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IDENTIFYING THE POTENTIAL OF VIRTUAL COMMISSIONING AS A PRACTICE FOR UNDERGRADUATE PROGRAMS

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Abstract

Virtual commissioning provides opportunities for educational use cases, although it was not designed for them. Originally it was introduced to improve the process of designing, constructing, and implementing a production process or machine. Current works do not offer analysis of virtual commissioning practices intended for undergraduate study settings. In this paper, eight theses in the bachelor's program at the UAS Technikum Wien Mechatronics/Robotics have been retrospectively analysed. The analysis results were used to identify virtual commissioning practices in different undergraduate program settings. Further results suggest that a prerequisite for undergraduate students to accept the given tasks and keep their motivation high, is to provide software and environments to enable them to get started after only a short period of time. Thus, software and virtual environments must be adapted to the prior knowledge of the students. The results lead to the assumption that teaching single identified practices can lead to a more purposeful learning of designing and programming a machine.

Keywords: Virtual commissioning; engineering education; digital twin; simulation.

1. Introduction

In the course of the digital transformation and constant optimisation, the established processes of the manufacturing industry are also facing upheaval. A significant change in processes is emerging in the planning and implementation process, the so-called commissioning of plants, among other things. By digitally simulating the processes at an early stage, they can be implemented faster, more error-free and ultimately more cost-effectively. The two main reasons for this are that the necessary work steps of the various disciplines for the realisation (or modification) of a plant can be carried out in parallel instead of one after the other. On the other hand, by simulating the processes, errors can be detected more quickly and corrected more cost-effectively. The number of prototypes usually required can thus also be drastically reduced, which has an effect on the costs of development. Due to these digitalised working tools, the term virtual commissioning is increasingly used in this context. By integrating these methods into teaching, it would be possible to practise low-cost, but nevertheless complex mechatronic and mechanical engineering development activities at the UAS Technikum Wien.

Virtual Commissioning (VC) describes various practices to simulate mechatronic systems while developing or changing that system to reduce real commissioning time. Depending on the task, the main simulation scenarios are described as Model-in-the-Loop (MiL), Software-in-the-Loop (SiL) and Hardware-in-the-Loop (HiL) [1]. While VC has been subject to research for several years [1], [2] and scholars have exemplified how to introduce VC practices in education [3], [4], little work has been conducted to investigate how to systematically introduce the subject to higher education. This paper aims to contribute to this issue by analysing achievements in bachelor theses and describing various practices used in this educational context.

2. Related work

Engineering education is an ongoing research topic [3], [4], [5]. As Eichinger and Richter describe in their paper [6], they face the challenges of digitalization to offer mechatronic courses on three levels: basics, development methodology and development tools and software tools.

Focusing on VC, Brazina et.al. describe [7] VC as part of an educational process using different tools from ABB and Siemens as well as physical machines such as a robot and CNC machines. Describing a similar approach, Fernández et. al. describe [8] using a robotic cell to be used in educational settings to learn VC processes.

Many other platforms such as described in [9], [10], [11], [12], [13] strive to bring digital transformation aspects into educational settings. All these works implemented various settings where they use VC to convey knowledge for single learning objectives. To date no work known to the authors has been published, which identifies how single practices during VC can be used as tools for undergraduate study programs.

3. Methodological approach

Before implementing VC simulations in educational settings, VC practices should be broken down to specific tasks and analysed in perspective to effort and difficulty for students. Thus, in eight bachelor theses conducted within three years, students were tasked to implement and use various aspects of VC practices. This work reflects on the approaches students chose, the results and the learnings made by supervising theses.

The results of those projects as well as the challenges documented in the theses are the basis to retrospectively gaining insight using qualitative and descriptive data analysis [14]. Convenience sampling method [15] is applied in order to identify potential VC practices for undergraduate programs for industrial engineering settings. Used data were anonymized and can be found referenced as Student A, Student B, etc., in random order within the same year of implementation. The chosen sample only include male students, all between the ages of 23 till 26 years. The reason for the lack of female students in that sample is that within the analysed period, no female student chose one of the referenced bachelor projects in the study program (Mechatronics/Robotics) in which these were offered, most students is male.

