Creation of a Digital Twin and Its Control-Based on the ANSI/ISA-S88 Standard

1st Jan Holba  
Department of Control and Instrumentation  
Brno University of Technology  
Brno, Czech - Republic  
xholba05@vutbr.cz

2nd Michal Husáček  
Department of Control and Instrumentation  
Brno University of Technology  
Brno, Czech - Republic  
xhusak08@vutbr.cz

Abstract—This paper deals with development of detailed digital twin of small-volume liquid storage unit, as well as its complete virtual commissioning. The original design of the existing unit is substantially modified to increase reliability and robustness. The control logic for PLC, according to ANSI/ISA-S88 standard, is also created. Based on this implementation of the control logic for the digital twin, its real counterpart will also be put into operation.

Index Terms—Digital Twin, Industry 4.0, ANSI/ISA S88, Batch Process, Siemens NX

I. INTRODUCTION

The aim of this work is to develop a detailed digital twin and fully commission it virtually. This digital twin is a counterpart of real small-volume liquid storage unit. The original construction of the existing unit will be substantially modified to increase its reliability and robustness. Additionally, control logic for the unit will be implemented based on the ANSI/ISA S88 standard for batch processes. Based on the implementation of the control logic for the digital twin, its real counterpart will be subsequently commissioned.

II. THE DIGITAL TWIN

A digital twin (DT) is a complex model which allows detailed simulation of a real system. Thanks to the DT a system can be easily operated in virtual environment. This eliminates the problems associated with manipulation of physical system in the real world. DT cannot damage itself nor its surroundings. It does not wear down and does not depreciate itself in any other way.

During the life cycle of the machine, DT plays and irreplaceable role in development phase of the equipment. When creating the control logic for a given system, the programmer does not have to be located near the real machine. The given machine does not even have to physically exist yet. The control logic can be created remotely from the comfort of his home or office. The stress and fear of damaging expensive equipment is reduced, and the programmer can fully concentrate on his work. He can experiment as he pleases, restart the simulation at any time to any position, or pause it to debug his code. This is usually not possible with a real machine. After completing the control logic for the digital twin, close to none code modifications are necessary to get the real system up and running.

In addition to developing and testing of new concepts, the digital twin is also suitable for training new staff or for teaching. Workers can get familiar with the system in depth and learn how to react in the event of hazardous situation. During the training, the real machine performs its normal work and thus production is not limited in any way. In teaching, it is advantageous to use a DT mainly for financial reasons.

Creation and virtual commissioning of a DT is significantly less expensive than development of fully physically functioning machine on which students can learn to code. The effectiveness of learning, whether in school or in industry, will be significantly increased, because the fear of the possibility of damaging a real, often expensive, machine is eliminated.

Several people can use the simulation at the same time on different computers.

Simulation time can be scaled and action execution speed of the DT can be adjusted. It can be stopped at a certain point so necessary calculations can be performed. It can be run slowly for detailed analysis, or a large number of process cycles can be performed rapidly for measurement and analysis of long-term data without the need of lengthy measurements of a real system for several months. Likewise a huge number of different process modifications can be tested very quickly.

DT can be modified and optimized very easily based on the data analysis. During structure modification no material is used, so the equipment optimization is not expensive. The real system is then modified after thorough testing on the DT.

The DT simulation runs separately from real system. The complete feedback connection of the digital twin and the physical system results in the so-called Cyber-Physical System (CPS). The digital twin is constantly dynamically updated based on the measured values on the real machine. In this way, it is ensured that the real system and its digital twin move in a fixed manner and maintain a zero deviation even if the real system is delayed due to external forces or wear and tear, for example. However, the implementation of CPS is significantly more complex and will not be covered in this paper.

A. Digital Twin of Small-Volume Liquid Storage Unit

The digital twin that was created as part of this paper is a counterpart of real small-volume liquid storage unit. The task
of this unit is to fill a glass with a required mixture of liquids based on a prescribed recipe. This work builds on the work of Lukáš Rejchlík [1], but significantly modifies the original concept.

The central element of the cell is a three-axis manipulator. The vertical linear movement of the manipulator is driven by a BCI 6335 DC motor with a 21.6:1 gearbox. Horizontal linear movement is provided by a Hanpose 17HS4401 stepper motor with a NEMA17 flange. The same type of stepper motor also drives the rotary motion of the cup-grabbing arm. The actual position of the manipulator is being monitored by a pair of encoders and checked by limit sensors. The amount of remaining liquid in the storage unit is being monitored by the capacitive sensors.

An older version of the unit’s 3D model already existed, but it was a classic, static 3D model, not a digital twin. For the creation of the DT, the individual parts of the model had to be converted from the original CAD software SolidWorks to the Siemens NX program and assembled. Subsequently, it was necessary to modify the structure of the cell and thus solve a number of problems.

