SSN 2074-7888

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

Наукові праці
Донецького національного технічного університету
Серія: «Проблеми моделювання та автоматизації проектування»

№ 1 (), 2021

Покровськ – 27.05.2021

KEY TECHNOLOGIES OF AUTOMATION - A SHORT JOURNEY

Weyrich, Michael, University of Stuttgart, Germany

This article presents an overview from research with regard to the development of latest Industry 4.0 activities. Thereby for major technologies are presented from the fields of Modularity, Connectivity, Digital Twin, AI and Autonomous Systems. These technologies are discussed along with examples taken from research projects of the Institute of Automation Technology and Software Engineering of the University of Stuttgart.

Based on these examples, research trends are taken-up and used to illustrate a Journey into the future of automation technology, which is very relevant for the development of future industries in.

Key words: Modularity, Autonomous Systems, Mechatronic Modules, Networked Systems, Reconfiguration of Manufacturing Systems

1. Introduction

There has been much discussion about the future of automation in recent years. The topic of Industry 4.0 has been with us since around 2012 and has provided many impulses for the future, some of which have been implemented, are in development or research and will remain for some time to come. In this paper, we will give a glimpse at four key enablers of automation today and in the next 10 years.

Fig. 1 depicts the future technologies which are based on the concept of Modularity which are going to enhance automation technology in the next decade.

Apart from Modularity, the topics of Connectivity, Digital Twin and Autonomy are going to be key technologies in the coming developments and are going to determine the topic of automation over the next years.

2. Modularity as a stepping stone to future Automation

The increasing complexity of the industrial environment can only be mastered through Modularity [1]. What has been common practice for the products and their components in automotive and aerospace engineering for decades, will also continue to drive the manufacturing and process industry. Plants will all the more, be assembled from modules instead of looking for individual solutions.

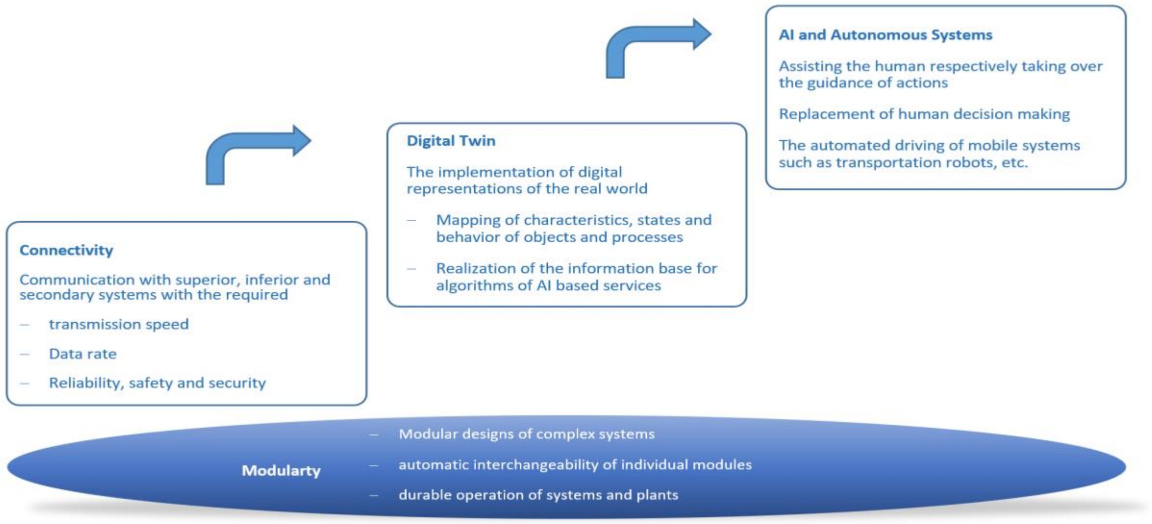

Figure 1: These four driving technologies will shape automation in 2030

Modular designs of complex Automation Systems save time for engineering, assembly and commissioning and reduces costs by using volume products.