4. Accompanied projects to set up VC practices

All virtual commissioning related projects are carried out in a lab infrastructure called digital miniature factory (DMF), see Fig 1. The digital miniature factory located in the university of applied sciences Technikum Wien is a smart manufacturing system consisting of different miniaturized production stations as well as mobile robots fitting all together on a table size 2m x 3m. It consists of different stations developed for certain production tasks like sorting, quality control or storing finished products. The dedicated product is a 3D printed carabiner which are produced colour-customised and then automatically packaged. All student projects in the context of the DMF were developed with industry related hardware such as PLCs from different vendors as well as image processing, encoders and several other sensors connected via IO-Link. The communication and networking of each individual station is based on the Industrial Internet of Things platform PTC Thingworx and the communication standard OPC UA. As all relevant information per station are gathered in the cloud platform (sensors, status, available services) intelligent decision making based on the order backlog, current data and next step strategies can be investigated. As the whole system is developed together with industry partners and

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students all development data (CAD, E-Wiring, software) is available to form the basis for research activities in the field of virtual commissioning.

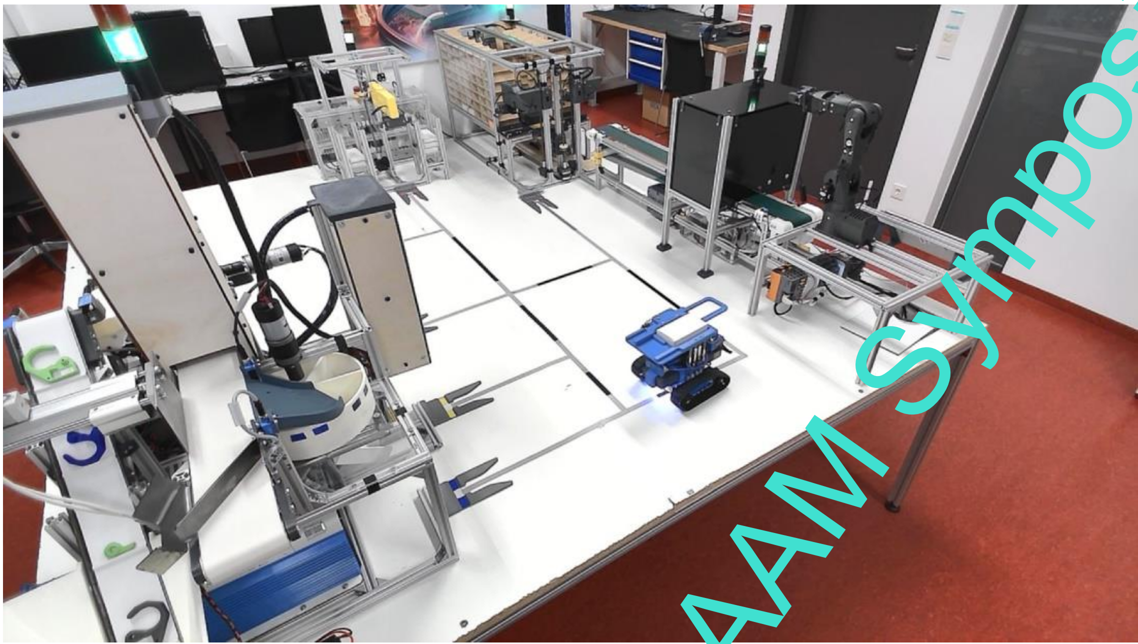

Fig. 1. Digital Miniature Factory Layout

Since 2020, eight students from bachelor's program for Mechatronics/Robotics (BMR) within the faculty of Industrial Engineering at University of Applied Sciences Technikum Wien have been supervised in VC-related projects to develop various aspects using VC simulation practices, see