The main problem originated from the method of dispensing liquids into the glass. A compression dispenser with an overflow chamber was used. The problem was that very high pressure needed to be exerted onto the mechanism to activate the dispensing. Since the handles of the dispenser as well as the manipulator itself are made of plastic using the 3D printing method, they could be damaged by the load. In addition, the overflow chamber of the dispenser has a constant volume, so it was not possible to dispense the exact required amount.

These problems are solved by the use of peristaltic pumps that allow us to dispense very precise volume of liquid. The lifespan of these pumps is typically quite long without the need of extended maintenance, they are also easy to control. However, pumps are no longer purely mechanical and need power to function.

The introduction of peristaltic pumps led to a modification of the original design of the unit. A substantial part of the unit was disassembled and redesigned. New bottle storage positions, that integrate pumps and capacitive sensors for liquid level monitoring, have been created. Because of the newly brought wires to each storage position, it was necessary to create a new, more compact counterweight housing that does not collide with the wires. Furthermore, the electrical wiring of the cell was modified. The final structure of the storage unit increases the number of storage positions from the original five to sixteen.

B. Physics Simulation and Virtual Commissioning of the Digital Twin

After completing the creation of the model, it is possible to switch from the Modeling application to the MCD (Mechatronics Concept Designer) application, which gives us the opportunity to create a very complex kinematic simulation. First, it is necessary to mark required parts as rigid and collision bodies.

Rigid bodies are objects that are subject to the laws of physics. They will be affected by external forces, such as gravity, or forces caused by other rigid bodies and actuators. Colliding bodies affect each other only in physical contact. These collisions can be unwanted impacts, e.g. collision of the manipulator with the structure of the cell. However, some collisions are necessary for the function, e.g. grasping the glass by the manipulator.

Rigid bodies can be connected to each other using various types of kinematic joints. Among basic joints are fixed, sliding, rotary etc. By assigning joints, we define the possible trajectory of objects. For example, a linear joint between a bearing and a guide rod ensures that the bearing will move along a precisely linear trajectory given the axis of the rod. If we want individual rigid bodies to be affected by the forces from other rigid bodies, we must assign them so called couplers. Example could be gear coupler for simulating gearboxes, or rack and pinion coupler for two-way transformation of rotary and linear motion.

Furthermore, it is necessary to simulate sensors and actuators. Sensors can work based on the principle of collision between two bodies. The calculation of collisions, however, tends to be computationally demanding, so it is appropriate to simulate the sensors based on the limit switch principle. Limit switch is activated if the tracked object exceeds the specified position, which we set to the sensor position. Speed control function has to be assigned to the drive units, and the maximum acceleration and torque has to be specified based on engine manufacturer’s datasheet.
This digital twin is controlled by a PLC industrial control system. Communication is carried out using the OPC-UA server. The OPC-UA server reads the selected signals from the PLC and rewrites the values in the model. If minimal delay between PLC and simulation is required, it is advisable to use a PLC simulated by the PLCSIM Adv. program instead of a physical PLC and communicate directly with the model. In addition, the use of a simulated PLC will enable the complete development of control logic solely on a computer, without the need for any additional hardware. Beware, the S7-1200, unlike S7-1500, cannot be simulated using PLCSIM Adv. at the moment.

III. TESTBED SELF-ACTING BARMAN

The created storage unit is part of the Self-Acting Barman project. The goal of the project is to create an automated production plant for mixed drinks based on the principles of Industry 4.0. The detailed description of the testbed can be found in the article An Industry 4.0 Testbed (Self-Acting Barman): Principles and Design [3].

IV. STANDARD ANSI/ISA S88

Industrial processes are divided into discrete, continuous and batch. The division is based on the nature of the final product. Batch processes are described by the ANSI/ISA-S88 standard. Output of the batch process are finite quantities of material (batches) [3]. Application of the standard is suitable for the Self-Acting Barman as the individual glasses represent separate batches of a product.

The standard is based on the division of batch processes into so-called models and their interconnection.

![Fig. 2. ANSI/ISA S88 models](image)

The division into these models will allow a significant improvement in the synergy between technologists (process model), integrators (procedural control model) and assembly workers (physical model). Development of individual models, as well as layers, can take place in parallel and there is no need for an expert who understands all parts of the production process at the same time. The description of production technologies and procedures can be very complex. If we divide the process into groups of simple sections, it becomes significantly simpler and the whole process becomes modular. This makes it easily adjustable, and we can use individual modules repeatedly in the process.

The testbed Barman is defined as a process cell. As a complex production facility, it would not be possible to implement it without further division into process units. This paper deals with the partial goal of implementing a small-volume fluid storage unit.

