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The virtual FMS – an engineering education environment

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Abstract

The challenge of education related to large technical systems is to provide enough hands-on experience. Virtual models and visualizations make it easier to explain the behavior of those systems. This paper discusses on the development of such a learning environment for engineering education that focuses on planning, operation, and analysis of Flexible Manufacturing Systems (FMS). The aim of the learning environment is to allow the students to achieve the intended learning outcomes mostly with learning by doing. For this purpose, the learning environment is introduced and the individual exercises are described with their teaching and learning activities. This kind of learning by doing in an environment, which is similar to environments in manufacturing companies, enhance the learning results and serve the needs of the industrial companies recruiting the students.

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1. Introduction

In this paper, an education environment for engineering students is presented. The education environment consists of physical and virtual manufacturing systems as well as a Manufacturing Management Software (MMS). The MMS is an advanced production planning and management software that suits high-mix-low-volume production environment [1]. The activities performed with the MMS can be seen both in the physical and virtual manufacturing systems. The education environment can be viewed from digital, virtual and real viewpoints of manufacturing entities, where the entities are autonomous and collaborative sub-systems of the whole [2], [3]. The real viewpoint embodies physical entities existing in a system e.g. manufacturing and material handling devices. The virtual

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viewpoint represent the physical entities as computer models, such as simulation models, animations, and visualizations. The digital viewpoint includes formally presented data and information of the real and physical entities. These viewpoints present the autonomy of the manufacturing entities while they are communicating with each other to enable collaborative activities. The formally presented information and knowledge is the explicit part while the know-how and experience of humans present the tacit part of the information and knowledge. The decision making in this kind of system is made by humans or humans have created the automated decision-making processes [2].

Similar to the digital, virtual, and real viewpoints are cyber-physical systems (CPS) that represent collaborative entities that are connected with other entities. CPS emphasizes that it is not enough to understand only the physical and computational entities but also their interaction with each other [4]. For the domain of manufacturing or production systems, the CPS can be understood as Cyber-physical production system (CPPS). The viewpoint can vary from individual machines up to production networks exploring the relations in autonomy and collaboration as well as their control and optimization [5]. A CPPS can be seen as a knowledge platform of real-world manufacturing environment that can be used in training of students and company employees [6]. It can offer the participants an environment for balanced relationship in that the theoretical aspects have a strong connection with practical problems [7]. Industry 4.0 is a broad and evolving term that is understood and focused differently. According to [8] it serves as "*a model for the vertical integration of smart machines, products and production resources into flexible manufacturing systems*".

Generally, flexibility has been part of strategies of many companies already for decades [9]. One concept in the area of flexibility is a Flexible Manufacturing System (FMS). It is an integrated group of processing machines and material-handling equipment under computer control for automatic manufacturing of palletized parts [10]. The development in the area of information and communication technologies, resulting also in the concept of CPPS, gives more opportunities to create more meaningful education environments for engineering education. In the context of CPPS, an engineering education environment is presented.

The rest of the paper is constructed as follows. Section 2 explains the education environment as well as its main components and communication activities. In Section 3, the pedagogical aspects of the education environment are discussed. The exercises, their pedagogical goals and improvements of the exercises are explained. In addition, the future development plans of the education environment are discussed while Section 5 draws the conclusions of the conducted work.

2. The virtual FMS education environment

The education environment is an example of a typical FMS existing in several Finnish companies. The actual setups in companies varies in terms of needed resources, but the principles of the environments are similar. Toivonen et al. [11] discuss the first implementation of the education environment. Since then, the environment has been expanded to a more complex manufacturing system and a management software has been implemented to control the environment. In the following the newly developed education environment is described.

