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Digital Twin: Applying emulation for machine reconditioning

M. Ayani [a], M. Ganebäck [b], Amos H.C. Ng [a]

[a] Production and Automation Engineering Division, School of Engineering Science, University of Skövde, Skövde, Sweden
[b] Projektengagemang Industri & Energi Sverige AB, El & Automation, Skövde, Sweden

* Corresponding author. Tel.: +46-500-44-8504; fax: +46-500-44-8598. *E-mail address:* mikel.ayani@his.se

Abstract

Old machine reconditioning projects extend the life length of machines with reduced investments, however they frequently involve complex challenges. Due to the lack of technical documentation and the fact that the machines are running in production, they can require a reverse engineering phase and extremely short commissioning times. Recently, emulation software has become a key tool to create Digital Twins and carry out virtual commissioning of new manufacturing systems, reducing the commissioning time and increasing its final quality. This paper presents an industrial application study in which an emulation model is used to support a reconditioning project and where the benefits gained in the working process are highlighted.

Keywords: Digital twin; Emulation; Virtual commissioning; Industry 4.0; Reconditioning; Retrofitting

1. Introduction

As machines get older, end users need to deal with an increasing number of issues. For example, they can suffer difficulties for maintenance, caused by spare-part discontinuation or lack of technical support, and this can lead to an increasing number of machine breakdowns.

In addition, the fourth industrial revolution, the so-called Industry 4.0, will require many technological advances and different uses of machines and devices. Machine connectivity, allowing data access and sharing at different levels, is one of the keys in this new paradigm. However, while new machines are being designed and prepared for these new features, many current and old systems are limited or cannot support them. [1]

The natural issues caused by machine aging and the new technological advances, can finally force end users to decide to end the machines' life cycle and replace it with a new one. Another alternative is to enlarge the machines' life by carrying out a reconditioning and retrofitting. This last alternative is more cost-effective, a faster solution, as well as an opportunity towards sustainable manufacturing, important for the future of manufacturing in the context of Industry 4.0. [2]

During the reconditioning process, defective or outdated parts are replaced with new ones. Retrofitting the machine with new controllers and Human Machine Interface (HMI) devices, allow logic updates and the possibility to include the desired new functionalities. All these modifications require the machine to be out of production during a certain period of time, including some previous preparation, reconditioning work, commissioning, verification and final validation before taking it back into production. In some cases, due to the end user's production requirements, this time could be limited to just some days or weeks, depending on the machine complexity.

For companies specialized in machine reconditioning and retrofitting, the challenge is not limited to the machines' construction complexity and time constraints, but even to the status of the technical documentation. This is even more critical when the company carrying out the reconditioning is not the one that built the machine in the first place. Outdated technical documentation, or in the worst cases, the lack of it, can require a reverse engineering phase in order to carry out a reconditioning project.

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Fig. 1: Inclusion of use of Virtual Commissioning in industrial automated solutions.

This paper suggests the use of emulation tools to create a Digital Twin (DT) of an old machine and support its reconditioning project. The proposed methodology tries to maximize the use of the DT during this process. The aim is to pay off the required extra time to build it, adding flexibility to the project, minimizing risks and ensuring high quality in the results.

This paper is structured as follows: section 1 introduces the paper; section 2 reviews the literature about emulation and DT; section 3 describes the followed methodology, section 4 explains the DT modelling, a real-world application study is described in section 5; and finally, section 6 draws the conclusions of the paper.

2. Emulation and the Digital Twin

Modern industrial processes and manufacturing plants are introducing more technology and are increasing its complexity. Companies require high quality in their new automated solutions, at a low cost and fast delivery. Therefore, test and validation processes become critical for OEMs and system integrators[3].The testing of the automated systems usually takes place during the on-site commissioning, once the equipment is being located in the real plant. Incidents at this stage could lead to miss the initial planning, or even worse, to cause damages on the equipment which will lead to unnecessary additional costs.

