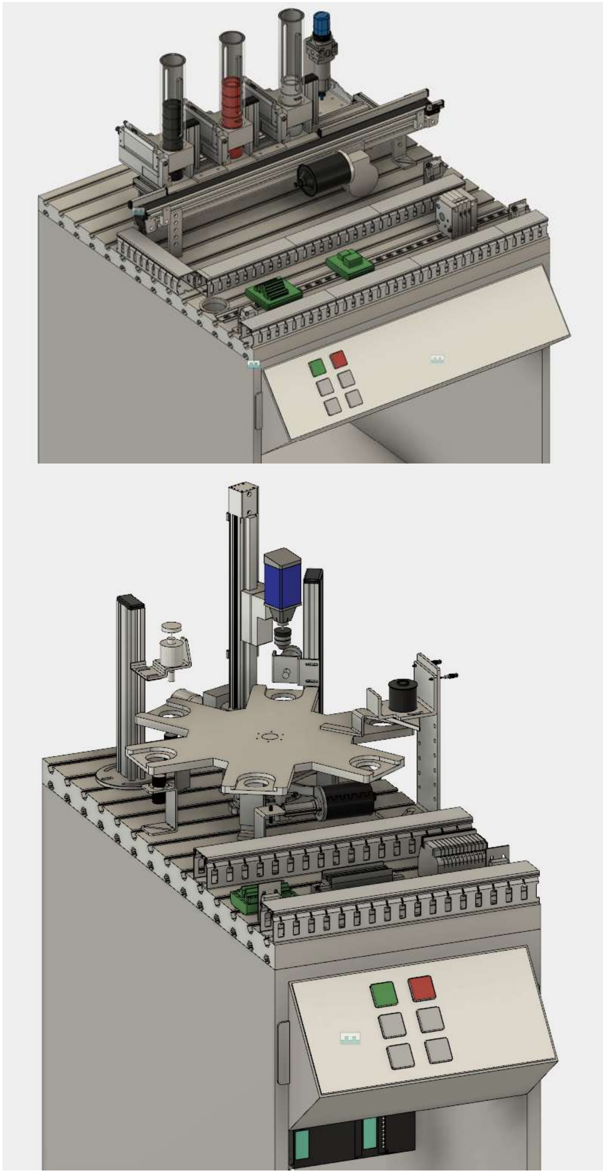

Figure 3: FESTO Didactic System example elements

The applied discrete event simulation (DES) tool is Tecnomatix Plant Simuation, which supports OPC UA communication, this software can collect and process data as a client.

Figure 4. Illustrates the architecture of the network and the connection with Plant Simulation.

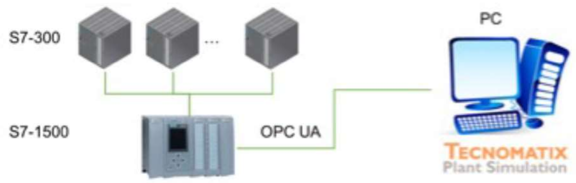

Figure 4: Network architecture using Plant Simulation

Originally the control and functionality of this mini factory is driven by a specialized software tool. In our work, we built up a live connection and communication with the simulation environment. Using the 3D digital models and the live communication a living digital twin has been established in DES environment.

There are several ways to establish communication among the machine-to-machine elements of the desired network architecture. The objects in our scope are Siemens products, therefore, the manufacturer's recommended solutions are considered, which are also used in industrial environments. These possible solutions are the following:

- Simit: Simit is a required interface at hardware and software level in a networked architecture. (PLC-Simit-PS)
- SimaticNET: it connects physically the tools with Ethernet functionality, and it also provides OPC support. The PLC-PC (PS, TIAPortal, SimaticNET) connection is created by the OPC server which is installed on the computer. It can be created using the support of softwares: TIAPortal and SimaticNET.
- OPC UA: the S7-1500 PLC 2.0 or newer firmware update provides the UPC-UA use on itself, furthermore version 14 of Plant Simulation supports OPC UA with a dedicated object. This way a direct contact between the PLC and PS using UPC UA communication protocol is provided.

The OPC Unified Architecture was born out of the desire to create a true replacement for all existing COM (Component Object Model) -based specifications without losing any features or performance. Additionally, it must cover all requirements for platform-independent system interfaces with rich and extensible modelling capabilities being able to describe also complex systems. The wide range of applications where OPC is used requires scalability from embedded systems across SCADA and DCS up to MES and ERP systems (Mahnke, Leitner, and Damm 2009).

OPC is used as system interface today; therefore, the reliability for the communication between distributed systems is very important. Since network communication is not reliable by definition, robustness and fault-tolerance are the important requirements, including redundancy for high availability. Platform-independence and scalability is necessary to be able to integrate OPC interfaces directly into the systems running on many different platforms (Mahnke, Leitner, and Damm 2009).

In the case of an active connection, the operating actual state of the PLC and its changes are continuously visible at the signal level in the simulation environment (Figure 5). By using sensor signals, the actual process can be mapped and modelled in real time, which is one of the pillars of creating a living digital twin. The simulation environment is then able to collect detailed real-time data to analyse system and process behaviour.