Table 1. As the Goals in this table suggest, implementing VC simulations requires various tasks to be practiced. Since the practices of VC require knowledge in mechanical, electrical as well as electronic engineering of a machine, students from study program BMR were selected since they fulfil the required criteria. Within a scope of 250-300 hours (equivalent to 10 ECTS) in 6th semester of their study program, BMR students are tasked to implement bachelor projects and document findings as part of a bachelor thesis. For each of these bachelor projects from this sample, targets to implement VC practices have been expressed to see how far candidates would proceed and what goals they would come up with.

Student	Year	Target given	Simulation provided	Goals achieved	Documented challenges	Simulation type
Student A	2020	implement VC	-	Kinematics, circuit scheme, SiL logic	To implement the kinematic process in the form of a state machine.	SiL
Student B	2020	implement VC	-	Kinematics, MiL logic, statistics	To implement the kinematic process.	MiL
Student C	2021	implement VC	Kinematics & SiL logic for different station	Kinematics, SiL logic, statistics	To simulate expected kinematic behaviour	SiL
Student D	2022	compare VC tools	Kinematics & MiL logic	Comparing tools	To argue scoring scheme to compare tools	MiL
Student E	2022	implement continuous simulation	Kinematics & MiL logic	advancing given MiL model, statistics	To understand and use given model, implement kinematic processes	MiL
Student F	2022	implement digital shadow	Kinematics & MiL logic, access for data exchange	advancing given MiL model, digital shadow	To understand and use given model, implement kinematic processes, set up connectivity to external data	MiL
Student G	2022	Implement and test alternative soft PLC	Kinematics & MiL logic	implemented SiL logic, virtually tested	To understand, use and advance given model, setup connectivity	SiL

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				alternative PLC, statistics		
Student H	2022	advance and test station	Kinematics & SiL logic	Implement changes of CAD model, statistics	To understand, use and change given model	SiL

Table 1. List of BMR theses selected for analysis in the paper.

In 2020, Student A and Student B were independently asked to implement any VC simulation for a given CAD model of a miniature storage station. Further, they were asked to implement any VC practice using different software tools. They chose iPhysics from Machineering and Visual Components. Both students developed their simulation from scratch and during supervisory meeting stated that they invested most of the time to implement and being in exchange with their software support.

Student A was creating a SiL simulation by implementing kinematics for the given CAD model of a miniature storage station as well as the corresponding circuit scheme and program logic, see Fig. 2. This logic control was programmed with structured text implementation on a virtual Programmable Logic Control (PLC) using CodeSys. Connecting the virtual PLC and the kinematics of the virtual storage station enabled this SiL simulation.