2.1. Description of the main components of the learning environment

Figure 1 presents the main hardware components of the education environment. The *Touch OP* is the user interface from which the operator uses the MMS and interacts with the system. The operator can use it to manually order pallets to the station or to confirm the completed tasks before sending the pallet back out. The Touch OP also provides the operator with information regarding the status of the system and its orders. A Touch OP typically controls both a Loading Station and a Material Station. Due to safety concerns, it cannot control a station that the operator cannot physically see. The *Stacker Crane* is a vital part of the system. It picks up pallets from the storage and transports them around the system. It is normally controlled by the MMS but it can also be driven manually if

needed. A system can have multiple Stacker Cranes and the movement can be in 2D or 3D depending on the storage setup.

Loading Stations are used to perform tasks on Machining Pallets. Such tasks are for example: installing fixtures, and adding materials to fixtures. The Stacker Crane brings the required pallets to the loading Station automatically so the operator does not have to worry about it. A typical system usually has around one to five Loading Stations. *Material Stations* are similar to Loading Stations except, instead of Machining Pallets, they handle Material Pallets. The required pallets are automatically brought to the Material Station when needed. This is being controlled by the MMS. Usually there is a Material Station for every one or two Loading Stations in the system.

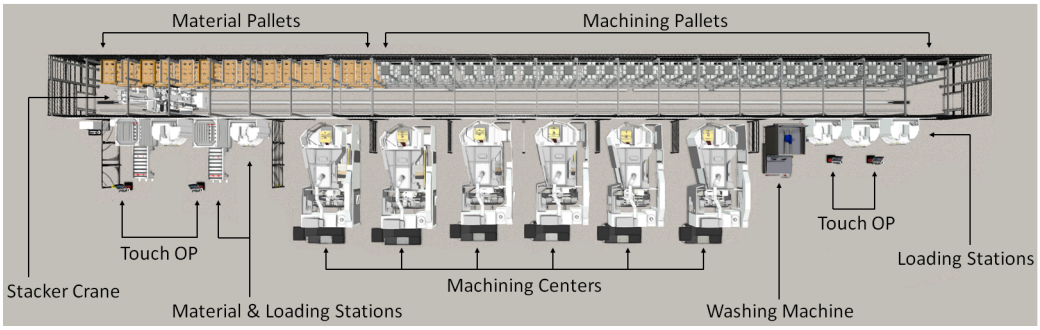

Fig. 1. Top view of the virtual model of the learning environment.

The *Machining Centers* are used to transform raw materials into parts. They often feature pallet changers and tool revolvers to ease automatic production. They communicate with the MMS to provide information about the NC-programs and tool statuses. The Machining Centers can be run completely autonomously without any operator input. The *Washing Machine* cleans and deburrs ready or work-in-progress parts. The machine uses high-pressure water to perform its tasks. Since not every part needs these tasks there are usually only a few Washing Machines compared to the Machining Centers in the system. The Washing Machine can also be operated completely autonomously without the need for operator input. *Material Pallets* are used to store raw materials in the system. The material is loaded onto the pallet and then the pallet is transported to the storage. When the MMS predicts the material is needed it creates a task for the Stacker Crane to bring the required material to the required Material Station. Then the operator can load the material onto a Machining Pallet. *Machining Pallets* are used to transport and store raw materials that need to be machined, parts that are work-in-progress and parts that are ready. The pallet has fixtures that are installed by the operator at the Loading Station. These fixtures are used to clamp raw materials onto the pallet, which enables the materials to be machined. The Stacker Crane transports these pallets depending on the tasks the MMS gives it.

2.2. Technical description of the communications of the learning environment

The system contains a virtual model that was built to visualize the FMS behavior. The virtual model has the same layout as the simulator. This model uses REST (Representational State Transfer) interface to request system state and operations list from the FMS simulator. The responses from the simulator allow replication of the system behavior in the virtual model. Figure 2 shows the relationship of different system parts.

