On the Application of cyber physical Production Systems

How a digital twin of physical Systems can be created, updated and utilised in manufacturing automation

Michael Weyrich
Institute of Industrial Automation and Software Engineering
University of Stuttgart, Stuttgart, Germany.
michael.weyrich@ias.uni-stuttgart.de

***Abstract*— This paper presents latest research approaches in manufacturing automation based on cyber-physical systems. Three industrial examples are given to sketch how cyber physical systems particularly Digital Twin, change the engineering, commissioning and operation of manufacturing. This paper introduces the concept of the digital twin and discusses how it can be created and kept up-to-date throughout that lifecycle. Methodologies are presented on how engineering data can be interconnected, how a digital twin can be kept updated in operation and data can be used to learn and steer operation.**

***Keywords*— cyber physical production systems, digital twin, information management, learning control and cognition**

I. INTRODUCTION (*HEADING 1*)

Cyber physical systems are a novelty in the field of automation technology since they have been conceived around the year 2006 by [Lee]. Cyber physical systems are by definition a combination of the physical assets of a real plant and the world of data, information and software, which form the cyber aspect.

As depicted in Fig.1 physical manufacturing systems consist of machinery, robots, gages and logistical units. These physical assets of the plant are connected using information technology and comprise of multiple data which regard the engineering and the operation.

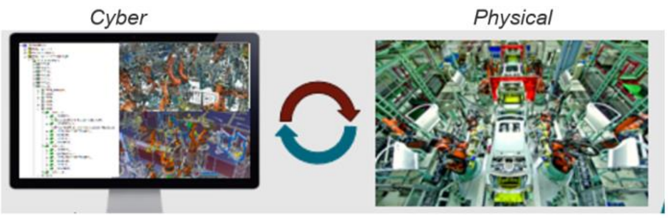

Fig. 1: Example of a cyber physical systems in Automtive Body and White production [4]

In today's manufacturing systems a very large diversity of e.g. hundreds of subsystems exists as there are multiple manufactures who integrate their systems with the subsystems of others. This results in an ongoing complexity of such systems making it very difficult to manage. The operation of such large scale systems demands for standardization, be it classification schemas for components and their grouping, information models etc. This is very much required as the linkage of components in Hard- and Software is extended. A change or update in one instance of a domain, e.g. a mechanical hardware device, may trigger multiple updates in other areas, such as in the electronics or software.

As a result, the automated manufacturing systems as of today and even more in the future are going to be a composition of software, data, which form a digital twin along with the electronics and mechanical hardware of the physical systems.

II. STATE OF THE ART

It was evident in research in the early 2000 (see for instance [3]) that the networking of physical assets results in a large diversity of data. A swarm of sensor systems capturing all types of information, stored in a cloud infrastructure accessible by mobile devices anywhere has become a reality today. Machine to machine communication systems, the "cloud" or internet-of-things (IoT) operating systems are available in terms of commercial products. Furthermore the product lifecycle of management activities have resulted in large Engineering backbone systems.

Due to the availability of these products, research questions evolve from a plain technical feasibility to the question of how to master the tremendous complexity of software systems and their data. Obviously the question is how the step toward cyber physical systems can be made, which assists a hybrid of "cyber" e.g. the information world and the "physical" world of hardware. [3, 4]

A physical system and its cyber part are being created which means in unison on a digital twin. As depicted in Figure 2 the characteristics and functionalities of physical assets are pictured by a digital twin along the life cycle.

