I4.0 TESTBED - INTRODUCTION AND STRUCTURE

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Abstract: This paper deals with the description of the newly growing testbed for Industry 4.0, which is developed by the Industrial Automation Group (SKUPRA) at the Department of Control and Instrumentation of the Faculty of Electrical Engineering and Communication of the Brno University of Technology. Within the first part of of this paper we introduce the idea of the Industry 4.0 phenomenon and motivation for the development of the testbed. The second part of the paper describes both the philosophy of the testbed and the construction itself. The last part of the paper deals with the basic description of the testbed functionality.

Keywords: Industry 4.0, Testbed, 3D modeling, Additive manufacturing, Rapid prototyping

1 INTRODUCTION

For a long time, we can see in the manufacturing industry a gradual *digital evolution*, which is aimed at achieving the principles of so-called *Industry 4.0*. This gradual development leads to increasing demands on industrial infrastructure and technologies, such as communications networks, safety, cyber security, cloud technologies, and many others. Moreover, the demand for professionals who understand this field and are able to use it in practice is increasing. In view of these facts, there is a need to introduce a large number of themes in teaching at universities, which are often difficult to grasp because of their interdisciplinary nature. For a student, who has only dealt with elementary automation-related tasks, such as sensor applications, programming of basic control algorithms, or modeling of controllers, the transition to a much more complex issue, which is undoubtedly a modern industrial system, is very difficult. Considering mentioned problems of interdisciplinarity, we will get requirements for a graduate, who is also an electric engineer, a designer, a mechanical engineer and an IT expert.

It can be said that after leaving university, the student will learn a lot of from practice. In the group of industrial automation, however, it is predominant opinion that students should acquire knowledge during their studies not only of austere information in the form of a list of used technologies and IT tools but also practical knowledge, experience and skills. It was this idea that initiated the motivation for the realization of the laboratory device, a testbed, which would demonstrate the principles of *Industry 4.0* not only on the theoretical level but also practically. This comprehensive workplace could enable students to address not only basic issues of the lower levels of the automation pyramid, but also new possibilities such as:

Design of algorithms for real production - Design and implementation of algorithms for real manufacturing processes control, both for discrete production (e.g. assembly processes) and batch production (according to ISA-S88 standard). *Implementation of the Cybernetic Physical System (CPS)* - Creating a digital twin for demonstration and testing. *Implementation of the distributed system* - Possibility to solve a large system divided into individual process units connected by industrial networks. *Demonstration of principles of Industry 4.0* - Modularity of production units, Product customization, Horizontal integration, and so on. *Use of cloud technologies* - Possibility to collect production data for their visualization, machine learning, data mining, and later optimization and production planning. *Operation and Design of the Production Control System (MES)* - Operation over real-world production that allows easy understanding of ISA S-95 concepts such as the recipe, phase, procedure, etc.

2 INDUSTRY 4.0

Three previous industrial revolutions were triggered by the expansion of steam driven mechanical production equipment, the introduction of mass production using electricity, and the use of electronic systems and computer technology in production respectively [1]. The Fourth Revolution, Industry 4.0, could be called evolution, due to its long-term gradual introduction in industrial production. It is mainly aimed at creating the so-called Cyber-Physical Systems (CPS). This new philosophy brings changes to a wide range of industrial areas such as technical standardization, functional safety, cyber security, education, legal framework, science, the labor market and, last but not least, the social system. This philosophy transforms industrial production from standalone automated units into fully automated, continuously optimized, intelligent manufacturing environments that can respond to external pressure on the flexibility associated with the onset of new technologies. This also raises new demands for the above mentioned fields. Industry 4.0's core principles are:

- Interoperability - The capability of CPS, people, and all system components to communicate with each other through communications networks.
- Decentralization - Decision-making and management are carried out in parallel within individual subsystems that communicate with each other through a common network.
- Real-time work - A necessary condition for communication, management and decision-making in real world systems.
- Virtualization - Replacing physical prototypes, production means, and manufacturing processes by virtual designs and simulation.
- Horizontal integration - Integration of all the processes within the product lifecycle from its design to the completion of production.
- Vertical Integration - Integration from the lowest level of production processes to the enterprise scale system planning (ERP systems).