A prerequisite of the individual modules are inter-changeability or interoperability in order to combine them quickly to systems and to have a resilient operation throughout the lifecycle.

Connectivity is the link between all components and modules. It is a prerequisite for a smooth flow of information. Of course, there are clear technological trends such as fast and real-time wireless communication technologies like 5G and successors [11].

In order to be able to use the data available in the devices - now or later - systems with open interfaces are increasingly being used so as not to create data islands. [2]

The Digital Twin being a key concept for digitalisation contains all the data of its objects [3]. It ranges from the development of the device type, the manufacture of the individual device, assembly and commissioning, from lifelong operation to recycling. With a Digital Twin, all the data of an object can be accessed from one place. It is important to preserve data digitally from the beginning and to store it in the Digital Twin and continuously update it. Data should not be stored in many different systems which are scattered around, but preferably in the Digital Twin which forms a so-called single source of truth. On this basis, data can be evaluated at any time and used for improvements.

3. Towards AI and Autonomous Systems

Autonomous Systems and AI are important trends and a big step into the future. AI can increasingly automate tasks that previously could not be automated or could only be automated with disproportionately high effort. As a result, the economic and societal benefits are likely to reach at least comparably high dimensions as was the situation in the previous periods of electrification or automation and digitization [4]. The key difference is that a much larger number of people will be directly affected in the future.

If AI is consistently used for control purposes, Automation Systems will not only be able to follow preconceived program structures, but will also be able to make decisions themselves in the future. The prerequisites for this are connectivity, clearly structured Modularity and a comprehensive Digital Twin.

Needless to say, such technologies are of particular importance because our industry, society, healthcare system and every individual will need to have much more access to extensive expert knowledge and unstructured information in the future than they do today.

More characteristics of Automation Systems which do not exist yet could be outlined utilizing artificial intelligence technologies. For instance, there could be a ability of specialization which would describe systems which utilize its knowledge specializing to situation. On the contrary a generalization ability would describes Automation Systems that perform the taxonomic relationship between a general concept and a specific instances. It would be a major step to transform conventional systems into a new generation of automation systems which include a Digital Twin and would utilize Artificial Intelligence functionalities. If that system is even modular, Smart modules would have the knowledge about themselves, their abilities and their role inside Automation Systems. This is one of the most important prerequisites to enable intelligent and Autonomous Systems of the future. Only these systems would be able to create a decision space wherein they could optimize themselves and the overall system

As such, these technologies represent an essential addition to existing methods; alone the complete replacement of proven methods by artificial intelligence still seems far-fetched.

Internal processes of companies aiming to Industry 4.0 are being looked at in many publications which investigate on the achieved maturity levels.

In the area of predictive maintenance in particular, many companies are already active and have implemented such systems or are in the process of planning this with suitable business models.

4. Examples of Mechatronic modules and the Digital Twin

A Digital Twin of a modular production system comprises of models from the mechanics, electronics and software domains. If the mechatronic modules of a real plant are equipped with a Digital Twin throughout the different phases of its lifecycle, then multiple possibilities for planning or reconfiguration or for maintenance are offered.

The Digital Twin consists of different models of a physical production system and its component. Thereby the Digital Twin reflects the properties and functions during the entire lifecycle.

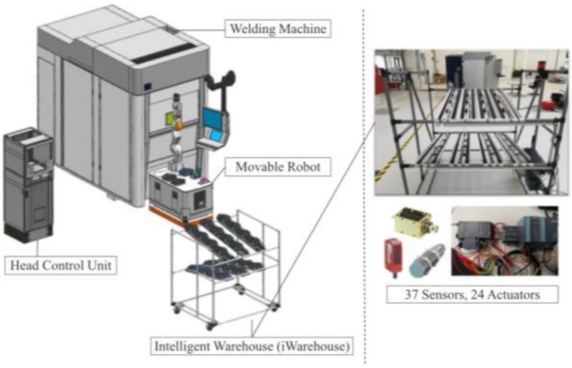

Figure 2: A real System and a visualisation of a Digital Twin

The Digital Twin is a concept to manage all generated digital models throughout their lifecycle and then to evaluate them by simulation or AI-supported optimization functions. Figure 2 depicts a model plant which is used to demonstrate the concept of Modularity and Digital Twin in the Arena 2036 a research centre in the Stuttgart.

