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THE ROLE OF A BEHAVIOURAL MODEL FOR THE VIRTUAL COMMISSIONING OF ROBOTIC MANUFACTURING SYSTEMS

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Abstract

This paper focuses on virtual commissioning of a robotic manufacturing system, its theoretical background, and an analysis of its importance in the design of automated and robotic systems. Virtual commissioning allows the PLC control program to be tested and debugged on a created digital model of the machine, called a digital twin of the machine. Just this solution can simulate and optimize the automated system design itself without the need to have real hardware (PLC, automation elements, or the whole machine/equipment). Virtual commissioning offers an effective alternative to reduce the risks and effort of real commissioning of the machine. This makes it possible to reduce the time to market and increase flexibility, efficiency, and quality. Virtual commissioning in a single-control system is a simple solution; we can either use the Software-in-the-Loop method with emulated PLC control, simulated behavioural model, and co-simulation model or Hardware-in-the-Loop method with real controller. The problem appears when we have various types of controller, including an industrial robot controller. The paper deals with the theoretical background and partial outlines of solutions in the use of different types of the control system, if interconnections or emulators for different control systems are available. The recommended solution is to use a separate solution for the 3D simulation of the robotic system and an independent solution for the behavioural model, which will be tested in the future.

Keywords

Virtual Commissioning, behaviour model, robotic manufacturing

INTRODUCTION

Digital technologies have already become an essential part in many areas, including industry [1]. Digitization offers entirely new possibilities to optimize devices, systems and processes, including the engineering of new devices in the field of industrial production [2]. Digital technologies and simulation tools are also an active part of the design of automated and robotic manufacturing equipment and systems. If we focus on automated and robotic cells and systems, the market provides solutions and simulation technologies specific to a particular type of industrial robot closely specialized by the manufacturer. On the other hand, there are universal solutions that implement industrial robots from different manufacturers [3, 4]. The continuous reduction of production and project time in the conditions of current automated systems requires the use of offline programming of industrial robots [5]. These methods can provide solutions for the integration of models of real devices, for finding appropriate solutions, whether for the layout of workplaces, the range of robotic arms and possibly for testing the technologies avoiding the installation of a real robotic cell [6, 7].

In addition to these features that can support designers in planning a robotic workplace in a virtual environment, these software solutions can emulate the actual control systems of an industrial robot [8]. In this way, it is possible to program the robot by using the simulation tools concerning its peripherals. This is possible without having to stop the production and it is possible to set up robotic programs in advance, which increases the productivity itself [9]. Offline programming of robots is a great advantage not only from a time point of view, but also from a safety point of view. There are no real safety risks of potential injury due to technical or personnel failure in a virtual environment. In this way, it is also possible to design realistic simulations using real robotic programs, if the technical design allows it. The program can be created and tested directly in a virtual environment, which eliminates the requirement to have all of the hardware and technological resources of production at once, or to stop production at least until the programs are uploaded online [7, 10, 11].

An additional advantage is the ability to test the control program during the design of the robotic cell and not after it has been installed. This makes it possible to implement a timely redesign, and thus avoid time and financial losses [12]. The aim of virtual engineering is also to minimize the physical tests of the control program, thus reducing the start-up time. However, it should be noted that the robotic program itself does not only solve the movement of the industrial robot along individual trajectories or the logic of the program [13]. An industrial robot communicates with individual peripherals or other robots. These peripherals are also controlled by PLC control e.g. [14, 15]. This question forces us to find solutions that would allow us to test peripherals at the PLC level and simultaneously the robotic program; in virtual environments and as part of industrial solutions at the level of simulation software. Thus, the goal is to find the solutions that would allow testing the functionality of PLC control and robotic control together. Such solutions just bring 3D simulation closer to a real robotic cell. With this approach, it is possible to design and test the production processes in a 3D environment, define and verify the sequences of the production processes with realistic behaviour, optimise the cycle times and simulate the commissioning of robotic systems. This can be summarized in one simulation technology, namely virtual commissioning.