The concept Virtual Commissioning (VC) is based on realizing the verification and validation of systems against a virtual model instead of in the real automated system. This can be done after or even during the development of the real-world system and before the real commissioning, see Fig. 1. Direct and obvious benefits of VC include the reduction in travel time and costs. Furthermore, it also provides a flexible platform to make tests and validations without the stress of the real on-site commissioning. Despite the many benefits, it is not widely used in automation engineering yet. One of the main reasons is the effort and knowledge needed to select the right technology and develop usable models.[4]

Different tools and technologies are available in the market for VC. They use different techniques, such as simulation and emulation, including functionalities focused on different types of automated systems. Industrial automated system models created using simulation techniques try to provide a similar behavior of the system. This is usually achieved by using simplified approximations or assumptions, to obtain an idea of how the system reacts and analyze its outputs. On the other hand, emulation techniques try to imitate the behavior of a system in order to perform the same work and produce the same results [5]. A main difference between them is that the emulation model needs the real control software in order to work, a Programmable Logic Controller (PLC) or robot program, while the simulation model does not need it. This difference makes emulation a more suitable platform for VC, which nowadays is its typical use, but can be more beneficial if it is used during the entire life cycle of the system.

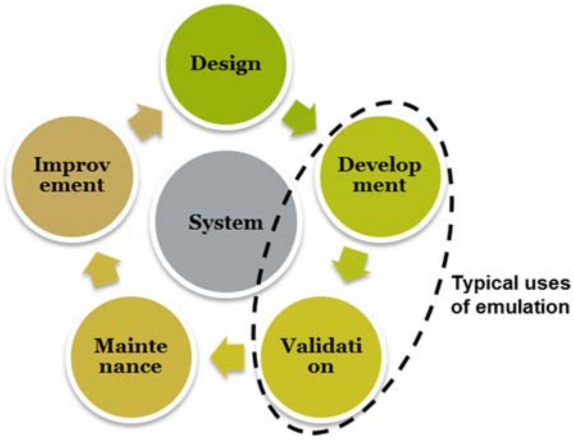

Fig. 2: Life cycle of an automated system and typical use of emulation.

Employing emulation in other phases rather than development and validation, can help to train expert users and operators, increase the stability and reliability of the system, or allow to implement system upgrades or modifications without compromising real production [6]. It can even be used in the design phase to support design decisions and also help in the sales process and initial discussions with customers. Finally, it can also be employed for optimization of industrial systems in order to achieve an efficient operation and performance. The effort to build an emulation model vary depending on the complexity of the system, but this cost will easier be paid off by using emulation in several phases of the life cycle, see Fig. 2. This way, emulation would be worth even for those less complex or critical systems.

The Digital Twin (DT) term was started to be used in the beginning of this decade. From the simulation point of view, it's a new concept for describing a new wave in modelling and simulation. While the use of simulation tools was previously restricted to design stages, today different type of simulation tools are used in testing, validation or optimization. In the automated industry, we could define a DT as a multiphysic and multiscale simulation model that mirrors the corresponding physical twin, allowing the extension of the simulation to all life cycle phases of the system[7].

Therefore, considering the differences between simulation and emulation tools, it can be assumed that emulation tools are the right solution for creating low level DT of automated systems. Emulation tools such Simumatik3D® integrate a rigid body physics engine in addition to the graphics engine. This allows to create geometric, kinematic and logic models of devices at sensor and actuator level, that can be combined to create a functional DT of a complete automated system.[8]

3. Methodology

The application study presented in this article is based on a real industrial reconditioning project of a core making machine used for producing foundry sand cores for the automotive industry. The machine was installed in the early 90s and the project consisted on a complete reconstruction of the electrical scope, replacement of outdated pneumatic, hydraulic and electric devices, rewiring, installation and final commissioning and validation. The project included the retrofitting of the old Siemens® PLC and Human Machine Interface (HMI) devices.

The required time frame for the complete reconditioning process, including the removal of old components, installation of the new ones and commissioning, was limited to four weeks. The stop in production could not last longer than this period.

The company Projektengagemang Industry & Energy Sverige AB carried out the project with the collaboration of the Production and Automation Engineering Division of the University of Skövde in Sweden, which helped creating the DT of the machine to support the company during the process.