3 TESTBED IMPLEMENTATION

The concept of the testbed is proposed and designed to implement and present the basic principles associated with Industry 4.0 phenomenon. The entire testbed represents the factory producing the real product, which in this case is a mixed beverage in the glass. The endeavor is to include the entire production pyramid, from process instrumentation to the ERP system, and to use the innovative principles of industry 4.0. The testbed will be constructed as a table on which the production line will be placed. The testbed functionality is described in the following section.

The customer chooses or configures the mixed beverage for which he sends the order via his web application account. Subsequently, the product is automatically placed into production. The production will take place sequentially in several production cells, each of which will carry out one part of production (mixing, dosing of liquids, ice dosing, etc.). The movement of the product container (glass with NFC tag) between the cells is realized by the industrial robot. After completion of all manufacturing operations, the robot will put the finished product on a conveyor belt, which performs its transport from the production line directly to the customers on which the product will leave the production line. This conveyor also serves to transport empty jars, which are eventually stored in the warehouse.

3.1 Construction

As mentioned above, the testbed is realized in the form of a table. There is a work area of 1000 x 2000 mm on this table, which houses several autonomous production cells along with a robot and a conveyor belt. Below this work surface there is a similar support area for control equipment, network and IT technologies. Both the construction of the table and the supporting structure of the autonomous cells are realized from aluminum profiles. The production line may consist of a maximum of 6 autonomous cells, four of which are placed directly on the work surface, and two outside the area at the back of the table. This will allow these two cells to have a larger dimension than cells on table (namely, larger than 330 x 330 x 500 mm). A conveyor of a carousel type is placed at the table top. This conveyor is realized by an oval rail, on which the carriages, connected to the drive through a rubber belt, are moved. On the opposite side of the table there is the SCARA robotic manipulator. This manipulator is equipped with a gripper for grabbing glasses to be able to move them between particular production units.

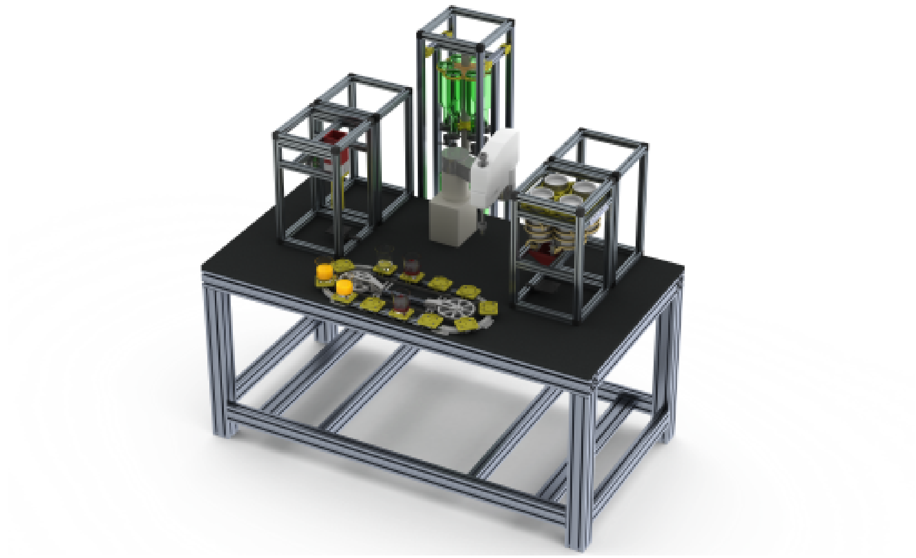

Figure 1: Visualization of the testbed.

The following cells may be located on the workspace:

- Warehouse of glasses - The part of the cell is a stacker that prepares the glass for a robotic manipulator.
- Warehouse of alcohol - After inserting the glass, the cell will fill the alcohol autonomously.
- Warehouse of non-alcoholic beverage - The cell fills a glass of liquid from four tanks, which can be cooled.
- Ice crusher - Ice cubes are stored in this cell. The ice is crushed and placed in a glass.
- Beverage mixer - This cell mixes all the ingredients in the glass.