DEVELOPMENT AND METHODS OF VIRTUAL COMMISSIONING

Virtual commissioning is an activity from a subset of actions grouped around the popular term - Digital Twin. This term can be used today in various technological and industrial sectors and has gradually made its way into the manufacturing industry environment as well.

A key element in the implementation of virtual commissioning is the simulation of 3D components of the machine and system. The software, therefore, uses the CAD tool data, and

establishes a connection to the necessary automation data. The development of virtual commissioning has focused on the area of testing new equipment and machines without damaging any of them [16–18]. We have been working on this issue for several years within many different projects [19–21]. As a result, there are clear conclusions that, from a technical point of view, our work has confirmed the benefits of virtual commissioning. The biggest benefit can be considered to be the time saving during the programming of the control logic operations, which could be tested at any time with a graphical representation of the digital model. This made it much easier to debug the program and detect any errors in the early stages of the programming. This allowed much better visualisation of the designed process during programming and allows the designer immediate feedback on the solutions. Virtual commissioning is primarily a tool for simultaneous team-based project solutions. Virtual commissioning can reduce the time to start up by up to 63 %, thus providing a speed-to-market capability [22]. The testing and validation of the control programs can be carried out by using one of these two configurations, Fig. 1 [23]:

- Virtual process model and emulated controller or software in the loop (SIL): consists of a combination of a system model to be controlled and an emulated PLC. This is a relatively inexpensive alternative, but since no real equipment is used, safety aspects such as possible robot collisions or personal injuries may be overlooked.
- Virtual process model and real controller or hardware in the loop (HIL): the actual PLC hardware and even some auxiliary modules and Fieldbus devices are used. An identical or very similar environment to the installation is created and the software is tested directly on the driver. However, this configuration means higher costs and less flexibility to make changes during the design phase. In addition, there is a higher risk of accidents.

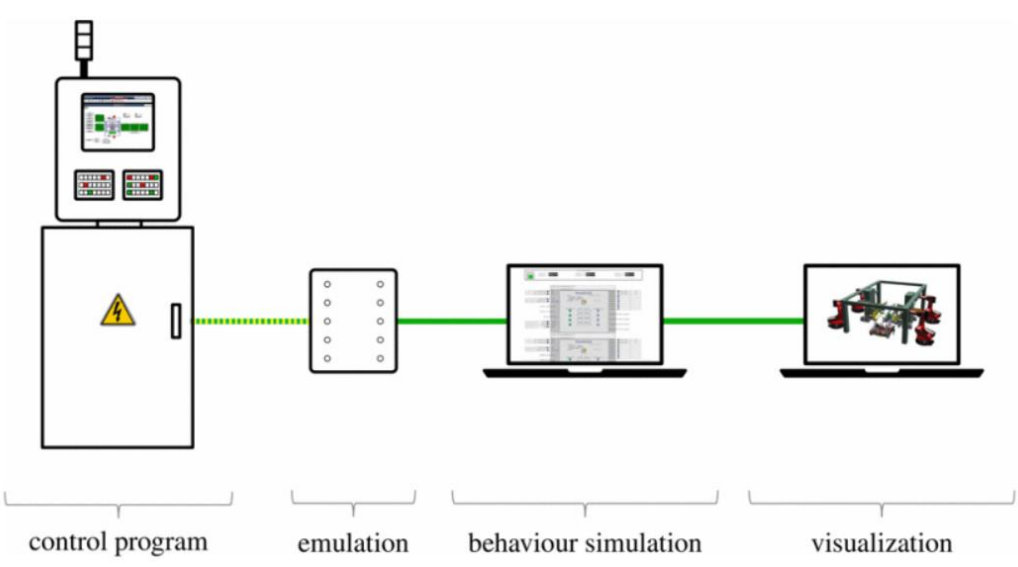


Fig. 1 *The basic configuration of virtual commissioning [24]*

In terms of the logic signals processed, the digital twin can be divided in terms of the size of the simulated objects. In the case of the manufacturing systems design domain, the two main objects are the manufacturing machine and the manufacturing system. The creation of digital twins in the process of manufacturing systems design as well as publications focused on this direction has long relied on the same scheme of procedure, Fig. 2 [17].