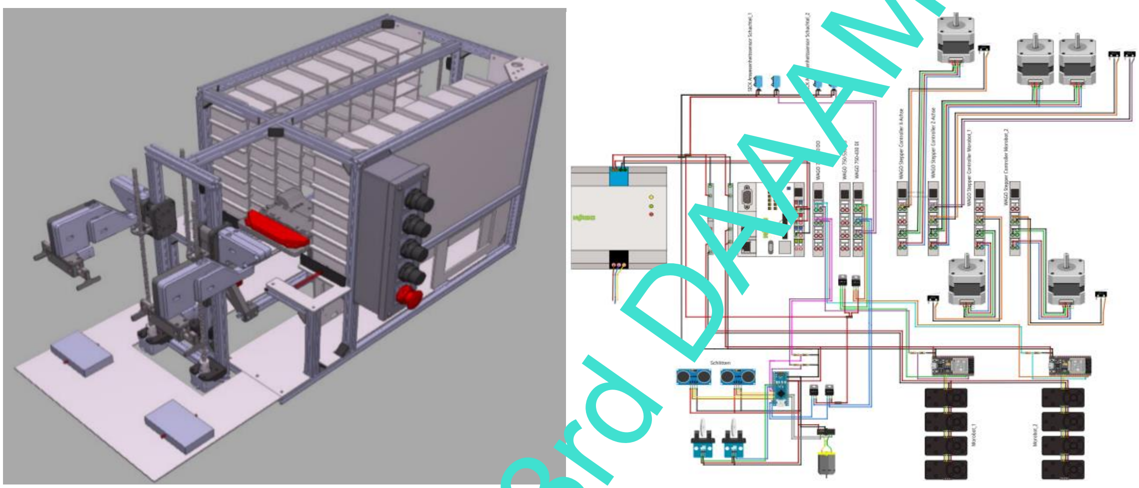

Fig. 2. implemented VC practices and circuit scheme, Student A

Student B was aiming for a MiL simulation and also implemented kinematics for the given CAD model of the same miniature storage station. He implemented an abstract programming logic enabling this MiL simulation. Further, student B implemented a statistic tool for demonstrating potential follow-up projects.

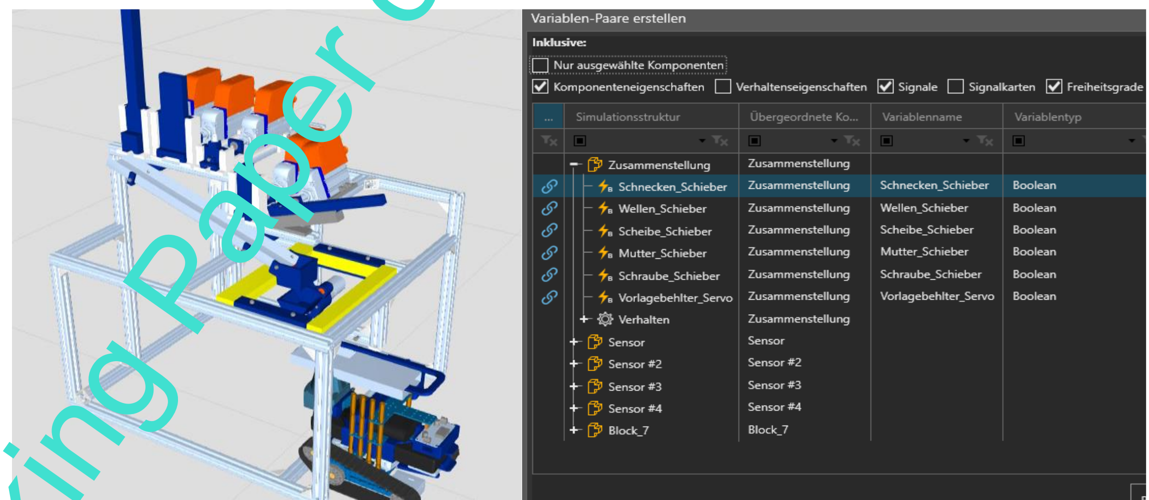

Fig. 3. Implemented VC practice and connection to soft PLC, Student C

Student C was asked to implement any VC simulation for a given CAD model of a miniature separation station, see

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Fig. 3. He was capable to implement a SiL simulation for the separation station using Visual Components as tool to implement kinematics. To implement a program logic he used ladder logic, to simulate a plc CodeSys software was used. Additionally, he analysed implemented kinematic behaviour of the separation station.

In 2022, five students chose to implement a VC practice. Based on the learning in the previous two years, for these five students the targets given were more specific, therefore being able to use prior implementations:

Student D was asked to compare different tools that can implement VC practices. Besides implementing a SiL simulation using NX MCD, he came up with self-defined metrics to compare chosen tools NX Mechatronic Concept Designer (NX MCD) and Visual Components. Therefore, he argued four parameters to compare on: integration of the tool, connectivity capabilities, support and functionalities. He argued that Visual Components would score higher for integration, connectivity and support parameters. Defined criteria to argue functionalities of the tools were rated equally high.