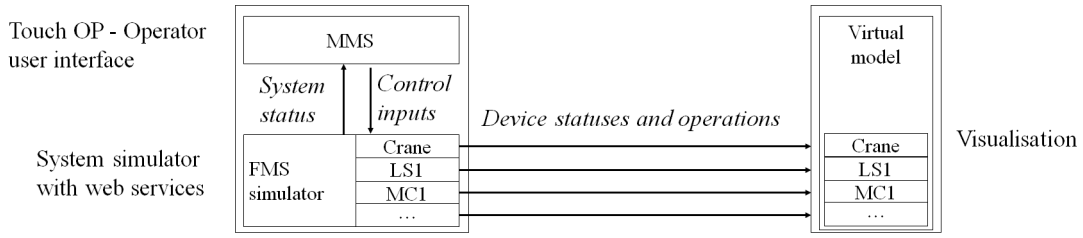

Fig. 2. Technical architecture of the system.

Each device has been modelled as an independent unit with a separate control logic. The main device from modelling perspective is the crane. The movements of the crane are controlled by a task list that holds the order of the transport tasks. This list and the active task are requested from the crane service of the FMS simulator to replicate the crane motion. Other devices are mainly controlled by the device state information. This indicates if the device is e.g. running, idling or in a failure mode. The change of the device status is also used to trigger movement of visual elements that are not included in the FMS simulator. For instance, the safety doors of the loading stations are such elements. Figure 2 describes the communication scheme between the virtual model and the FMS simulator. Each device has a corresponding web service. In addition, the pallets have a dedicated service that controls pallet location and fixture information. In future, a web socket interface will be implemented in the simulation software. This should reduce traffic caused by unnecessary polling of the web services.

3. Exercises of the education environment

The set of exercises consists of lectures, online performed exercises, as well as guided exercises at both a computer classroom and the physical facility. The exercises are required to be completed in a predefined order. This set of exercises follows the constructivist view of learning. It assumes that knowledge is achieved as a personal process of building, interpreting, and modifying understanding [12]. Therefore, each of the exercises will add new information above the previous exercises.

3.1. The flow of the exercises

Figure 3 presents the flow of the exercises. For a general introduction, a lecture explaining the basics of flexibility in manufacturing systems is given. The lecture is continued with a topic that is focusing on introducing the exercise environment and the exercises. The first exercise continues with the topics of the lectures. The aim is to understand the lecture topics in more details to familiarize itself by exploring online the user interface of the exercise environment. This is done by giving the students a set of questions that can be answered by browsing the Touch OP interface.

In the second exercise, the students perform production planning activities and see the results in a virtual environment. This is done using the same Touch OP interface that the students have used in the previous exercise. The third exercise is focusing on the operation of the environment. This exercise occurs in the physical premises of the exercise environment. In the exercise the students will see their production planning exercise, conducted previously, executed in a physical environment. The final exercise focuses on metrics that can be used to assess the performance of the environment. At this point, the students should be familiar with the environment and therefore understand what kind of performance metrics best suits people related to the systems with different responsibilities.

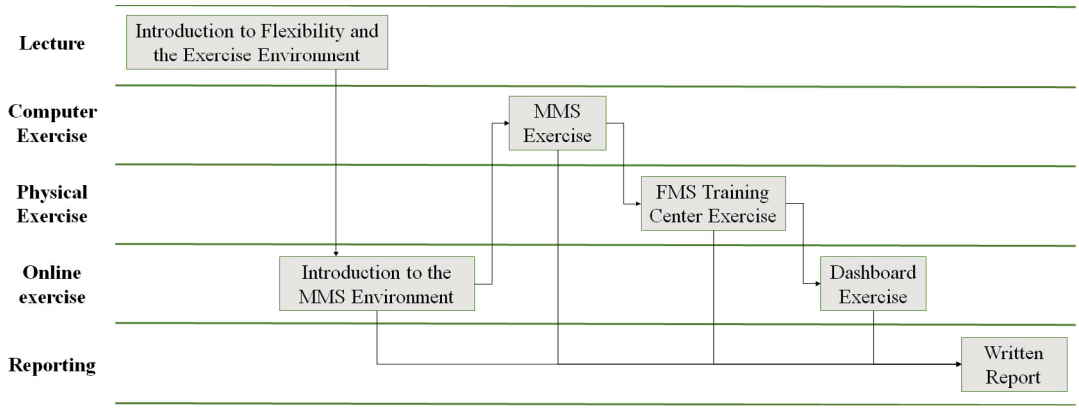

Fig. 3. The flow of the exercises.