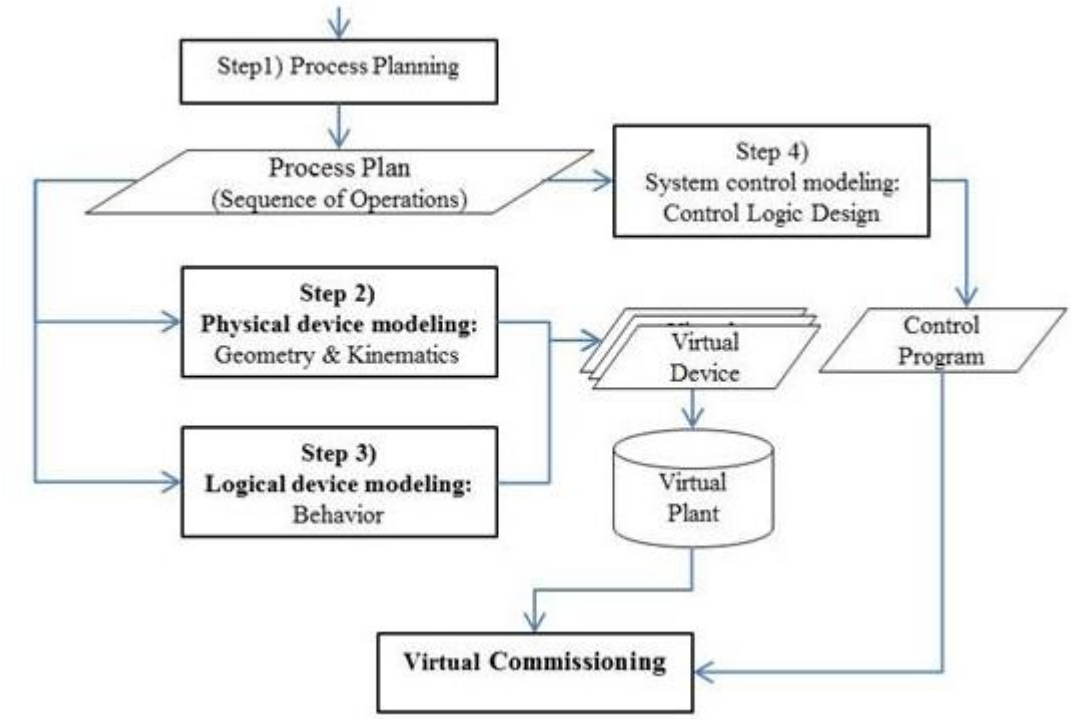


Fig. 2 *Concurrent design procedure for virtual commissioning [17]*

IMPACT OF CONTROL HIERARCHY ON THE BEHAVIOUR OF SIMULATION DEVICES AND THE DESIGN OF CONTROL LOGIC

The automated production systems also integrate the industrial robots. As mentioned above, PLC control systems are different when compared to the control systems for industrial robots. The virtual commissioning of the robotic systems has therefore its pitfalls. The idea is that programs should be tested virtually in advance to eliminate design flaws at an early stage and to verify information flows between PLCs and robots [25]. All these preparations help to design and operate a robotic workplace much faster and more efficiently [26].

However, in the case of virtual commissioning of robotic manufacturing systems, it is necessary to think about the arrangement of the original sequence of steps as well as the integrity of the other steps within the concurrent design procedure for virtual commissioning, Fig. 2. Apart from the Process Planning step, which has a specific position within Virtual Commissioning, there are several interactions between steps 2-4 that disrupt the independence of these steps and lead the researcher to a deeper interdisciplinary knowledge of engineering knowledge.