The project followed a methodology trying to take most of the advantage of the DT in its different project phases. This methodology is described in Fig. 3 and was a suggestion adopted following the regular methodology for similar projects, but modified to integrate the use of emulation. The steps where the DT was used are marked with orange color.

Due to the fact that the company carrying out the reconditioning was not the original machine builder and the lack and outdated technical documentation, the construction of the DT supported the reverse engineering phase (I). The DT

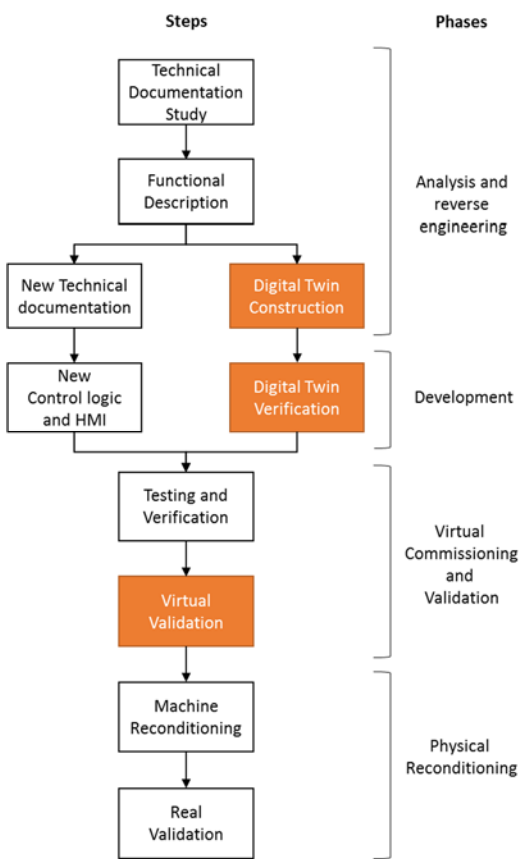

Fig. 3: Methodology, including different phases and their steps.

was verified during the new control logic development phase (II), allowing to easily test the new PLC logic and HMI. Finally, the DT allowed to realize the VC and Validation (III), and compare its results with the real machine, to obtain the required virtual confidence [9] by the customer before the physical reconditioning even started.

Following this methodology, the last phase (IV) was the only one restricted to be carried out during the limited period of four weeks. This allowed more flexibility to carry out the previous phases.

4. Digital Twin Modeling

The software used to build the DT is Simumatik3D®. The key features of this emulation tool are its ease of use, robust physics and 3D engines, as well as that the software does not require programming skills to create and use the models. The software uses a component based approach, so emulation models are created by introducing different components from a library and connecting one to each other using specific ports, imitating the real-world. The library includes basic electric, pneumatic and hydraulic components.

Each component model in the Simumatik3D® library is created to reflect the geometry, kinematics, logic and interfaces of its real analogue. This is possible because the software includes three simulation engines: a 3D graphics engine, a rigid body physics engine and a logic engine. Each component model has specific parameters that can be changed to modify its appearance or behavior, and different connection ports to connect it with other components. These features allow creating and adjusting component models with a high accuracy level that can be individually validated against their real analogues.

An example of a component represented in the different domains can be a pneumatic cylinder, shown in the Fig 4. This component is graphically represented with two cylinders, one for the body (blue) and the other for the rod (yellow). In the physics domain each cylinder has its own mass and collision shape, in accordance with the graphical geometry. The Body and the rod are connected to each other with a linear joint and even the piston inside the cylinder is modeled to allow position detection using sensors. Finally, the logical function calculates the cylinder movement depending on the pressure applied in both pneumatic ports. The cylinder parameter list includes the cylinder radius, length and stroke limits, among others.