How do we keep the Digital Twin up-to-date? One difficulty is to automatically synchronize the models with the Digital Twin over the entire lifecycle of the manufacturing system. By identifying anchor points and their relations in the software domain, the Digital Twin and the modules of the manufacturing system are synchronized, allowing the models in the Digital Twin to be adjusted automatically. In this way, the Digital Twin can be used to reconfigure modular systems in the field.

An additional asset is the networking of modules and their status data and other information with regard to the coordination of distributed functions of a manufacturing plant.

For this, there are concepts that enable the model-driven development of service-oriented plant controls. With little effort, module controllers can be integrated into a network. This makes it easy to implement decentralized controls of modular production systems. Reconfigurations such as expansion, decommissioning, changes to the plant structure or process modifications in a module can be carried out in this way. In addition, coordination enables the service-oriented IT architecture of systems and facilities.

5. Reconfiguration of Manufacturing Systems

Using the Digital Twin for Self-Organized Reconfiguration of Manufacturing Systems.

Due to the increased demand to realize small lot sizes and the inability to predict all objectives of a system at the time of its development, changes in the requirements of a production system occur more and more often during its operation [10]. These changes go beyond the flexibility range of the production systems that was planned in the first place.
Figure 3 summarizes the implemented technologies and components of the Digital Twin architecture.

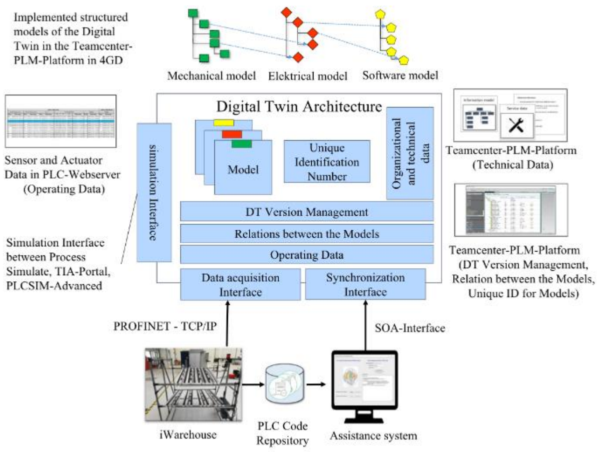

Fig. 3: Overview of technical implementation of the component to the proposed architecture of the Digital-Twin [6]

A Digital Twin consists of models and associated interfaces to tools, model version management, the operating data of the physical asset, the organization and technical data of the real asset, information about its relations to other Digital Twins in the real world, a unique identification number and an interface for communication with other Digital Twins and system. The Digital Twin of the intelligent Warehouse consists of all its cross-domain models, e.g., its 3D-CAD, electrical circuit, functional and simulation models, as well as the organizational and technical specifications.

The Reconfiguration of Manufacturing Systems and their components is therefore becoming increasingly relevant. The research focuses on the potentials that the Digital Twin can offer in the area of manufacturing with regard to reconfiguration management.

The objective is to find a concept that extends manufacturing systems with the ability for self-organized reconfiguration with the help of the Digital Twin.

How is autonomous reconfiguration management enabled?

The Digital Twin provides the basis for automatic planning in engineering and for re-use in operation.