As an example, consider the Control Logic Design. The latter is considered in general theory to be the "black box" of virtual commissioning, which must not be interfered with for simulation and is superior to simulation. However, in the case of larger robotic applications, this principle has to be modified, since in this type of robotic application we encounter a larger number of control systems and a different structure of the control hierarchy.

This is where the disadvantages of a decentralised solution become more apparent when each unit (i.e. robot, machine, CNC...) has its own control system.

There are robotic applications with PLC overriding control, as well as robotic applications where the robotic controller takes over the main control task. Both of these control systems can also be in an equivalent position. Special cases are the safety settings of these control systems (Safety PLC, Robot Safe Move). The different control hierarchy settings have a significant

impact on the virtual commissioning process. This can often be observed within robotic applications in the automotive industry standards environment, where other higher-level (MES) and lower-level manufacturing technology control systems (welding control, riveting tong control, etc.) enter the control hierarchy, Fig. 3.

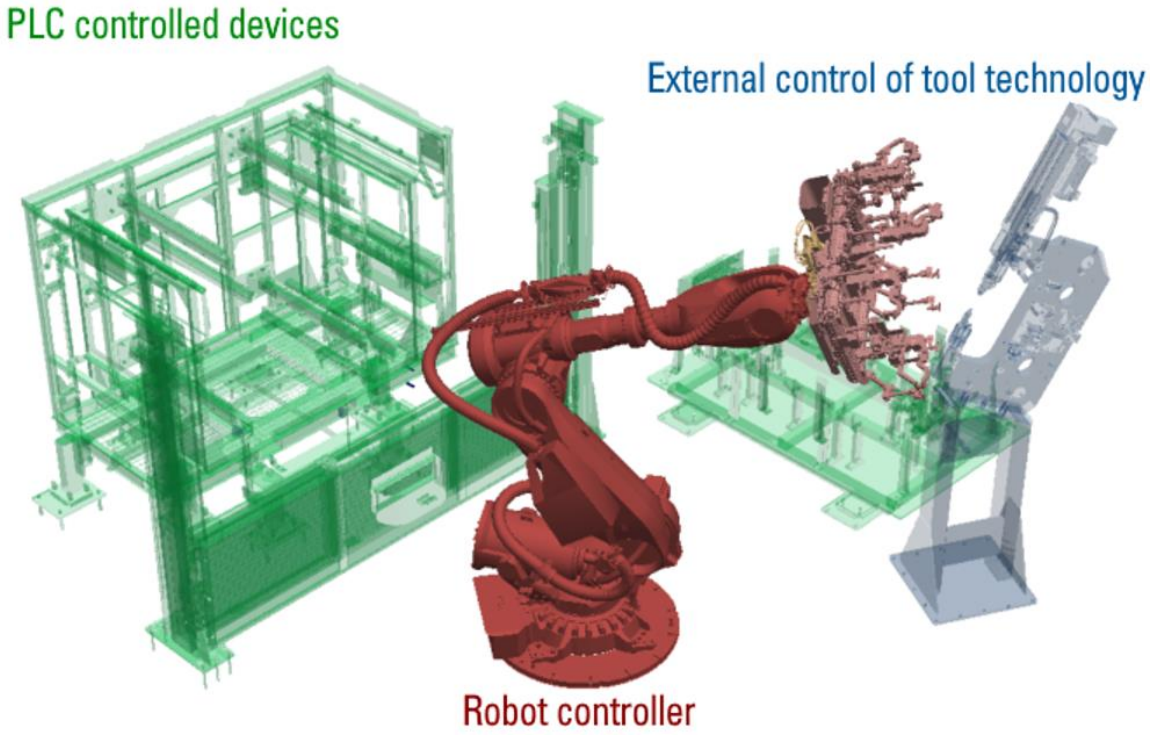


Fig. 3 *Colour division of the production system in terms of different types of control systems*