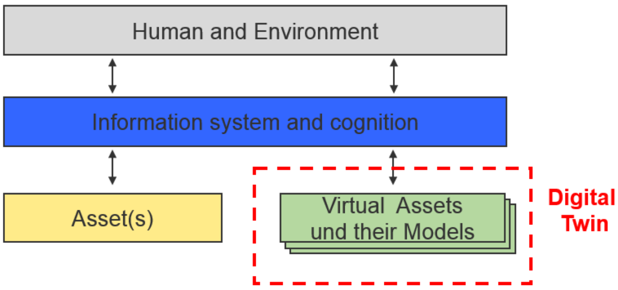

Fig. 2: A Digital Twin is a part of a cyber physical system

A full integration of cyber physical systems and availability of a digital twin, i.e. a cyber representation which could be managed in a cyber or physical way, is still a future vision [1, 2] as a number of frontiers of the automation technology as of today need to be overcome.

As it becomes evident from the interaction with experts in the field [6] the following issues have been raised and need attention:

- Improved techniques are required for establishing the communication between the components of the cyber physical systems in order to reduce the effort for interoperability.
- New types of standards, e.g. for the semantic processing of information, are required but are difficult to conceive.
- Means to manage the complexity of very large automation systems a yet to be invented.
- The topics of analytics, machine learning and artificial Intelligence need to be deployed to enable Self-X functionalities and present limitation in automatic adjustment of systems.

The outcome of the fulfilment of these aspects, a new way of how assets of the physical world are working with the digital twin, being the cyber part, would result in a new engineering and operation process for automation systems [7].

As Figure 3 illustrates the present engineering process as of to date, which is rather sequential and runs through the phase of engineering, commissioning and test until the operation and runtime of production starts. In some cases a retrofit might be an eventual stage in which the manufacturing is being rebuilt, before a new operation phase would start.

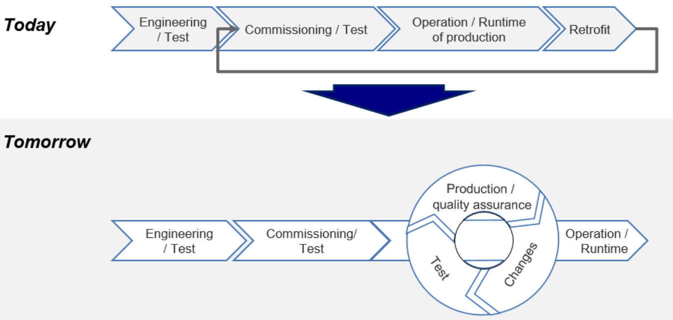

Fig. 3: Design moves to runtime in which changes are omnipresent

This means that once the production has commenced, a change of the system might be normal leading to a situation in which new products could easily be manufactured as the manufacturing would change that way.

Consequently, this implies an enormous paradigm shift as a continuous change is the normal mode of operation. This also means that traditional concepts of quality assurance become obsolete and dissolve with system testing [8].

III. Examples of Cyber-Physical Systems for Application in Manufacturing

An illustration of the usage of Cyber-physical systems based on examples of research work with major manufacturing and automation supplier companies; their perspectives are be highlighted:

1. The Engineering for Change and the modular configuration of systems
2. The maintenance of a digital twin once automatic changes in manufacturing are taking place
3. The utilization of big data for quality control during operation

All three provide an overview on present research challenges which are due to the extended availability of data and information which form the cyber part respectively utilize that information as a digital twin of the physical system.

A. Example 1: How to seamlessly integrate the multiple sub disciplines in digital twin in engineering?

To date automated manufacturing systems are designed by means of computer aided design systems (so called CAD or CAx-Systems). For many years these systems have been utilized during the engineering phase in order to design the mechanics, electrical wiring or the sequential control.

By doing so, different views of the design data are supported in the Engineering phase. As a result various computer-based models of a manufacturing system exists such as a description of the 3D appearance of the parts, the layout of the machinery in the plant, electronics, and models of the control software or administrative data of the various components. A large variety of these components can be administrated in commercial tools)* which interconnect the information in an extended database.