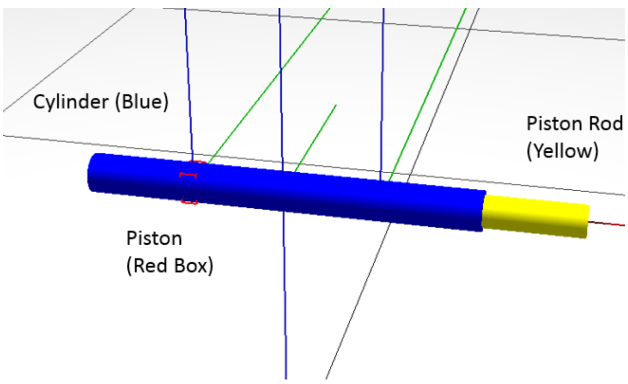

Fig. 4: Geometric and kinematic model of a pneumatic cylinder.

In addition to the library components, 3D models can be imported in the model, with their kinematic properties, and create more complex mechatronic subsystems.

Once all the components are introduced and connected in the model, they can be commanded using industrial control systems. Simumatik3D® allows connectivity with industrial controllers using the standardized OPC-UA technology, widely supported by different brands of PLCs and robots.

5. Application Study

5.1. Phase I: Analysis and Reverse Engineering

The complexity and variety of elements included in the studied machine provided an interesting and complete case. The reconditioned core making machine is a machine that produces sand cores for a foundry. Sand cores are produced as a result of 1) mixing sand with additives, 2) introducing the sand in what is called a sand box to form it, 3) exposing the sand to specific gases so it is rapidly hardened, and finally 4) pulling it out from the box.

The machine includes electric, pneumatic and hydraulic components, including several linear and rotational movements, conveyors and fixtures to handle the sand boxes, sand cores and all necessary mechatronic parts. To control the process of gassing and ventilation inside the machine, it also includes a number of sensors and valves.

The work started by analyzing all the different machine movements, study the old PLC logic and creating a sequential description of the machine. Mechanical and electrical drawings were studied to understand the machine construction and how different elements work together. This effort was necessary to understand the machine functionality and be able to start building the machine DT with Simumatik3D®.

Different parts of the machine with separate functionalities were later identified and separately documented. After listing all sensors and actuators, these were added in the emulation model, see a snapshot in Fig. 5. Simumatik3D® is an emulation software that includes all basic electric, pneumatic and hydraulic components that are used in the machine, which allowed an easy construction of all the mechatronic parts in the DT.

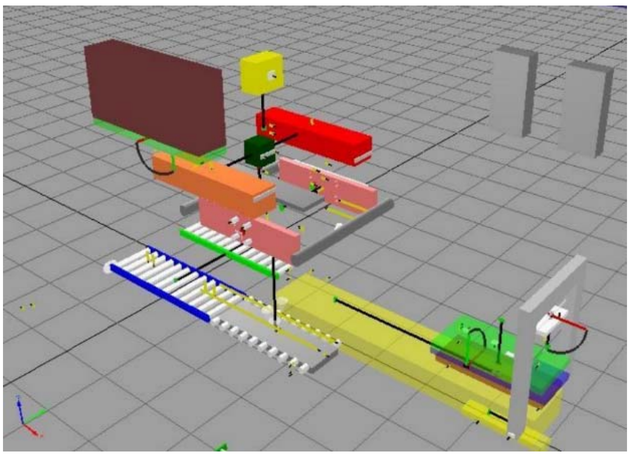

Fig. 5: Emulation model created during reverse engineering phase.

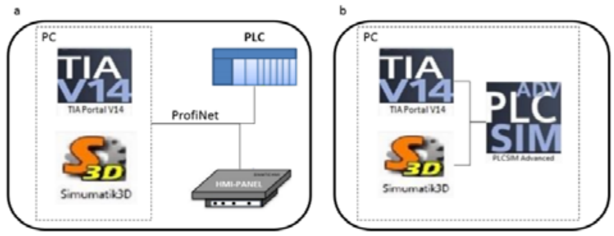

Fig. 6: (a) Real control hardware setup, (b) Complete software setup

5.2. Phase II: Development

The retrofitting of the machine was realized replacing the old Siemens® S5 PLC and HMI device by new generation Siemens® 1500 CPU and HMI panel. The system redesign adopted a more distributed architecture. All sensors and actuators in the machine, with around 200 digital input and output (IO) signals and 7 analog signals, were reconnected using distributed IO devices. The new local network of the machine was based on the industrial ProfiNet® fieldbus, connecting the PLC with several IO modules and the HMI. The control logic and HMI interface were developed using Siemens TIA Portal® platform.

