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Web-Based Control and Process Automation Education and Industry 4.0*

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The higher education processes of engineering disciplines, especially Industrial Automation, Process Automation, and Mechatronics, face the challenges of the fourth industrial revolution, which is introducing system modelling paradigms, such as the Cyber-Physical Systems, and several new technologies, such as the Internet of Things, Industrial Internet, Cloud-based Manufacturing, Smart Manufacturing, and others. This paper describes how communication and web-based technologies can be used to build an efficient laboratory learning model of the remote and distributed control system and enabled remote access to physical processes. Our experiences are presented with several remote experiments. The user interface of the first experiment is implemented by professional supervision tools and is using web-based SCADA technology. In the second experiment, we discuss the process of developing fault detection and isolation applications for online and remote education by using industrial equipment from the field of Process Technology (batch, continuous) supported by web technologies. Through-out the course, the student can develop and test model-based and data-driven FDI schemes in Matlab/ Simulink remotely by using an industrial communication interface. Next, an improved platform is proposed for web-based remote-control system experiments suitable for control education. Finally, the proposed platform can be assembled quickly as an example of an IIoT system.

Keywords: control engineering education; distributed control systems; remote laboratories; Industry 4.0

1. Introduction

Control Engineering, Industrial Automation, Process Automation, and Mechatronics are disciplines where engineers face challenges of the Fourth Industrial Revolution, which is commonly known as Industry 4.0. This is a concept driven by new system modelling paradigms such as Cyber-Physical Systems, and several new technologies, such as the Internet of Things, Industrial Internet, Cloud-based Manufacturing, Smart Manufacturing, and others [1, 2]. The main objective of this revolution is to develop new business models that tap the potential optimization in production and logistics caused by increased and integrated industrial automation, cloud computing and big data, global databases, networked intelligent system monitoring and control, and autonomous decision-making. A core element of Industry 4.0 is the full digitalization of production, and the exploitation of data, to enable intelligent planning and control of production processes and networks. Such a digitalization of industrial production can create quite new digital market models. For the purposes of such a complex production and market networks, the leading institution and firms BITCOM, VDMA and ZWEI in Germany, developed and published the RAMI 4.0 (Reference Architecture Model Industry 4.0) and the Industry 4.0 Component models [3]. The second model is a very important model for purposes of Industry 4.0. It is intended to help producers and system integrators to create HW and SW components for Industry 4.0. It enables better description of cyber—physical features and enables description of communication among virtual and cyber—physical objects and processes. The HW and SW components of future production will be able to fulfil requested tasks by means of implemented features specified in the Industry 4.0 components model.

Industry needs new engineers who can hit the ground running with a balance between theory and practice, an attitude of professionalism, experience in multidisciplinary teamwork, and outstanding communication skills. Universities need to shape their engineering curricula to prepare students better for professional practice. Trends in relation to engineering education practice will need to be adjusted in accordance with the requirements of Industry 4.0. The need for new innovative engineering educational processes is obvious. Industry 4.0 requires Industrial Engineering Education 4.0.

In the study [4], the authors propose the use of learning factories that can make a substantial contribution toward the understanding of Industry 4.0. Workplace-related scenarios can be mapped through practical learning, and a variety of learning modules can be used for the smart factory. The new job profiles of employees in Industry 4.0 are described and the various learning modules are discussed, together with their individual learning targets and mapped scenarios.

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Future engineers will be facing technology complexity challenges. For example, Industry 4.0 devices can contain complex systems of IoT devices, cloud-computing based analytics, management complexity associated with networked systems, software, configuration, compliance, and security. For engineers, a deep understanding of interrelations between the electrical, mechanical and computer components of digitalized and intelligently managed production processes will be a vital ability. In [5] the authors present their results of teaching methods and technologies to train the next generation of engineers that will be ready to work in the Industry 4.0 environment. They have achieved new laboratory sessions and laboratories based projects by providing remote laboratories using Industry 4.0 technologies, especially industrial communication technologies, which enabled them to build industrial networks laboratories that are accessible onsite, and online remotely through the Internet. In conclusion, they state that the general analysis of students' performance and feedback is positive.