3.2. Pedagogical aspects of the exercises

Biggs [13] has introduced an operational framework for teaching design. It includes intended learning outcomes, teaching and learning activities as well as assessment tasks that will be transformed into grades. The intended learning outcomes explain what the students should learn. The teaching and learning activities explaining how the learning is planned to happen while the assessment tasks are used to evaluate what the students have learned. Table 1 explains how the operational framework is applied in the set of exercises discussed before.

Table 1. Descriptions of the exercise activities, learning outcomes, and assessment tasks.

Individual activity	Teaching and learning activities	Intended learning outcomes	Assessment tasks
Introduction to flexibility and the exercise environment	Passive learning by attending the lecture and taking notes	Basic understanding of flexibility as well as the tasks and the aim of the exercises	How a student describes flexibility in the context of the presented information
Introductory exercise to the MMS environment	Active learning individually or in small groups online by following the given instructions	Understanding what information the environment includes and the meaning of the information	How a student finds the asked information from the system and reports the meaning of the founded information
The MMS Exercise	Active learning in a computer-class room in small groups interacting with a teacher	To understand what tasks are necessary to set up and execute different kind of production plans	How a student reports the procedure to prepare and execute production plans
The FMS Training Center Exercise	Active learning at the physical premises in small groups interacting with a teacher	To get hands-on experience on what preparations and tasks are required in the physical facility	How a student connects the virtual exercises with the tasks performed in the physical facility
The Dashboard Exercise	Active learning individually or in small groups online following the given instructions	Understanding how the operation of the system can be evaluated using different performance metrics available	Choosing relevant performance metrics that represent essential information to persons with different responsibilities

The assessment tasks presented in Table 1 are part of a written report the students will return. Therefore, the tasks will not be evaluated independently but are parts of the assessment criteria. An individual student may not learn much during the first parts of the exercises, but if the understanding increases when the exercises advance, it will be counted in the assessment. The most important issue is what the students will understand after completing the whole set of the exercises. The PDCA-cycle is widely used principle of continual improvement in different kind of organizations [14], [15]. The preparation and execution of the exercises follows this principle. During the planning of the exercises, a group of university teachers and researchers were testing the flow of exercises and exercise material. From the feedback, the exercises were improved, presenting one PDCA-cycle.

Feedback will be collected from the students during or right after the exercises. The teachers will observe the tasks the students are performing. Students are encouraged to point out any difficulties to perform the tasks or to understand the instructions. This enables the instructions to be updated for the next groups of students. This updating of the instructions is the second PDCA-cycle, which can be utilized to minor changes of the exercises.

The students are required to give feedback to pass the course. This feedback can be customized and a few specific questions related to the exercises will be formed. Second source of feedback at this point can be investigated from the written reports the student will return. These two sources of feedback are available only after the course and the utilization of the PDCA-cycle can be complemented only after the course has ended. This feedback after the exercises will be utilized to improve the exercises for the following implementations of the course.

3.3. Future Work

The improvements activities of the education environment were discussed before. Another viewpoint of the future work is to expand the exercises to master level studies. The education environment serves several different viewpoints of further studies of the students and are briefly explained as follows:

- *Management of production systems*: Production planning and control of order delivery process and the exercise environment as a part of a larger virtual factory environment.
- *Integrated production automation systems*: Robotics and automation exercises within the learning environment as well as safety issues in industrial facilities.
- *Manufacturing technologies*: 3D modelling and simulation of manufacturing processes enabling collaborative product and process design.