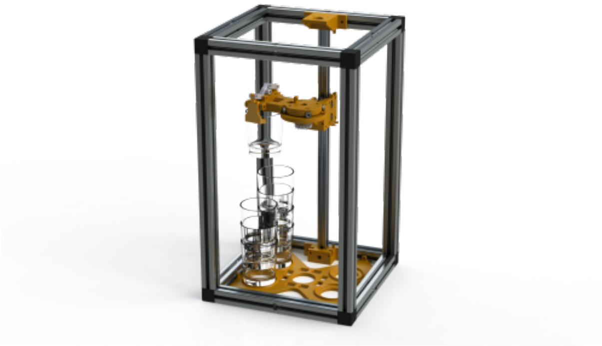

Figure 2: Warehouse of glasses - 3D model of warehouse

A large amount of material is required to realize the design of the testbed. Apart from the aluminum profiles used for the construction, there are a large number of different unique plastic parts. The choice of classical manufacturing processes would be very inefficient because of their uniqueness. Therefore, emphasis is placed on the use of rapid prototyping, i.e. additive manufacturing. The construction parts are produced by the process of 3D printing from thermoplastic materials.

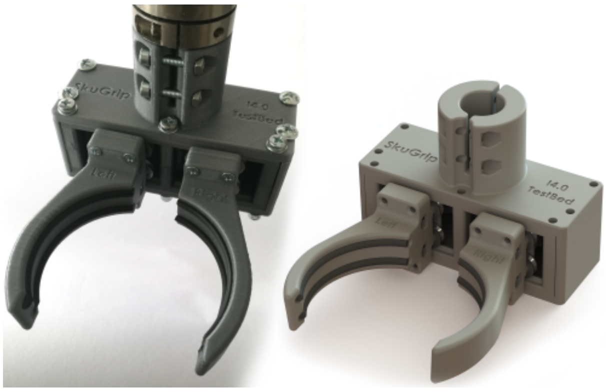

Figure 3: Gripper for manipulator - Demonstrates 3D printing for component manufacturing. (on the left side printed gripper, on right side 3D model)

3.2 INDUSTRY 4.0 AREAS COVERED

One of the main principles of Industry 4.0 is a transition from standalone automated units to integrated automated manufacturing environments. Individual cells therefore constitute autonomous decentralized cyber-physical systems (CPS), which are the cornerstone of intelligent factories. Cells will be able to interact with each other and surrounding cyber-physical environment and will be able to respond to current conditions and requirements. Their production will be fully autonomous. Also conveyor belt and SCARA manipulator will be considered as autonomous equipment. Each autonomous cell has its own control and sensors to control the perception of the environment. It is also connected to the communication network.

For communication and defining subsystem functionality, standardized SOA principles (Service Oriented Architecture) will be used in combination with the Publisher-Subscriber communication model. This will allow individual CPSs to offer their services to other CPSs. It is also planned to use the standardized Administration shell interface that implements the so-called digital twin. This twin can be seen on the testbed either as a twin of the production equipment or as a twin of the product. The administrative shell through OPC UA enables communication between CPS and also provides a hardware model of a hardware unit.

Testbed will also use MES and ERP systems. These systems should allow receipt and order management, warehouse management, or calculations of key performance indicators to evaluate production efficiency. This will enable students to understand the structuring of control algorithms to integrate into these systems. The product lifecycle management is also planned in the production framework. The glass will be equipped with a NFC tag that contains detailed information about the product which should be fabricated. It will also store data logs from the production and consumption of the product. This information then passes to each cell in which it finds itself, which actually controls production. The product lifecycle will end when the glass returns to the warehouse and reads the accumulated data from the NFC chip. This can be used to develop testbed optimization solutions.

4 CONCLUSION

Nowadays we are dealing with a testbed construction for Industry 4.0. Basic cell constructions are already proposed and are implemented and models for virtual commissioning are developed in conjunction with Siemens tools (Tecnomatix Process Simulate, NX). The next step comprises finishing the construction process and creating control for individual autonomous cells. Subsequently all the equipment will be link through the Ethernet.

Even though the testbed is far from the final state, the team of people composed of bachelor, master, doctoral students and assistant professors uses it for constant improvement and gaining new experiences in the field of Industry 4.0. We can say that the testbed fulfills its intended function already today.

ACKNOWLEDGEMENT

The completion of this paper was made possible by the grant No. FEKT-S-17-4234 - „Industry 4.0 in automation and cybernetics” financially supported by the Internal science fund of Brno University of Technology.

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