Once the basic control project was created, including the hardware configuration and variable declaration, the DT sensors and actuators were assigned to its respective variable in the PLC. At this point, it was possible to download the control software to a controller and test it against the DT.

The emulation test environment was setup in two different ways, to test the capabilities and differences between using real hardware versus using soft-controllers, Fig. 6. Siemens® provides a soft-PLC solution called PLC Sim Advanced® which emulates a real PLC controller. This software can run in a regular PC and execute the PLC logic as it's homologous. Because the use of OPC-UA is supported by the real and also the soft PLCs, both configurations were supported by the emulation model created in Simumatik3D®. When running the complete software setup, an extra computer screen was used as HMI. When using real control hardware in the setup, it reduces the processing load in the computer, providing better performance during the emulation, while using a complete software based setup can be a more cost effective and flexible approach.

During this phase the DT was used to support the development of the control and HMI program, allowing testing and debugging it. All IO signals were tested against the DT using the electrical drawings and the IO list, thereby variable addressing was verified as part of the integration work. The IO validation was carried following the same steps as in a real IO validation. Output signals in the PLC were forced to validate the actuator movements and input signals were monitored to check the status change of different sensors.

The emulation model was adjusted and complemented with different features and devices as it was required. Process related parts in the machine were finally implemented and tested in the DT. Finally some 3D models where imported and used in the DT to provide a more realistic experience, see Fig. 7.

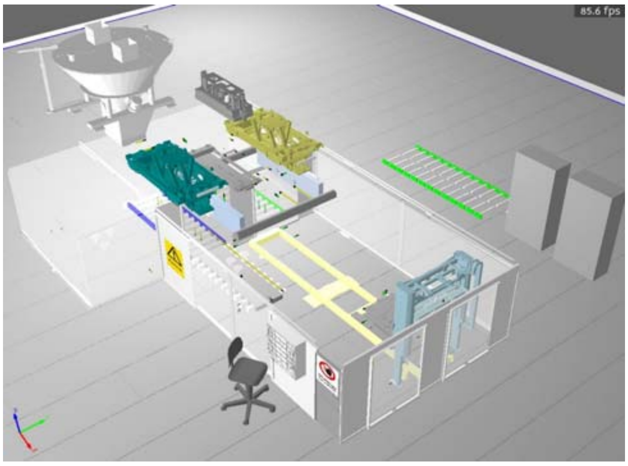

Fig. 7: Complete emulation model of the core making machine.

The final verification of the DT was carried out with the support of the actual machine operators and technical staff. All possible movements were tested and compared with videos recorded from the real machine and the technical documentation. The machine operators could provide important feedback to adjust the DT and finally get an accurate model.

In addition, the use of the DT during the development phase, allowed discussions with the customer and its technical staff and operators. As a result of these discussions, small modifications and adjustments in the control program and HMI were agreed. These kind of discussions usually take place after or during the real commissioning, which in this case, provided an important qualitative benefit to the project.

5.3. Phase III: Virtual Commissioning and Validation

Once the development and preliminary testing of the control logic was finalized, the verification and validation of the machine was carried out. This included the verification of the manual movements and HMI features, automatic sequence execution and testing of fault situations in the first place. In the second place, the validation of the system requirements was realized.

Thanks to the use of the DT many issues where detected during the VC. Errors in the PLC program and HMI were as a result fixed, for example:

- Errors in interlock signals between different movements.
- Synchronization issues between different machine sequences.
- Errors programming the activation and deactivation of output signals for actuators.

After the VC, the DT provided the possibility to perform a Virtual Factory Acceptance Test (VFAT) together with the customer. The Factory Acceptance Test (FAT) protocol used against the emulation model was the same as the one to be employed later, during the real FAT. Some issues detected during the VFAT could instantly be corrected and validated while others could be revised in a second round.