Student E and Student F were first asked to simulate all processes within the digital miniature factory, see Fig. 4. Therefore, the advanced given MiL models for the storage and separation station using Visual Components. After implementing missing CAD models, kinematics and abstract programming logic, Student E focused on evaluating each stations' workloads and overall equipment effectiveness (OEE) for the DMF. Student F advanced the common built-up simulation to be used as a digital twin of the real DMF. He therefore changed the previous program logic and connected the simulation to the real DMF's stations via the industrial network communication standard OPC UA.

Student G was asked to advance the model for the sorting station to change and analyse an alternative virtual PLC. He therefore received a MiL simulation setup for the station in Visual Components. He advanced the model to be tested in SiL simulation and analysed the current PLC logic on a virtual simulation of the current PLC. After that, the PLC logic was adapted and tested for an alternative soft PLC.

Student H was asked to adapt the CAD model of the storage station, revise and test the PLC code accordingly. He therefore received a SiL simulation of the storage station. After implementation of the changed model and program logic of the simulated storage station, the implemented change could be analysed, the improvements in comparison to the previous setup could be argued.

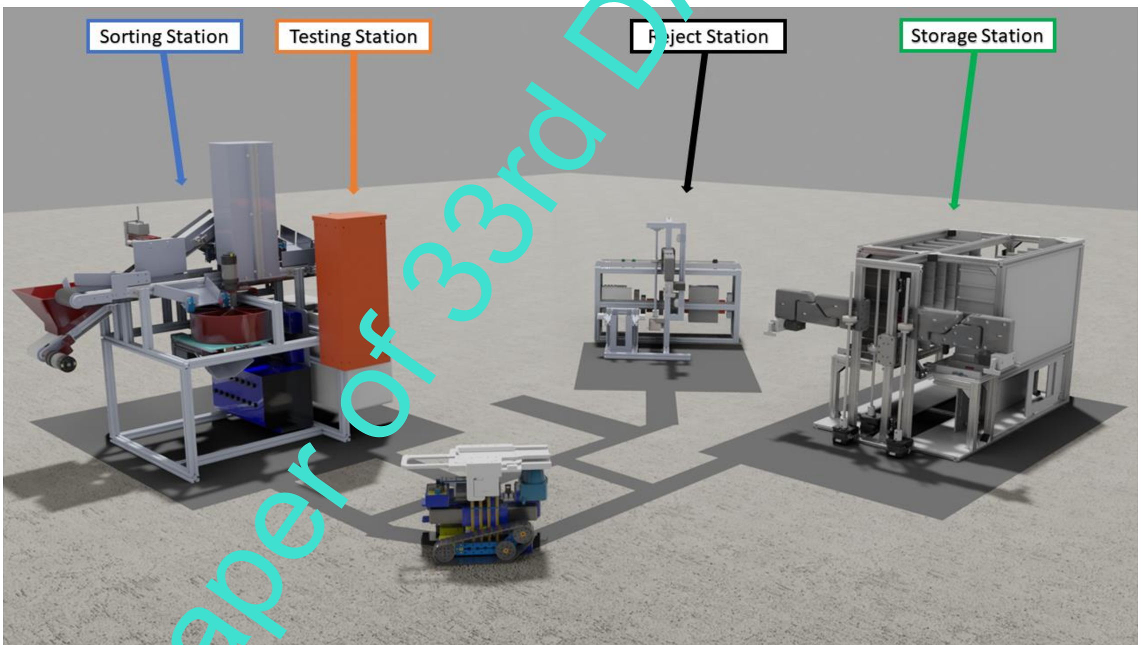

Fig. 4. Simulation of digital miniature factory (DMF)

5. Results and Discussion

As stated in section 3, convenience sampling method was chosen to collect the results. Therefore, the described peer group does not inevitably represent all undergraduate engineering students, but an excerpt based on the availability of students willing to do a bachelor thesis project in the field of VC. Since that students could influence which thesis project they were assigned to, a higher motivation can be expected compared to when all students would be randomly assigned to one bachelor project. It can be assumed that based on the higher motivation, these students perform better than the average student. In case of his analysis, this circumstance helps to unveil more advantages and challenges of using VC in the context of bachelor thesis. The insights collected therefore may also help identifying practices that can be useful not only for students in undergraduate mechatronic study programs.