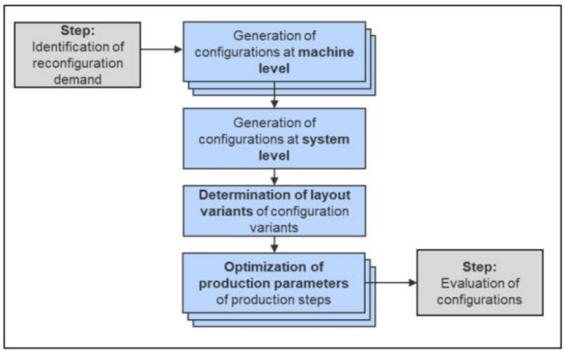

Fig. 4 Generation of alternative configurations (according to [5])

As it is sketched in Figure 4 there are several steps to the generation of a reconfiguration machine.

Firstly, a Generation of configurations at machine level takes place. At this level, the objective is to find new configuration proposals for the different modules that can perform at least parts of the given manufacturing sequence. These configuration proposals include both the software and the hardware of the respective module. Therefore, this step is based on the given requirements, as well as on the capabilities (manufacturing operations) of the module. It should be possible to compare these capabilities with the production processes demanded by the requirements. These capabilities can be linked to their corresponding software and hardware parts to achieve a scalable granularity. In addition to the alternative configurations of the module which can offer new capabilities through reconfiguration, the current module configurations with the capabilities they already possess, are also considered. Furthermore, modules that are currently not part of the production may also be considered at this level. Thus, a solution space is established which consists of these possible configurations of all modules which can offer at least one production process of the required production sequence. To cover the whole required production sequence, the Generation of configurations at system level, is carried out subsequently. All possible variants are formed, which are capable of carrying out the required production sequence. These variants consist of the different modules, where each module is in one of the possible configurations given in the solution space. For each variant, the individual modules are assigned to one or more production processes. After finding the possible variants at system level, the modules have to be positioned within the layout of the production system through the determination of layout variants. This is based on the description of the given layout structure. Whilst forming these different variants, it is crucial to determine the effort for this system level reconfiguration measures, starting from the currently applied configuration of the modules. This effort is calculated with respect to the given criteria (time, cost and energy), allowing a comparison later on. Note that this concept also offers the possibility to consider different layout structures. Thus, allowing a comparison of these and finding the optimal structure for the given requirements. In the last step of the generation of alternative configurations, the Optimization of production parameters for each step of the production is conducted. This Optimization aims for the best result with regard to the given weighted criteria (time, cost and energy).

The result of this step is a set of optimized production parameters for each variant, as well as the optimization result itself, which can be used as a comparison later on. Henceforth, all possible configurations have been found and are ready to be evaluated and compared. [7]

Today, reconfiguration of production systems is based on both whole-system documentation and undocumented (expert) knowledge, and is mostly accomplished individually. This is done in a time-consuming and error-prone process that can be automated by using a Digital Twin.

6. AI, Autonomous Systems and their reliable operation

The emergence of the Digital Twin makes it possible to use simulation even during the operation of systems. AI-based optimizations or predictive maintenance can be enabled by running a simulation parallel to the operation.

In the case of distributed systems, however, the difficulty arises that different simulation tools must be used due to the heterogeneity of these systems. The addition of components during runtime causes high dynamics. This requires an extension of the simulation during runtime. An operation-parallel simulation at runtime enables a prognosis and therewith an optimized operation of the production system. However, current systems consist of many different components, making these systems very heterogeneous and requiring different simulations to be used simultaneously in a so-called co-simulation.

How can different simulations be coupled and used for forecasting?

"Plug-and-simulate"-enabled co-simulations allow systems to be dynamically coupled at runtime and evaluated using AI algorithms. However, as decision-making becomes more autonomous, the safeguarding of adaptive Automation Systems becomes increasingly important.

How can adaptive systems be safeguarded?

Autonomous Systems can transform automatically, but must be monitored in the process: Advances in artificial intelligence and automation technology are producing systems with increasing autonomy.

In particular, these systems must be equipped with assessment mechanisms that allow functional safety to be evaluated during operation in a flexible environment.

Methods are needed to help plant operators validate their automation system. This is achieved within the framework of a validation process in which changes are detected, their effects analysed and the necessary behaviour models verified. This provides plant operators with an automated statement as to whether the functional requirements for a production system are still met after a change has been automatically implemented.