The integration of the emulation of individual control systems within the virtual commissioning encounters technical problems such as synchronization, data management, communication line throughput, security, etc. One option for interfacing control systems at the I/O level between the robot and the PLC is OPC UA [27]. The other option is to use the SIMIT software platform. [28] However, this solution is suitable for communication between the PLC and the robot and possibly for the creation of logical models of behaviour. Our task, therefore, is to find a suitable simulation tool for the virtual commissioning of the robotic program. The main difference between the robot manufacturer's simulation software and the manufacturer-independent robot simulation software is that the robots simulated in their parent software are absolute copies of real robots and their control systems with all dynamic properties. For the second group of software, it is often necessary to purchase the Realistic Controller Simulation (RCS) modules that calculate the dynamics of the robot. That means that the simulation software equipped with this module is a mirror of the real robot, and therefore the robot operation times are almost identical to reality, which is important for the fidelity of the simulation and the adherence to the required cycle time of the production system [28]. Not every robot manufacturer's software allows PLC connection at SIL or HIL level. Thus, our task is to find the solutions to link the PLC signals and the robotic program with the co-simulation of the robotic workstation. We are currently familiar with virtual controller emulators from various robot manufacturers, as well as PLC system manufacturers offering virtual controller capabilities. In the case of tool controls and other slave systems, emulators are not commonly available. This fact complicates full virtual commissioning using the Software in the loop method. Nor can it be expected that in the future manufacturers will be involved in the development of such emulators.

RESULTS AND DISCUSSION ON RESULTS

A solution to the technical problems of emulating the control of slave systems in the virtual commissioning of robotic manufacturing systems may be to reconceptualise the Behaviour Model with its wider application. The Behaviour Model was originally intended primarily for test signals outside the Control Model (PLC control program), or for processing states resulting from the kinematics of a 3D digital model, and was often an associated integral part of robotic simulation software. For robotic applications with a higher number of control systems, it is convenient to generate test sequences and logic operations just within the software designed for the creation of behaviour models.

If such an approach is used, it is directly necessary to use external software outside the primary simulation software with a 3D digital model representation (such as Tecnomatix Process Simulate). The use of external software allows for the decentralization of the workload at both the hardware and engineering level. From software dedicated exclusively to the behaviour model, it is possible to create a communication node between the simulation, the behaviour model and the individual emulated controllers of the control systems (PLC, RCS). Such a node fundamentally changes the hierarchy of steps leading to virtual commissioning and makes the behaviour model the most important step towards successful execution. This assertion is supported by the possibility of creating extensive functions describing the behaviour of electrical and electro-pneumatic components as well as communication interfaces governing the communication between e.g. the robot and the PLC. At the same time, test sequences for critical system states can be created more efficiently. All these functions can be stored as libraries in external software for creating behavioural models (SIMIT, RF:ViPER, MatLab) and thus the virtual commissioning process can be repeated more efficiently. The disadvantage of dedicated behaviour modelling software and the creation of such libraries is naturally the need for additional software licenses in an already complicated software setup for virtual commissioning. In conjunction with this, the knowledge of simulation and automation engineers needs to be extended with new programming languages and knowledge.

CONCLUSION

The behavioural model of the production system is one of the fundamental elements of virtual commissioning and its importance and scope grows with the number of devices and peripherals of the production system. The present paper discusses the issue of equipment commissioning in a virtual environment. The paper presents the basic background and procedure for virtual commissioning to emphasize the role of behaviour model generation. It further develops the impact of the behaviour model on the efficiency and quality of simulation using a larger number of emulated control systems. In this context, the paper develops a reflection on the use of external software for modelling the behaviour of robotic manufacturing systems, thus changing the virtual commissioning procedures depending on the system design standard. The standards using a larger number of external control systems significantly increase the robustness of virtual commissioning with respect to the software and hardware setup as well as the knowledge of simulation and automation engineers in current manufacturing system design practices.

In line with this treatise, the creation of custom libraries in external environments is needed to model the behaviour of tools and equipment used in robotic manufacturing systems. The goal is to create these libraries in accordance with the automotive industry standard, which has a robust and complicated control structure. These libraries will allow to bring the digital twin technology closer to praxis in the field of manufacturing systems design, where this technology is still considered as a non-traditional application.

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