However many question arise on the seamless integration of the information in a digital twin. Product lifecycle databases)* entail the above mentioned data of mechatronic components from multiple domain but the data is very often not very well connected between each other. Once a change in the design happens all the different sources might be affected. For instance if a sensor is replaced by another model it is required to update the mechanics, the wiring as well as the software. Despite the fact that all data might be stored in a database, different CAx-tools need to be deployed to update the data. In practical application such updates lead to a significant amount of manual work which has to be done by human operators.

This problem leads to the research question of how a Digital twin can automatically be synchronized or at least how a computer aided assistance function can help update the data sets which from the digital twin of the manufacturing installation.

The Fig. 4 illustrates the information architecture of such an assistance system. A manufacturing cell is made up of data in the domain of mechanical design, electrical / electronic design and software. Each of the assets which are represented in the digital twin has three types of data which are stored in a repository or come from a library which is reused. Additionally the system entails information, e.g. on how the components are interconnected by means of a product structure.

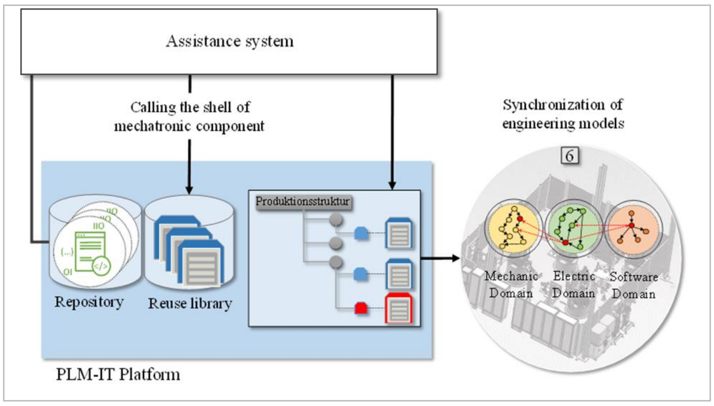

Fig. 4 Concept of an assistance system which keeps the digital twin of a mechatronic manufacturing up-to-date

A method for automatic detection of changes is researched based on the industrial setup on. In [5] we explain how so-called anchor points can be utilized to interconnect information models of the multiple domains.

The research work conducted has a strong empirical aspect and requires physical installations of manufacturing which should be typical machinery utilized in practice. In this work, the research campus Arena 2036 is the testbed for experiments which provides the required installation of "real life" machinery and a full set of state-of-the-art PLM/CAx tools.

We are very fortunate to have the installation of th Arena 2036 available for empirical research in order to understand how the cyber physical systems evolve in practice.

B. Example 2: How to manage the vast variety of information of manufacturing facilities in automotive?

In automated manufacturing in the automotive industry a huge variety of data is being created describing the manufacturing facilities. These data need to be systematically administrated over the course of time as product changes and updates happen during the operation phase.

Automotive manufacturing for instance in body-and-white has invented an elaborated set of methods and tools in order to obtain and administrate their data. Today, the manufacturing planning is based on Standards and De-factor Standards of the automotive manufacturing company and their equipment suppliers.

In Fig. 5 an outline of today's data is provided and the means on how to structure them. Many ideas on standard and schemas are already implemented in automotive, basically aiming towards the structuring of information. Be it by means of markup languages such as Automation-ML or specially released standards which are agreed upon by the stakeholders in the automotive community.

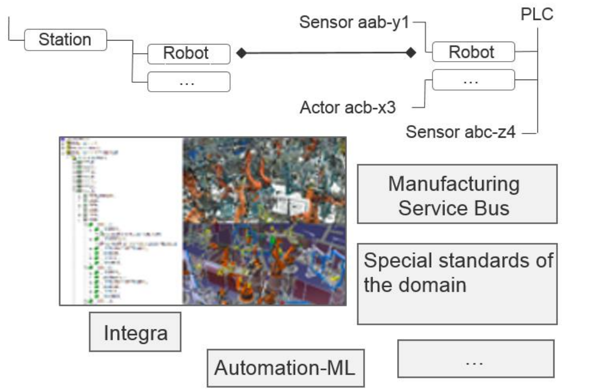

Fig. 5: Schemas for structuring engineering data in Automotive Body and White [4]

However, despite all efforts a central question on how to create transparency remains, e.g. by automatically interconnecting fragmented information. With the appearance of cyber physical systems and the digital twin this question becomes even more relevant as data is required for retrofits or a contours update of the cyber-physical equipment.