As stated in the study [6], the required competences for Industry 4.0 are classified as personal competences, social competences, action competences and domain competences. Personal competency can be understood as the ability of a person to learn and to be flexible with regard to work time, work content and work place, and is able to respond quickly to market need and environmental conditions. Social competency refers to the ability to communicate, cooperate and to establish social connections and structures with other individuals and groups. Increasing scope and complexity require a mindset that is oriented towards building and maintaining networks of experts to be able to cooperate, and to communicate complex problems in different languages. Action-related competency of a person is the ability to take individual or socially constructed ideas to action. It is the ability of an engineer to integrate concepts into his own agenda, to transfer plans successfully into reality, not only on the individual, but also on an organisational level. Domain knowledge includes methodologies, languages, tools that are important to deal with the requirements of Industry 4.0 projects' implementation. For engineers, a deep understanding of interrelations between the electrical, mechanical and computer components will be a vital ability. In [6], the authors proposed a model of an Industry 4.0 learning factory in combination with scenario-based learning. They suggest a scenario-based Industry 4.0 Learning Factory concept that they are planning to implement in Austria's first Industry 4.0 Pilot Factory. The model will serve as a basic infrastructure for the implementation of new innovative teaching methods.

We include problem based learning in most of our learning, teaching and support strategies. Experience based learning is becoming an important teaching step within the engineering and technology curriculum, at all levels of education. Especially, control engineers need to have a deep understanding of the theory behind the concepts in the automatic control field, and a wide experience implementing these theoretical solutions in real problems and plants. Traditional hands-on labs offer students opportunities of experimentation with real laboratory process automation systems; therefore, they are very important for engineering practice and technology education. Unfortunately, universities are under constant pressure to reduce the expenses associated with laboratory based education of engineering students. Lack of financial support, as well as demands for the implementation of a study process that is independent by space and time, are the main reasons for an intense implementation of e-learning in higher education. Remote and virtual labs provide students with certain engineering experience and allow them to explore systems and their real behaviours similarly to traditional laboratories, but with less temporal and space restrictions. Recent research works [7–14] have shown that many institutions have created their own virtual and remote laboratories to support life-long learning and autonomous students' learning activities in various disciplines, including Electronics and Microelectronics, Power Electronics and Electrical Drives, Chemistry, Physics, and Control and Automation. Earlier systems relied on custom software development, e.g., cgi/Perl, Java/C++, etc., but the more recent implementations of the web experiments [15, 16] are based on existing software platforms such as LabVIEW or Matlab.

However, we didn't get results about how we can use methods and applications from the Industry 4.0 world for education in engineering using Remote Labs. Some of the approaches are focused directly on industrial control systems [17–20], but not in the sense of application Industry 4.0 building elements, more in terms of the exploitation of distributed control systems technologies (programming logic controllers, Supervisory Control and Data Acquisition—SCADA systems, and industrial communications). In study [21], the authors illustrate the advances in learning process control, with the aid of a laboratory scale—membrane separation unit, which is almost an exact model of a real industrial process. This paper discusses the importance of informatics and automation in the field of Process Control and includes design of the human machine interface and process visualization, local and remote control of process using modern industrial communication devices. The basic control loops can be examined and tuned. On the higher level, advanced control strategies can be proposed to optimise the plant operation.

