Lesson Learned from Semester of Online Teaching of Automation Using Simulators

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Abstract. The year 2020 has taught us a very important lesson about communication between university lecturers and students in laboratories. This paper is showing conclusions after a semester of remote personal contact with students and laboratory equipment. In normal cases authors of this paper providing their lessons in a laboratory equipped with industry effectors, Robots, Pneumatic equipment, and PLC’s. It was replaced with simulators, because of the lockdown due to the coronavirus pandemic. In the paper, we describe the on-line didactic process conducted with simulators such as Factory IO; Festo FluidSim; Roboguide.

1. Introduction
In the year 2020, the COVID-19 pandemic situation forced the standard university lectures to be conducted remotely. However, there are areas where it would seem that replacing the student's personal presence, like in the laboratory, it will have a negative effect in the form of low teaching efficiency. The belief that the learning outcomes are lower may come from the deeply rooted opinion that personal participation in classes brings the most effective didactic effect. This claim is based on an often-cited work by Edgar Dale [1]. The results of Dale's research, however, are usually overinterpreted, which leads to the erroneous definition of human perceptual abilities in distance learning [2]. Although the software environments presented in our study have so far served as a supplement to the normal curriculum, in 2020 they completely replaced the teaching work with students in the laboratory. In the teaching of machine operation and control engineering, the simulators and on-line methods are fully justified as proven and effective tools [3]. In teaching programming languages and computer technologies, as well as soft skills, distance learning methods are successful and have been confirmed by the long-standing operation of many learning platforms [8],[9],[10]. In teaching elementary skills in the field of automation and robotics, the last years' experience of forcing online teaching of what seems to have to be taught through face-to-face contact with the teacher and equipment brings an interesting lesson. All the presented here cases are based on the experience gained by authors at the Institute of Automation and Robotics, Warsaw University of Technology.

2. Software description and use cases
2.1. Factory IO
Factory I/O [11] is an environment for 3D simulation of production lines for the design and testing of industrial process automation systems [6], [7]. The software is designed as an easy-to-use program that allows you to quickly build a virtual factory using parts from popular manufacturers. Factory I/O works with simulators of PLC controllers from leading automation manufacturers, including Siemens, Allen-Bradley, among others. Factory I/O also includes many scenes with typical industrial installations.
The software package offers a collection of components that are used in current production lines. Such elements include conveyor belt modules, transport roller systems, pallet lifts, CNC stations cooperating with robots, etc. The simulated machine park is supplemented by a set of various sensors, thanks to which it is possible to build and set-up a sensory system for the production processes.

The factory I/O environment works very well as a training platform for PLC, SoftPLC, Modbus TCP/IP, etc. In the didactic process at the Institute of Automation and Robotics, Warsaw University of Technology, Factory IO software was used in the preparation of theses on the machine automation system design. The aim of one of such work was to design an automated production process with a safety system. A simulation of the production and safety system was carried out using the virtual PLC Siemens SIMATIC S7-1200 and the TIA Portal software (Figure. 1).

The project has been divided into stages that showed the details related to the design, programming, and simulation of the selected production line, including the transport line for processed elements, plastic elements processing lines (Figure. 2), and the carton packaging and storage line (Figure. 1). The implementation of all these elements made it possible to implement the project of a simulated production line with a safety system and to propose and conduct a simulated safety audit for all machines during the operation of the finished line. Audit objectives were adapted to the existing machines, which made it possible to analyze the operation of the safety system. The thesis also included a description of single and comprehensive production line tests and their documentation. Additionally, the project was expanded with a video showing the overall operation of the lines, individual machines, and the detailed work of the safety system with violations.

Due to the difficult contact with the student caused by lockdown, most consultations were carried out remotely. The work was done during the summer semester. The final defense was also carried out remotely, following the rules adopted at the Warsaw University of Technology, developed for the university’s work in the event of the COVID-19 pandemic.

![Figure 1. Factory I/O window with information about correct connection to the controller](image1)

![Figure 2. The carton packaging and storage line, during safety system tests](image2)
2.2. FluidSim

In the Institute of Automatic Control and Robotics, the program FluidSim [12] was used to learn basic pneumatic, hydraulic and electrotechnical connections (Figure 4) in the form of sharing the instructor's window, who discussed the schematics on-line. Moreover, the FluidSim environment was used to describe the functions of the PLC controller in automation systems. Diagrams of fluid and pneumatic automation systems simulated in the program are in accordance with DIN ISO 1219. The program allows users to generate technical documentation on the basis of simulated systems.

