Analysis of the Industry 4.0 key elements and technologies implementation in the Festo Didactic educational systems MPS 203 I4.0

R Ružarovský¹, R Holubek¹, M Janíček¹, K Velišek¹ and G O Tirian²

¹Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Production Technologies, J. Bottu 25, 917 01 Trnava, Slovak Republic
²Politehnica University of Timisoara, Faculty of Engineering in Hunedoara, Department of Electrical Engineering and Industrial Informatics, 5 Revolution Street, Hunedoara, 331128, Romania

E-mail: roman.ruzarovsky@stuba.sk

Abstract. Industry 4.0 is one of the key words and strategies in current industrial production. It is important to define the Industry 4.0 strategy, analyse its objectives, and characterize the key elements and technologies of Industry 4.0. The Industry 4.0 concept uses the Industry 4.0 reference architecture, which assists and guides automated system developers in their design and construction, and of course in the development of a new assembly product. Given that the existing assembly system for education - Festo Didactic MPS 203 I4.0 is used to explore the possibilities of using digitization in design, it will be necessary to analyse this system in terms of reference architecture and key elements of Industry 4.0 implemented. The result is in conclusion of how deeply the key elements of Industry 4.0 are implemented in this educational system. The aim of this result was to create a digital twin of the system and test it in a virtual environment after the verification and validation of the digital twin model.

1. Introduction
The term Industry 4.0 was first introduced publicly by a group of representatives from various fields (such as business, politics, and academia) in 2011 as "Industrie 4.0" (German language) as part of an initiative to increase German competitiveness in the manufacturing industry [1]. Industry 4.0 is characterized by a continuous digitized connection of industrial production, leading to a fully digitized, intelligent, interconnected and autonomous factory [2], [3]. The result of Industry 4.0 is not only a change in technical production, but also extensive organizational implications and opportunities [4], [5]. A revolutionary change is taking place, of which we are a direct part, and it is important to understand this broad-spectrum issue on a global scale and then apply industry 4.0 subobjectives to the issues of production technology, robotics, automation of assembly processes and their design according to Industry 4.0 reference architecture [6]. The strategy is to use the potential and possibilities of the technical elements of Industry 4.0 and create conditions for the design and construction of assembly systems of the future in an automated, modern digital world, where monotonically repetitive work will be performed by an industrial robot cooperating with humans or other machines. People, machines, and means of production have to be able to communicate along the
entire value chain. Production systems are under pressure from consumers to meet the requirements and needs of end consumers.

1.1. Basic goals of Industry 4.0
As mentioned above, the implementation of the Industry 4.0 strategy aims to restore the competitiveness of industries through the deployment of cutting-edge technologies. The importance of deploying Industry 4.0 in highly developed industrial countries is to bring industrial production back through product innovation and production processes that use all resources efficiently for production. Changing global market trends and increased competition are forcing companies to produce customer-specific products and continually reduce service delivery times. As industrial production becomes even more complex and dynamic, companies will need to focus on the challenging goal of producing high-performance, customer-oriented products at the same cost as today to meet tomorrow's market needs [7]. The concept of single batch production and customization of products emerges. The automated assembly system has to be able to produce any product. The primary objectives of Industry 4.0 according to Syska [8] are defined as follows:

a) Product customization - Products are very adapted to the requirements of individuals in conditions of very flexible production (large series).

b) Production batch size 1 - The aim is to be able to produce products at the request of customers at a price as in series production. The production batch of one piece is essential in this case, Figure 1.

c) Horizontal and vertical integration - Overall interdisciplinary interconnection, extensive involvement of customers and business partners in economic and value-added processes, combining products and services to increase quality, Figure 2.

Figure 1. Mass customization vs. mass production and piece production, the relationship between costs and volume [9]
1.2. Main technologies and basic technical elements associated with Industry 4.0

It is important to become familiar with the basic meaning of the technical concepts of the key elements related to Industry 4.0. Industry 4.0 consists of the transformation of industrial production, which is driven by technological progress and guided by nine main technologies / pillars, which represent the vision of a productive system of the future, Figure 3. The main technologies represent a new interpretation for the production environment, which are interconnected and are mainly used to innovate the production system, respectively: manufacturing company.