At this stage, with the old machine still in production, the virtual confidence level and the progress in the development was highly superior to a regular reconditioning project before real commissioning.

5.4. Phase IV: Physical reconditioning

The removal of old components and the installation of the new ones lasted for over two weeks during the physical reconditioning of the machine. Once the new electrical cabinet including the new PLC and HMI were installed, the real commissioning started with the hardware configuration followed by the IO testing. The machine was working as expected as soon as the logic was downloaded to the PLC, demonstrating that the use of the DT resulted in an important reduction of the commissioning time, 60% shorter with 50% less rest points. As mentioned, the final validation was carried out following the same FAT protocol used in phase III. The machine was back in production in the required time frame, which would have been impossible to achieve without following the methodology described in this paper.

6. Conclusions

This article has presented a reconditioning project in which a Digital Twin has been built employing the emulation software Simumatik3D®. This approach has proved to be beneficial to support an efficient reconditioning process. Known the implicit challenges of any reconditioning project, building the DT can help engineers during the reverse engineering phase. Once the emulation model is created, all the benefits of Virtual Commissioning are gained in the development and testing phases. The time and cost invested on building a virtual model is paid off with the reduction of the real commissioning time and costs, and has even a positive impact in the quality of the delivery and working conditions of all the stakeholders involved. In addition, all work performed with the DT impacts substantially in sustainability, due to the fact that energy consumption required for operating the DT is much lower than the real system.

Virtual confidence can be obtained before starting the physical reconditioning work, providing new resource and time planning possibilities for these kind of projects. Furthermore, there is room for improvements in the planning at different phases, due to the fact that project deliverables, including the developed control programs, can more efficiently be scheduled to reduce time and use of resources. Therefore, the possibility that DT offers to make more flexible time plannings, could by its own, be a reason for adopting the methodology presented in this paper.

The methodology presented in this paper will further be developed as part of a research project with the aim to be employed by different companies in the future.

References

[1] R.G. Lins, B. Guerreiro, R. Schmitt, J. Sun, M. Corazzim, F.R. Silva, A novel methodology for retrofitting CNC

machines based on the context of industry 4.0, 2017 IEEE International Systems Engineering Symposium (ISSE), 2017, pp. 1-6.
[2] T. Stock, G. Seliger, Opportunities of Sustainable Manufacturing in Industry 4.0, Procedia CIRP, 40 (2016) 536-541.
[3] O. Mathias, W. Gerrit, D. Oliver, L. Benjamin, S. Markus, U. Leon, Automatic Model Generation for Virtual Commissioning based on Plant Engineering Data, IFAC Proceedings Volumes, 47 (2014) 11635-11640.
[4] Z. Liu, N. Suchold, C. Diedrich, Virtual Commissioning of Automated Systems, 2012.
[5] I. McGregor, The relationship between simulation and emulation, Proceedings of the Winter Simulation Conference, 2002, pp. 1683-1688 vol.1682.
[6] M. Oppelt, L. Urbas, Integrated virtual commissioning an essential activity in the automation engineering process: From virtual commissioning to simulation supported engineering, IECON Proceedings (Industrial Electronics Conference), Institute of Electrical and Electronics Engineers Inc., 2014, pp. 2564-2570.
[7] R. Rosen, G. von Wichert, G. Lo, K.D. Bettenhausen, About The Importance of Autonomy and Digital Twins for the Future of Manufacturing, IFAC-PapersOnLine, 48 (2015) 567-572.
[8] C.G. Lee, S.C. Park, Survey on the virtual commissioning of manufacturing systems, Journal of Computational Design and Engineering, 1 (2014) 213-222.
[9] J. Oscarsson, M.A. Jeusfeld, A. Jenefeldt, Towards Virtual Confidence - Extended Product Lifecycle Management, in: A. Bouras, B. Eynard, S. Foufou, K.-D. Thoben (Eds.) Product Lifecycle Management in the Era of Internet of Things: 12th IFIP WG 5.1 International Conference, PLM 2015, Doha, Qatar, October 19-21, 2015, Revised Selected Papers, Springer International Publishing, Cham, 2016, pp. 708-717.