With AI and machine learning, it is required to satisfy algorithmic transparency. For instance, what are the rules, in a neural network that is obviously no longer algorithmically tangible, to determine who gets a credit or how an autonomous vehicle might react to several hazards at the same time? Classic traceability and regression testing will certainly not work. Future verification and validation methods and tools will include more intelligence based on big data exploits, business information, and the processes' ability to learn about and improve software quality.

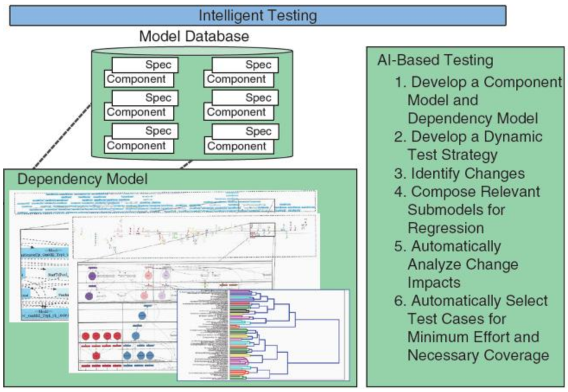

Fig. 5 Intelligent testing for Autonomous Systems (see [8])

Figure 5 provides an overview of intelligent testing for Autonomous Systems. Unlike brute force, intelligent testing considers white-box and black-box dependencies and, thus, balances efficiency and effectiveness. See "Cognitive Testing for Autonomous Systems" for a concrete case study.

A key question arises as to which way AI can support the process of validation. Obviously, there are many AI approaches, ranging from rule-based systems, fuzzy logic, and Bayesian nets to the multiple neural network approaches to deep learning. However, the process of validating an autonomous system is multi-layered and rich in detail. Various levels of validation testing can be distinguished, such as the systems level, the components, and the modules.

The potential for intelligent testing is manifold.

On a system level, there are questions about which test cases must be executed and to what extent. This means that intelligent validation is required to help with the selection and even the creation of test cases.

7. Conclusion

In this paper a few examples from research at the Institute of Automation Technology and Software Systems have been presented.

However, what are the application scenarios and pathways to these new technologies and new industrial businesses?

It would be desirable to give high preference to the use of disruptive technologies in order to be at the cutting edge of development.

However, when it comes to technology development, there is the question of how existing technologies should be developed quasi-incrementally or how to switch to entirely new disruptive approaches. This is a complicated question to answer, especially when several technologies that have been in development for a significant period of time reach tipping points, resulting in sudden innovations.

Research indicates that the following major patters are driving the future of automation technology [8].

“Smart Modules”: Modularity is clearly driven by the abilities of Communication of subsystems among each other and their further IT Integration.

But Modularity also implies a “Self-configuration” which can be measured by the capability of automatic adaptation, automatic planning and re-configurability. These performance indicators are associated to the characteristics of self-configuration of modules, which show how easily an automation system can be modified to a new configuration.

“Self-optimization” based on an AI is linked with efficiency and the ability of Perception and Data Processing based on a Digital Twin. If a system is able to perceive its own status based on a Digital Twin and the processing of the entailed data and information, it can improve its own performance leading to Self-Optimization.

“Decision Support” of future Automation Systems implies social interaction and maintainability, which are a basis for knowledge creation and reasoning. It is evident as the processing of data and information in a Digital Twin of Networked System would consequently support any decision making.

All these points regard future technologies. However, how can we make existing plants capable of meeting the challenges of the future?

A methodical approach to the digitization of existing manufacturing plants, logistics and related fields are important for digitization.

Automation Systems must be flexible and modifiable to cope with the requirement of future Industry 4.0 applications.

In the case of systems that are usually designed for a service life of several decades, the question arises as to how adaptations or modifications of software and hardware are possible in accordance with the state-of-the-art in digitization.

There is no manual on how digitization will look like for a specific technology and business area in the near future.