**Figure 2.** Horizontal and vertical integration in Industry 4.0 production systems [10]

**Figure 3.** The Nine Pillars of Industry 4.0 - Transforming Industrial Production [11] : VR, AR, new HMI, Networking, horizontal and vertical connection, Cloud, Software as a service, Platform as a service, Infrastructure as a service, Data mining, artificial intelligence, 5G network, products with intelligence, Additive production, SLS e.g., Data safety, HRC and Cobots, Digital Twins

„Internet of Things“, „Big Data“, „Cloud Computing“, „Simulation“, „Augmented and Virtual Reality“, „Autonomy Robotics and Collaboration“, „Additive Manufacturing“, „Cybersecurity“ and „Integration of Horizontal and Vertical Systems“ are the key Industry 4.0 technologies mentioned in connection with the issues most often. Many of these nine advanced technologies / pillars of Industry 4.0 are already used in production either separately but are integrated with each other. However, the basis of Industry 4.0 is not to isolate these technologies, but to interconnect them and make full use of
them. Production, assembly lines and cells are connected into a fully integrated, automated and optimized production flow for higher production efficiency.

2. Analysis of the Industry 4.0 reference architecture for the key elements implementation
In the introductory chapter, the general objectives of Industry 4.0 and the related basic technological pillars of Industry 4.0 were defined together with the basic elements of Industry 4.0. How key elements work and how they can be integrated into assembly systems with specific solutions and examples of suitable implementation is the aim of this analysis. Design of assembly systems and their transformation into digital production or Industry 4.0 can be solved from two sides. The conditions for the transition to Industry 4.0 are different. If it is possible in terms of willingness to invest and all ideas for digitization are transformed into a completely new object with new equipment and processes, qualified staff, and a suitable management structure in combination with digitized value chains and completely compatible data. It is a classic top-down approach. If production is in the process and it is not possible to solve the project, so to speak, on a "bare field", or it is not certain whether the considerable resources spent on the transformation process will actually bring the expected benefits, then the assembly system for Industry 4.0 is moved and designed in smaller and manageable steps and is therefore a bottom-up approach. According to experts [12], both approaches are justified.

The top-down procedure according to the Industry 4.0 reference architecture model can be applied according to the so-called Industry 4.0 reference architecture model. The reference architecture is based on the publication "Guideline Industrie 4.0" [12], prepared by a group around the German and European Association of Mechanical Engineering Companies and Machine Designers and Manufacturing Plants VDMA. The guideline describes the reference model of the Industry 4.0 architecture and the procedure that takes into account the vision around Industry 4.0 and reduces them to feasible processes regarding the development of a new concept of the Industry 4.0 production system. This "VDMA Toolbox" manual is a procedure for implementing Industry 4.0, e.g., into the assembled product ("Toolbox Industry 4.0 Product") or assembly system ("Toolbox Industry 4.0 Production"). The main idea is to apply the tools and technical elements of Industry 4.0 in the development of a new product Industry 4.0 and in the design of production and assembly systems Industry 4.0 according to the presented model of reference architecture and guidance files "VDMA Toolbox" manual.

2.1. Industry 4.0 Product and Production According to VDMA Toolbox Manual
The "VDMA Toolbox Industry 4.0 Product" manual is intended to support the creation of ideas for the development of innovative Industry 4.0 products, Figure 4. The second part of the "VDMA Toolbox Industry 4.0 Production" manual deals with the production process, Figure 5.
The VDMA toolkit helps companies evaluate: “What is the current state of ours, what is the state of our technology, what technology have we already used?” And set goals: “What direction do we want to take in the coming years? What level would we like to reach? What makes sense for our customers, markets, and industries? In the first step, the current status is determined and defined in the appropriate toolbox. Then the desired state must be defined. The manual "VDMA Toolbox Industry 4.0" and its use will need to be explained on a specific example of an automated assembly system Industry 4.0 in the following chapter. These assembly systems are built according to the Industry 4.0 reference architecture model.

3. Design and application of the Industry 4.0 keys in the MPS 204 I4.0 production system
When designing automated assembly systems according to the Industry 4.0 reference architecture, it is important to rely on them and try to implement them into devices and systems according to the Top-down model according to the Industry 4.0 reference architecture model. When designing automated assembly systems, it is possible to use several key elements of Industry 4.0, which belong to the basic 9 technologies of Industry 4.0. The MPS® system 203 I4.0 assembly system from Festo Didactic, GmbH, Germany, Figure 6, will be used as a model for the Industry 4.0 reference architecture. This model is designed according to the "VDMA Toolbox" manual and this manual together with the operation of the integrated basic elements of Industry 4.0 is analysed, implemented, and evaluated in the following sections of this chapter.