Should a new vehicle require adjustments in the manufacturing systems, all the planning data needs to be up-to-date. The work which is described in [4] analyses how planning data can be updated. This means it investigates on an automatic data update of planning objects based on multiple methods and aims to interconnect them.

In order to update the digital twin the following sources of information are engaged:

- Existing planning data which are stored in CAx-databases as per example 1
- IT Network Scan of all fieldbus systems in the shop floor can be utilized in order to capture all components which are utilized in the system
- 3D Scans of the shopfloor are undertaken to obtain volumetric data on all the physical installation
- High-resolution pictures of all installed systems with high resolution panoramic cameras which document all types of detail in the manufacturing

The research work on how to connect these pieces of information is ongoing, but will be very much required to create an up-to-date digital twin of the manufacturing line in operation.

C. Example 3: How to engage data driven qulity control during operation?

Sensor data entail information about the plant and process and can be analyzed to improve process quality. The control can be based on the process data obtained during operation and can be used for Prediction and optimization of product quality for automatic control or as recommendation of action for the operator.

In this setting the digital twin captures operational data which help to identify patterns which can thereafter be used for action proposals.

The ultimate goal for this research is that systems learn about dynamics and disturbances based on real process data.

As per Fig. 6 a special learning approach needs to be conceived in order to adjust the various quality loops which are responsible for the quality of the manufacturing operation.

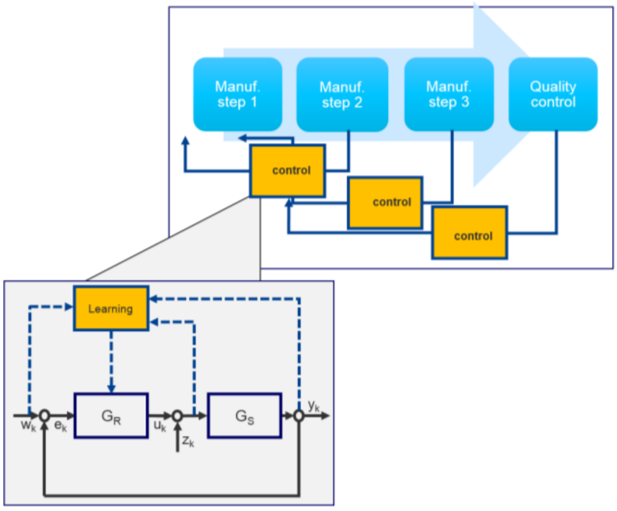

Fig. 6: Cascaded quality loops for learning control of manufacturing operation.

The research of [9] is based on terra byte of real factory data of machinery and all types of sensors to obtain that quality control. Results can be achieved by deploying learning algorithms. The challenge is however twofold: First: The structure of the model, the manufacturing and its quality control needs to be adequate. Second: known correlations and relationships in the process need to be available. Both aspects support the convergence of the algorithms. So far, anomalies in the manufacturing systems can be detected or even predicted which results in an adjustment of the control loops.

Conclusion

This paper presents a model for the digital twin as a core element of cyber physical production systems and provides scenarios on how the digital twin can be utilized in industrial application.

It is evident that the digital twin concept is very straight forward and clearly supports the engineering, commissioning and later operation. However, the work also illustrates the diversity of the various data sources which feed the digital twin. From the examples presented it becomes obvious that the synchronization of the digital twin with the physical world is albeit challenging, can provide an enormous potential as it enables a new way of work with a reconfiguration and optimization of manufacturing operation.

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