We present in this paper how technologies of the remote and distributed control and Web-based SCADA can be exploited for distance learning and control education. In the following sections, we outline our major experiences in relevance to the remote and web-based process automation education. We started with a description of our laboratory model of the remote and distributed control system, which we have built over the years. Next, we focus on the laboratory experiments and exercises suitable for remote education carried out by students in undergraduate and postgraduate programmes. Laboratory experiments, which are today used mostly in control engineering web-based courses, are control design oriented. However, they can include other tasks, such as process modelling, process identification or analysis of process control performance. Experiments for control design are realised by hydraulic and mechanical systems, mechatronics systems, robotics systems, depending on the course specifics, level and education goals. The communication and web technologies we used are explained briefly. Web-based or remote experiments in control design courses became well accepted by students. Therefore, we introduced a remote Fault Detection and Isolation (FDI) experiment for students, which is described in the fourth Section. In Section 5, we present an improved web and remote laboratory platform concept. An example of an IIoT, realised in the framework LMRDCS, is described in Section 6. Finally, Section 7 provides some conclusions and discusses our future work in this area.

2. The laboratory model of a remote and distributed control system

Industry 4.0 is based on reliable communication technologies introducing new types of data exchange (Master/Client, Publish/Subscribe) on encryption based channels. With years of teaching experience in the field of Process Control and SCADA systems, we started developing web, remote and distributed control schemes for the industrial environment a few years ago in the scope of a national R&D project. One of the benefits was to be able to offer future students experimenting on real process industry equipment to understand better the parts of the process, communication systems, control optimization of real processes, advanced control schemes, big data handling, etc. Some of these present today core parts of the Industry 4.0 technology. With years of improving and upgrading by following the latest technology and concepts in industry, we managed to introduce to students some basic inside view of the emerging Industry 4.0. Our intention is to build study models for Industry 4.0 concepts, such as process optimization and communication on industrial processes.

As mentioned, we began in the scope of an R&D project, where we built an efficient Laboratory Model of the Remote and Distributed Control System (LMRDCS). The main objective of the laboratory model is to perform research and development activities in the field of Communication Technologies, which we meet frequently in the implementation of remote and distributed control systems. However, this model is also used for teaching our students how to design and implement a remote and/or distributed control system based on modern communication and web technologies. We use LMRDCS for performing practical experiments as a part of courses such as Control System Components, Industrial Automation Process Modelling and Identification, and Process Control systems. The model can also be used in distance learning, as web-based teaching and learning with performing remote experiments. The Lecturer can access the experiment from a distant Lecture Room, as well as use the experiment in practical exercises, where, for instance, students can handle the Process Control system themselves to see the process responses at certain disturbances, set point changes, and controller parameter tuning.

The current implementation of the LMRDCS is presented in Fig. 1. Several laboratory processes, such as the distillation process, electric furnace, hydraulic system, air-conditioning system, heat exchanger and building automation model, which are automated locally, are connected and supervised with a distributed control system. Different communication technologies and Standard Protocols are employed for realization of this industrial communication network. The industrial Standard Protocols PROFIBUS, CAN, LON and TCP/IP are used with wire (Ethernet) and wireless (GSM, GPRS) communication technologies. The model is suitable for study, implementation and testing of industrial communication networks such as:

- Wide Area Network (WAN)—an industrial network that covers a broad area and uses public communications links;
- Industrial WLAN and VPNs—wireless industrial networks based on GSM/GPRS technologies and remote-control applications with point-to-point communication technologies;
- Remote Terminal Units (RTU), Industrial Gateways and Data Concentrators, Industrial Internet of Things (IIoT), and other incoming communications technologies, which are specific to the implementation of Internet 4.0.