The future development of the education environment will be emphasized more after the initial execution of the exercises based on the feedback and development ideas deriving from the students as well as what will be learned from the exercises from the viewpoints of the teachers. Therefore, the future development ideas of the environment may differ from the planned ones based on what new issues and ideas will raise during and after the exercises.

4. Conclusions

This paper presented an engineering education environment of a FMS. The exercise environment and the planned exercises were discussed in detail. The set of exercises of the environment were carefully planned with the aim that the students will learn different topics during attending the individual exercises. After completing all of the exercises the students should have a comprehensive understanding of a typical FMS. To evaluate this, different assessment tasks are used to evaluate what the student actually learned. Based on the feedback from the exercises, the future development of the education environment can be improved both from the viewpoints of students and teachers. The authors of this paper believe that this kind of learning by doing environment enhances the learning experience of the students compared to only theoretical teaching on the topic.

References

[1] Fastems, Manufacturing Management Software MMS, Available: https://www.fastems.com/mms/. Accessed 5th November 2018.
[2] H. Nylund, P.H. Andersson, Framework for extended digital manufacturing systems, International Journal of Computer Integrated Manufacturing 24/5 (2011) 446 – 456.
[3] H. Nylund, K. Salminen, P. Andersson, Digital virtual holons – An approach to digital manufacturing systems. In: Mitsuishi, M., Ueda, K. & Kimura, F. (eds.) Manufacturing Systems and Technologies for the New Frontier, The 41st CIRP Conference on Manufacturing Systems, May 26.-28.2008, Tokyo, Japan (2008) 103-106.
[4] L. Monostori, B. Kádár, T. Bauernhansl, S. Kondoh, S. Kumara, G. Reinhart, O. Sauer, G. Schuh, W. Sihn, K. Ueda, Cyber-physical systems in manufacturing, CIRP Ann. Manuf. Technol., 65 (2016) 621-641.

[5] L. Monostori, Cyber-physical production systems: Roots, expectations and R&D challenges, Procedia CIRP, 17 (2014) 9-13.
[6] D. Kreimeier, F. Morlock, C. Prinz, B. Krückhans, D.C. Bakir, H. Meier Holistic learning factories - A concept to train lean management, resource efficiency as well as management and organization improvement skills Procedia CIRP., 17 (2014) 184-188.
[7] K. Seitza, P. Nyhuis, Cyber-Physical Production Systems Combined with Logistic Models – A Learning Factory Concept for an Improved Production Planning and Control, Procedia CIRP, 32 (2015) 92-97.
[8] H. Kagerman, R. Anderl, J. Gausemeier, G. Schuh W. Wahlster, Industrie 4.0 in a Global Context: Strategies for Cooperating with International Partners", Acatech Study, Munich, Germany, (2016).
[9] A. Sethi, S. Sethi, Flexibility in Manufacturing: A Survey, The International Journal of Flexible Manufacturing Systems, 2 (1990) 289-328.
[10] H. ElMaraghy, A. Caggiano, Flexible manufacturing system, CIRP encyclopedia of production engineering, (2014) 524-530
[11] V. Toivonen, M. Lanz, H. Nylund, H. Nieminen, The FMS Training Center - a versatile learning environment for engineering education," Procedia Manufacturing CIRP, 23 (2018) 129–134.
[12] S. Grabinger, J.C. Dunlap, J.A. Duffield, Rich environments for active learning in action: Problem-based learning, ALT-J 5/2 (1997) 5-17.
[13] J.B. Biggs, Constructive alignment in university teaching. HERDSA Review of Higher Education, 1 (2014) 5-22.
[14] ISO, ISO 9001:2015 Quality management systems – Requirements
[15] R. Basu, Implementing Quality – A Practical Guide to Tools and Techniques, Thomson Learning, London, (2004).