The advice would be: Bring your knowledge together: Client knowledge from marketing, strategic knowledge of future market developments and trends from the R&D departments and research institutes, in order to understand what is possible in the future in terms of technology.

About the Author

Prof. Weyrich studied electrical engineering, specialising at the University of Applied Science Saarbrücken (Germany), University of Westminster (London, U.K.) and at the Ruhr-University Bochum (Germany), focussing on automation technology.

Thereafter, he worked as a Research Assistant in the European Centre of Mechatronics and was awarded a doctoral degree in 1999 from the RWTH Aachen (.

Prof. Weyrich worked with Daimler AG for eight years, from 2004 onward, he was the head of “IT for Engineering” at DaimlerChrysler Research and Technology Bangalore (India).

After his return to Germany, he joined Siemens AG as department leader for 2 years, focussing on innovative technologies in Motion Control.

In 2009, he was appointed as Professor for the Chair of Automation in Manufacturing at the University of Siegen and as Director of the Automotive Centre Südwestfalen.

Prof. Weyrich assumed the role of Director of the Institute of Industrial Automation and Software Engineering at the University of Stuttgart in 2013.

In April 2018 he was awarded with an honorary doctorate of Donetsk National Technical University, Department of Computer Engineering.

References

[1] Koren, Y., Gu, X., and Guo, W., Reconfigurable manufacturing systems: Principles, design, and future trends. Frontiers of Mechanical Engineering, vol. 13, no. 2, (2018)

[2] BMWi, Details of the Asset Administration Shell-Part 1 –The exchange of information between partners in the value chain of Industrie 4.0, Version1.0 (Vol.0).8. (2018)

[3] Costello, K. And Omale, G. Gartner Survey Reveals Digital Twins Are Entering Mainstream Use. Retrieved from https://www.gartner.com/en/newsroom/press-releases/2019-02-20-gartner-survey-reveals-Digital-twins-are-entering-mai. (2021)

[4] Gronau, N. and Theuer, H., Determination of the Optimal Degree of Autonomy in a Cyber-Physical Production System, Procedia CIRP, vol. 57, pp. 110–115, 2016

[5] Mueller, T., Jazdi,, N, Schmidt, J.P., Weyrich, M: Cyber-Physical Production Systems: enhancement with a self-organized reconfiguration management, Procedia CIRP, 2020

[6] Ashtari, B.,Jung, T.,Lindemann, B.,Sahlab,N.,Jazdi,N. Schloegl, W. and Weyrich, M.: Anarchitecture of an Intelligent Digital Twin in a Cyber-Physical Production System. AT–Automatisierungstechnik, 67(9) ,762–782. (2019)

[7] Stock, D., Bauernhansl, T., Weyrich, M., Feurer, M. and R. Wutzke, "System Architectures for Cyber-Physical Production Systems enabling Self-X and Autonomy," in 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), 8-11 Sept. 2020, Vienna, Austria, 2020

[8] Ebert, C. and Weyrich, M. "Validation of Autonomous Systems," IEEE SOFTWARE, vol. 36, no. 9/10, pp. 15-23, 2019, 2019.

[9] M. Weyrich, M. Klein, J.-P. Schmidt, N. Jazdi, K. D. Bettenhausen, F. Buschmann, C. Rubner, M. Pirker, und K. Wurm, „Evaluation Model for Assessment of Cyber-Physical Production Systems", in Industrial Internet of Things: Cybermanufacturing Systems, S. Jeschke, C. Brecher, H. Song, und D. B. Rawat, Hrsg. Cham: Springer International Publishing, 2017, S. 169–199.

[10] Marks, P., Hoang, Xl., Weyrich, M., Fay, A.: A systematic approach for supporting the adaptation process of discrete manufacturing machines. Research in Engineering Design 29 (4), 2018, 621-641

[11] Faul, A., Jazdi, N, Weyrich, M: Approach to interconnect existing industrial automation systems with the Industrial Internet. IEEE 21st International Conference on Emerging Technologies and Factory 2016