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The main objective of this work is to identify, whether and what practices during VC could be used for different undergraduate programs. Following practices could be identified:

- Implementing kinematics: The implementers need to cinematize mechatronic systems in the VC tool. To do so, planned movement spaces of the designed mechatronic system need to be correctly interpreted. Using VC tools allows to verify implemented movements since they can provide direct feedback on input.
- Implementing abstract program logics (MiL): The implementers need to program abstract program logics. To do so, present actuators need to be activated depended on signal inputs. Using VC tools allows to simulate various setups of actuators and sensors and their corresponding software logic to explore approaches to connect actuators and sensors.
- Implementing PLC program: The implementers need to program PLC program logics. To do so, simulation variables for simulated sensors and actuators need to be implemented to describe the same information exchange that would be expected from real hardware. Using VC tools allows to learn on advantages and challenges of different system designs to identify the approach, which addresses the goal the most.
- Implementing connections between different tools: The implementers need to setup a connection, usually between heterogeneous tools. Using different tools allows overcome natural limitations of single tools to e.g., implement model behaviour to the cinematized model. Using multiple VC tools allows to extend the simulation capabilities for single tools and to learn on different communication standards.
- Using and arguing through statistical evaluation of a mechatronic system: The implementers need to find meaningful parameters and interpret them accordingly to derive findings from existing mechatronic system setups simulations. VC tools provide means to collect data and to evaluate it or to export it to other software.
- Comparing hardware virtually: The implementers need to decide what hardware setup would fulfil the set requirements to verify each hardware setup. Using VC tools allow evaluating different hardware in simulation to make a decision on which hardware might be more suitable to achieve project goals, informed by own experience.
- Implementing a digital shadow: The implementers need to set up a simulation interpreting incoming variables correctly to verify and run implemented simulations. With VC tools, implementers can run the digital shadow within an environment which can collect, replay, and validate data directly.

The following statements collected during supervisory meetings with students describe further aspects that have a positive impact on the results:

- Students who received a prepared simulation to base their work on, seemed to achieve more results within the same time.
- The motivation and focus of students appeared to be higher when specific targets were suggested.
- The most popular tool seemed to be one to get going the fastest not the one being most versatile.
- No matter if VC was set as a target or not, VC simulations were practiced reaching various goals.
- Only one out of eight projects (conducted by student H) could have been realised without using VC practices by shifting to the use of real hardware setups. The need to adapt or change hardware due to targets or failures, could not only have cost more time but also resources in terms of material and space.

Single practices identified in the context of above stated theses could be adopted considering student’s skills and learning targets. Using a single practice at a time may lead to a more purposeful learning of designing and programming a machine. Further, the results of this analysis indicate that a providing software and clear objectives can lead to higher motivation among undergraduate students. This increase in motivation can be connected to the fact that familiarizing with the topic of VC and the tools to implement VC is facilitated in terms of time and comprehensibility.

6. Conclusion and Future Work

From discussing documented bachelor thesis results in the study program of BMR, this paper concludes that various aspects throughout the process of designing and programming a machine seems to be beneficial not only for students but also for saving construction material. To potentially implemented in teaching, software and virtual environments must be adequately adapted to the prior knowledge and abilities of the students. To deliver better descriptions of the effort and difficulty to implement VC practices to be used by undergraduate students as well as for lecturers, further investigation should be carried out. We would like to follow on these findings by implementing and evaluating selected practices in future courses at our institution.

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