It is a model of a small production line, which consists of three individual stations, where the product passes through the conveyors through all of them and creates a prefabricated product. Unlike conventional automated MPS stations from Festo Didactic, these stations have integrated several Industry 4.0 elements and technologies and, above all, are built according to the Industry 4.0 reference architecture.
architecture to be able to produce products customized in one-piece batches. This is ensured by the fact that each station contains an RFID code reader and a mounted product, the cylinder with a lid is equipped with an RFID chip. The assembly system executes orders from the MES system, which stores the product in the RFID chip and the product is monitored and contains production and operational information. At the first station "Distribution", the product as a cylinder is separated from the others in a gravity hopper and moved under an RFID reader, where data from the MES system are written. The second station "Assembly" is designed for automatic insertion of the lid on the cylinder by a pneumatic manipulator. The product decides on the basis of the order whether the lid will be fitted or not. The third station "Sorting" is designed to divide the assembled products into three places depending on the stored information.

Figure 6. The assembly system MPS® system 203 I4.0 and division into the stations

The testing and analysis of the assembly system shows that, in addition to the standard elements of automation, it also contains several elements and technologies of Industry 4.0, which result from the reference architecture: RFID technology, MES, Modularity, Big Data, Networking, OPC UA architecture, M2M communication, Predictive and "Smart" maintenance, Augmented reality and Cyber-physical system, Figure 7.
Figure 7. MPS® 203 I 4.0 – Industry 4.0 technologies implemented in the MPS

3.1. RFID technology - product controlled production

The basic element of Industry 4.0 is the implementation of RFID technology into products with respect to the reference architecture and product tracking in the process, as it is a customized product and the production of Industry 4.0 is focused on a one-piece batch. In the assembly system, an RFID chip is implemented in the cylinder and the data is written to it automatically via an RFID reader on the first "Distribution" station. Production data and material flow is recorded on the basis of the created order and is sent from the MES system. The product therefore composes the production itself on the basis of the created order. The MES system monitors the movement of the product via RFID counters at each station, Figure 8.

Figure 8. RFID chip implemented in a cylinder under an RFID reader

with RFID data in the MES system

3.2. MES system (Manufacturing Execution System)

The MES system is part of the automation pyramid. The automation pyramid contains a hierarchical structure that allows the various technologies and systems used to plan, manage, and determine the value creation process to be integrated into the various levels of the production plant. The focus is primarily on industrial production. The combination of tasks and levels allows you to map the entire order fulfilment process, including support, management, and delivery process, Figure 9.
Figure 9. Configuration of production parameters in the MES system

3.3. Modularity of the MPS system and devices

One of the ways to achieve the goals of Industry 4.0 to produce products customized in one-piece batches is to have machines, equipment, and assembly cells designed so that the entire assembly system is flexible, which is also defined by the reference architecture. Production resources must therefore be modularized. The entire assembly system is created in a decentralized manner, where the individual modules are designed as a separate cyber-physical system, a mechatronic system with its own control system and connectivity. The module should include a standardized interface so that the module can be connected to the assembly system and manufactured. Industry 4.0 defines this concept as "Plug & Produce". Modularity is important not only at the level of local automated equipment, but also at the level of machines, stations, assembly cells, or lines, Figure 10.

Figure 10. Modular design of the MPS assembly system feed module. The standardized interface is not only at the level of automated modules, but also at the level of stations via OPC-UA as machine-to-machine (M2M) communication

3.4. M2M communication, OPC-UA architecture

The basis is the communication between the various parties involved in production resources within their management systems. Industry 4.0 defines this as M2M machine-to-machine communication and describes the automated exchange of data between machines. In order for this exchange to occur, the machines must be networked and capable of data exchange. In the past, individual manufacturer's solutions were used, which allowed good communication between systems of the same type, but
never with third-party systems. OPC UA has brought a much more general standard. It is based on a software interface that includes the manufacturer's communication and sends it to generally accepted communication protocols. The MPS assembly system and its stations at the PLC level communicate via the OPC UA standard. The basis is a PLC series ET 200SP CPU 1512SP-1 PN from Siemens, which has a built-in OPC-UA standard, and data is exchanged via DeltalogicS7 / S5 OPC UA Server. The introduction of a communication standard at the OPC UA level is a prerequisite for communication between the individual stations of the MPS system. Individual stations are built on a platform called "Plug & Produce", which means that the station can be physically connected to others and immediately produced on it. This is due to IT technology. The station is configured so that it can be "called" in the MES system by assigning an IP address, and then the conditions for production and assembly are created, because the station is assigned operations (functions) on which they can be performed, Figure 11.

Figure 11. Configuration of stations with the "Plug & Produce" system in the MES system and in a structured data document in XML format

4. Evaluation of The MPS 203 I 4.0 According to The VDMA Toolbox Manual
Product Industry 4.0 according to the VDMA toolbox manual, so it is a tool to support product development towards Industry 4.0 products. MPS 203 I4.0 is already a product built on the principles of Industry 4.0. Based on the analysis and testing of the module, the individual indicators of the VDMA Toolbox manual were evaluated and it was determined to what possible level the product is transformed into the Industry 4.0 product, which can be seen directly in Figure 12.