A. 1.4. Process Model

A process model does not define a specific physical device. It describes the batch process from a recipe perspective. It defines what raw materials, in what order and in what proportion need to be mixed, but does not specify what equipment needs to be used. We can compare the process model to a kitchen recipe. The model is structured into four levels and each level contains one or more parts.

In this case, on the highest level is the process that describes the entire workflow of drink preparation by the Barman testbed, from receiving the order from the user, through preparing the glass, pumping the drink and mixing it, to issuing the finished drink to the user.

In the lower layer, there are process stages that describe the work approach of individual process units. One of these units is the storage unit, which is the subject of this paper. The process stage of the unit is further divided into process operations and, if necessary, further into process actions. Process actions describe the approach to picking up the glass, moving it to the required positions, filling the required liquids and dispensing the glass.

B. Physical Model

The physical model describes the equipment that is needed to perform the procedure that is described in the process model. It describes specific physical equipment and divides it into individual sections. Combining physical equipment at lower level creates a new element at a higher level. This element then behaves as a whole, and a change at a lower level is possible only by redesign. The physical model is divided into seven layers. But the first three layers, i.e. Enterprise, Location and Operation, are not directly related to batch production and therefore will not be considered further.

The process cell is the entire testbed Barman. It consists of several process units. These are, as described in the article [3], a glass storage, a carbonated water maker, small and high volume liquid storages, a shaker and an ice crusher. Each process unit is further divided into equipment modules. For this storage unit, these modules are the transport module and the dispensing module. The equipment modules then consist of control modules such as stepper motor, DC motor, peristaltic pump, capacitive level sensor, etc.
It combines the previous two models. It describes functions, that ensure the equipment, defined in physical model, is used in a way that leads to completion of the process defined in the process model. The model consists of four levels: master recipe procedure, procedures of individual units, operations and phases.

![Fig. 3. Procedural Model for Barman Testbed](image)

The master recipe procedure controls the entire process cell to perform the desired process. In the barman testbed, this master recipe procedure is to mix a drink and hand it to the user based on his request.

On a lower level are unit procedures that are related to individual units from the process cell. One of the process units of our testbed is my storage unit. The procedure of this unit describes all the functions required to dispense the desired liquids into the glass and pass it to the next unit.

The control logic is further divided into operations. The standard defines that only one operation can run on each unit at a time. It also says that a unit procedure consists of one or more operations. If there is no need to divide the production into several operations, there can be only one. Operations then consist of phases that form the lowest level of control logic. Several phases can run in parallel and can be repeated within one operation, as follows from the modular concept of the entire standard. Phases are the phases of loading the glass, transport, dispensing and unloading the glass.

The standard helps with structured control, where the entire process cell does not have to be controlled by one powerful and expensive control system, but the individual elements in the lower layers of the procedural model are controlled separately by simpler control systems. If we look at the Barman testbed, there is no single control system that independently controls the entire production, but each unit has its own control system with its own logic. Units communicate with each other using an administrative shell. The communication interface recommended by the S88 standard allows the use of a standard central MES for temporary development purposes until fully decentralized solution is available.

V. TESTING

At the time of writing the article, the DT is fully operational virtually and work is underway to commission a real unit. Due to the fact that the DT is very detailed, the real commissioning is based purely on the calculations of conversions of the input and output signals of the control unit. At this point, the most important phase of transport is fully operational, which on a real cell performs the same movements as the DT. However these movements are not completely identical, because created simulation is classified as a DT rather than a CPS, as mentioned at the end of chapter II.

VI. CONCLUSION

The digital twin represents an ideal way of developing and testing new devices. It helps in development and production as well as in teaching. The digital twin of the small-volume liquid storage unit, which was developed as part of this paper, features complete kinematics simulation and is fully controllable by both a real PLC via the OPC-UA server as well as by a simulated PLC. The application of this digital twin enabled the remote development of the control logic from the comfort of home without the need to be present at the real unit, which was not yet complete at this stage of development. Furthermore, the digital twin significantly eased experimentation and debugging by eliminating fear of damaging expensive equipment, enabling full focus on control logic development thus increasing its efficiency.

A substantial part of the original structure of the unit had to be disassembled and redesigned. That led to increase in its reliability, robustness and accuracy of liquid pumping. At the same time, it was necessary to modify the electrical wiring of the unit and a complete electrical diagram was created.

The use of the ANSI/ISA S88 standard and the associated division into individual models and levels enabled the organized development of the control logic of the batch process. The created and debugged control logic require minimal modifications for real deployment.

ACKNOWLEDGMENT

The completion of this paper was made possible by the grant No. FEKT-S-23-8451 - “Research on advanced methods and technologies in cybernetics, robotics, artificial intelligence, automation and measurement” financially supported by the Internal science fund of Brno University of Technology.

REFERENCES