According to the manufacturer's description, the program is a good self-study tool for the student. On the FluidSim website, one can find that “FluidSIM 5 is a comprehensive software for the creation, simulation, instruction and study of electro-pneumatic, electro-hydraulic, digital and electronic circuits. All of the program functions interact smoothly, combining different media forms and sources of knowledge in an easily accessible fashion. FluidSIM unites an intuitive circuit diagram editor with detailed descriptions of all components, component photos, sectional view animations, and video sequences. As a result, FluidSIM is perfect not only for use in lessons but also for the preparation thereof and as a self-study program.”.
The Microsoft Teams, considered as leading distance learning tool [4], [5], was used to connect students and lecturers. As part of the lectures, students were asked to make connections that performed specific discrete functions (Figure 5). The tasks were transferred in text form, with a specified deadline for completion of works. The students’ work was presented in the form of screenshots, program files, and video recordings of the virtual layout. A valuable experience is the ability to learn how to use the program remotely and the statement that the very operation of the program causes the students to ask questions about the phenomena occurring in a real facility compared to the simulator. The inability to conduct any other than a virtual experiment causes that they accept the answer without checking the real mechanism. In case of difficulties in understanding the task or its execution, the tutor can take control of the student’s desktop, making corrections and giving instructions.

![FluidSim window view during simulation](image)

**Figure 5.** FluidSim window view during simulation

The use of Fluid Sim during the lockdown due to COVID-19 pandemic allowed to teach students symbols compliant with the standards, rules of creating technical documentation, basic physical dependencies, as well as elementary combinational and sequential systems.

### 2.3. Roboguide

Roboguide is an offline FANUC robotics simulation software developed by FANUC. It contains varieties of FANUC robot models and controllers which could easily simulate the tasks in work cells. Roboguide allows the users to fully simulate the tasks in a 3D virtual environment to minimize unexpected programming issues without physical robots. Together with the simulated teach-pendant and diversity option of tools, Roboguide could satisfy the wide range of robot applications in the industries [13].

As the pandemic limited us for lecturing the student to manage the knowledge of robots in the lab, Roboguide became a highly practical tool for teaching. The students could make the simulation of the robots and manage the knowledge after remotely teaching and tutorials. From the teaching perspective, setting tool frames and user frames of robots are the fundamental skills that students should manage. The part of the teaching activities was done by watching a series of videos we prepared in our lab and the remote lecture basis on the physical FANUC robot (Figure 6) and the other was performed by Roboguide. In the video, we demonstrate to the students how to use the teach-pedant of FANUC robot and how exactly setting the tool frames and user frames.
As simulation software, Roboguide’s interface and some functions are different from the physical robots. Therefore, the training of operating the software is necessary and could make the students understand better the knowledge again. After the remote lectures and watching the videos, the interests of students in the robots are aroused, and instruction and demonstration of using Roboguide to practice were arranged (Figure 7).

Roboguide is commercial professional software, full version must be purchased. Fortunately, the students could install the academic version which is enough for the practice. In the remote lectures and tutorials prepared for basic Roboguide usage, we perform the teaching actions in Table 1.

**Figure 6.** Video made for teaching students how to set the tool frame

**Figure 7.** The instruction we prepared for students to understand the functions of Roboguide

1. Standard bar - it contains all the basic functions of the robot.
2. View bar - camera operation and distance measurement
3. Cell Browser - program structure viewer
Table 1. Basic Roboguide teaching arrangement

| Teaching steps                  | The skills students learnt                                                                 |
|---------------------------------|---------------------------------------------------------------------------------------------|
| 1 Roboguide introduction        | Students learn how to use virtual teach pendant and the difference from the physical robot |
| 2 Roboguide setting tool and user frames | The students choose the proper tools and workspace and correctly set the tool and user frames |
| 3 Roboguide pattern drawing simulation | The students could use make basic programs and perform certain task in Roboguide          |

When the Roboguide remote demonstration and tutorial are completed, the tasks are assigned to the students. The tasks are drawing different patterns and welding a part using Roboguide. The students shall send back the .frw and .AVI exported from Roboguide to the lectures for checking the correctness. Roboguide provides several different exported format such as .AVI or .frw for easier checking if the task was performed smoothly or need some corrections which are friendly for students and lectures (Figure 8).

Figure 8. Students welding task done by Roboguide

In summarize, despite the pandemic limited actual classes and labs, the students could keep on learning in remote way. Roboguide works not as FANUC robot simulator but as a great remote teaching tool for students and lecturers without physical contact.

Conclusion
Remote work requires the preparation of separate tools that were not in such extended usage before the pandemic or were used for other purposes. Distance learning methods took time to develop. Our vision of classes conducted with the use of simulators has been developed with videos from laboratories. Classes in the second wave of the pandemic are prepared much more carefully, their effectiveness will probably also be higher. We assume that the next step will be on-line video from the studio, in which the teacher will present the exercise and the recording of these films will be accessed by students.
The lecturers of the described classes agree in the conclusion that the effectiveness and comfort of expanding knowledge are greater in the classes conducted in person. Moreover, it does not cause a feeling of isolation in students and the teacher. However, we would like to point out that the methods of digital participation in classes allow for effective transfer of knowledge and can be highly useful in educating people who, for various reasons, cannot come to the labs and classrooms. Lessons learned from the difficult year 2020 will allow us to prepare better teaching materials for distance learning, if necessary. These materials can also be used as complementary to the standard live teaching process with the possibility of self-study.

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