In terms of integration of sensors and actuators into the product, the system has integrated sensors, it is at level No. 2, partly at level No. 3. The module communicates within the communication at level No. 4 or 5 with PLC or MES system via Profinet bus and can send the collected data at regular intervals. As for the functionality for storing data, it is at the interface of levels 2-3. It can store the collected data in the operational memory, but it does not have an integrated storage medium for storing data. The module has an integrated QR code for identification. Within the monitoring, the module is at level no.3. As for IT services and business model, it is not directly related to the product as such, but to the services of the manufacturer, which allows an online configuration of the module and thus the customer can participate in creating the model itself, while also having support for the service and other additional services.
There is no digital twin or MPS® system 203 I4.0 assembly system, resp. digital model. The aim is to create and implement this model in a simulation model and test it with control software using the tool "Virtual Commissioning".

5. **Digital twin of the MPS® system 203 I4.0**

When designing assembly systems, it is important to work and deal comprehensively with all pillars of Industry 4.0 according to the standards of the Industry 4.0 reference architecture. From the point of view of the design and construction of the assembly system as an area of production technology and production systems, it is adequate to rely in detail on the basic pillar of Industry 4.0 - the area of simulation and digital twin. This tool makes it possible to design, simulate, and verify the project of the assembly system in the preproduction stage before the actual commissioning of equipment, machines, industrial robots, and the entire system without the integration of the control system into the virtual model. The case studies were created in the Siemens Tecnomatix Process Simulate program so that the entire assembly process can be simulated and evaluated according to the sequence of individual operations in chronological order. This time sequence of operations is combined into one time loop and thus time-based simulation. The second way to use Industry 4.0 digital resources to design assembly systems is to use Event-based simulation. The advantage of creating an event-based simulation is the creation of 3D models of production equipment with integrated control logic, logical simulation uses Boolean algebra and analog signaling. The event-based simulation is based on real programmable logic control (PLC) code and hardware via the standard OLE process control (OPC) protocol. Therefore, this is "Virtual Commissioning".

**Figure 12.** Evaluation of the MPS 203 I4.0 assembly system according to the VDMA Toolbox manual.
The aim of the research is to identify the opportunities and uses of virtual commissioning technology. An existing assembly system that is in actual operation is used to examine these aspects. Tecnomatix Process Simulate software from Siemens PLM is used to implement virtual commissioning. The simulation is based on Event-based simulation and can be controlled by real PLC hardware. The first phase of the design deals with the analytical part of the assembled product, the assembly procedure and the analysis of the structure of the assembly process. Based on the analysis of the assembled product and the determination of the production batch, the assembly process will be planned. The assembled product will enter the assembly process as a model of a cylinder with a lid in three design modifications, which differ only in the materials used. By connecting the lid with the cylinder by insertion, the final assembled product is created. The assembly process will be performed automatically via the MPS® 203 I4.0 assembly system at three stations.

As can be seen in Figure 13, the virtual commissioning of an assembly system can be characterized as a simulation model, which includes a virtual system model (virtual object model, system layout, material flow) and a control system consisting of PLC, a control program (LAD - ladder diagram) and HMI control panel (Human Machine Interface).

The virtual model of the assembly system was tested and verified by a virtual commissioning tool, where the individual signals were mapped via the connection between Tecnomatix Process Simulate 14.0.1 and Siemens TIA Portal V14 also using the HMI panel control created in the SIMATIC WinCC V14 module. Signals created from logical behavior models were exported from the Tecnomatix Process Simulate 14.0.1 environment and imported as symbols into the PLC tag table.

6. Conclusion

The Fourth Industrial Revolution, known as Industry 4.0, is constantly evolving within manufacturing processes and technologies. Based on scientific conclusions and experience, this issue advances and is integrated into automated assembly systems, where the basic elements and technologies of Industry 4.0 are increasingly used. An important factor is that various tools already exist for the implementation of the basic elements and technologies of Industry 4.0, and the paper presents the basic architecture of Industry 4.0 from the point of view of the product and from the point of view of the assembly system with specific case studies. Digital technologies are used in the design in the preproduction phase, where the physical system is connected to the virtual one. The applicability of these new approaches in digital design was verified by creating a digital twin and performing a virtual commissioning of the automated assembly system MPS® system 203 I4.0 from Festo Didactic, GmbH, Germany.
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