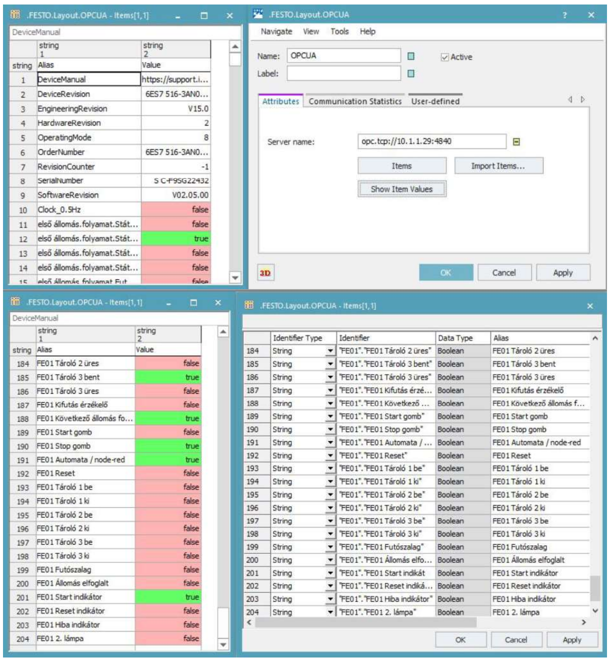
Figure 5: Mapped and modelled sensor signals for the Digital Twin

The OPC UA communication capability not only allows the reading of PLC signals but has also the capability of writing them. This architecture allows higher level of configuration and management, more complex logic can be applied than on the original PLC level.

The digital model of the physical system in the simulation environment is completed, the Digital Twin is able to monitor the individual workflows in real-time and collect the performance data (Figure 6).

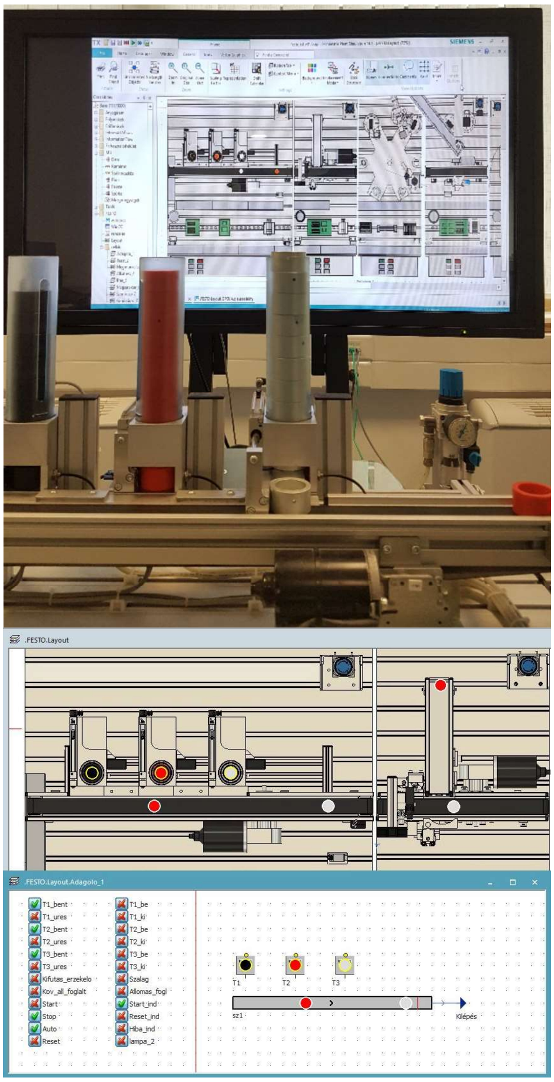

Figure 6: Physical system and its real-time Digital Twin

3. PROACTIVE PLANNING AND PRESCRIPTIVE SIMULATION WITH THE HELP OF DIRECT LINKED DIGITAL TWIN

The simulation based predictive framework introduced on Figure 1 can be extended with the functionality of prescriptive simulation (Figure 7.). The live and interactive connection between the physical and cyber counterparts enables data gathering, analysing and system configuration. Based on collected data, on statistical learning and on the ability to simulate different scenarios prescriptive alternatives can be evaluated. The results serve as basics for the decision making by classifying reactions on possible scenarios and deviations of the system under investigation.

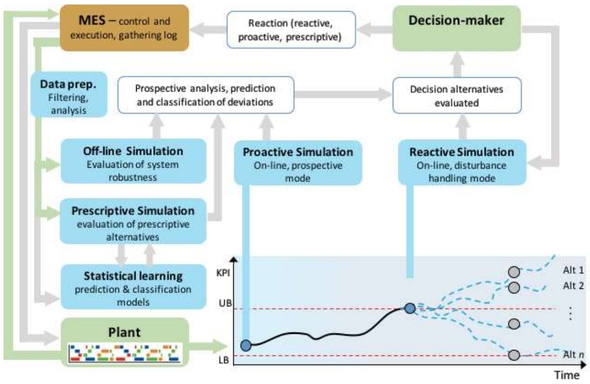

Figure 7: Proactive planning and prescriptive simulation

The simulation using the Digital Twin model of the system under investigation can provide prescriptive alternatives for different possible deviations or parametrizations. This can be achieved through statistical and machine learning functionalities. For this purpose, a separate but identical Digital Twin is used, which has no real-time connection with its physical counterpart, but is able to use control and log data of the MES system. Through experiment planning and several simulation-runs prescriptive alternatives are evaluated and stored. The cognitive decision making – which can also be a specialized Digital Twin model – can evaluate the current status of the plant or production process. This analysing step is able to use the prescriptive alternatives as the base of similar cases or historical data. After decision making the configuration is able to react back on the system. With the earlier introduced network architecture, a direct PLC field level configuration is possible as well.

4. SUMMARY AND OUTLOOK

In this paper, we introduced the establishing of digital twins for cyber-physical production systems. Using industrial PLC network and a discrete event simulation tool a live and interactive connection was established between the physical and cyber world. Based on this achievement a modified proactive framework with prescriptive simulation was presented.

In our future work, we are working on standardisation for automatic model building, and on machine learning capabilities using the above introduced framework. Furthermore, we are investigating the signal transmission and network communication speed, and its effects on the real-time digital twin.

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