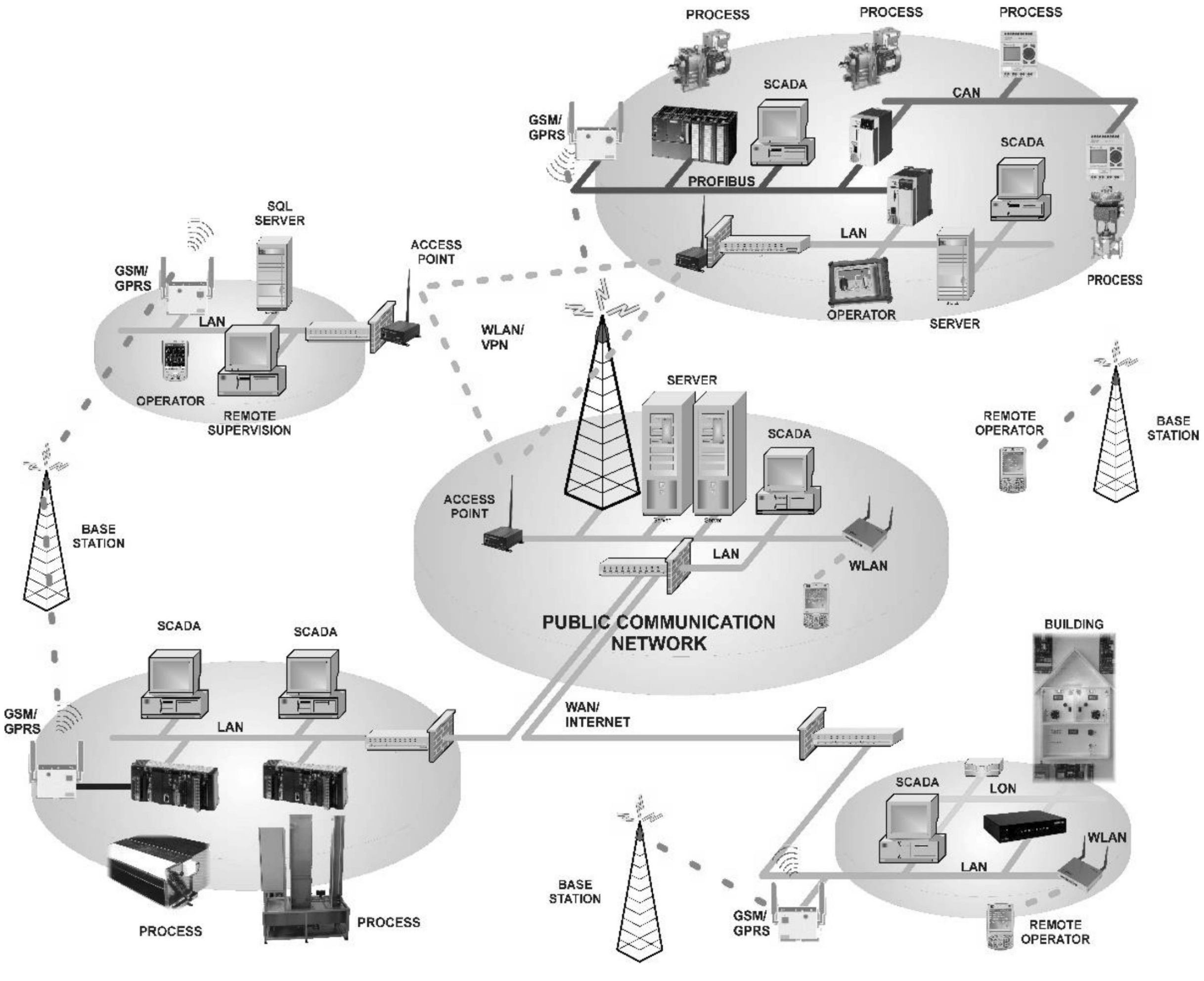


Fig. 1. The Laboratory Model of remote and Distributed Control System (LMRDCS) realised in the Laboratory for Process Automation, FERI, University of Maribor. On the upper right part of the model, the distributed control system of a hydraulic process with Profibus, and CAN industrial communication protocol is depicted symbolically. This process is used in the remote learning experiment described in Section 3. On the lower left part of the model, the laboratory LAN is shown with several laboratory processes. The three-tank process is used for the FDI experiment described in Section 4.

Different supervision systems are realised with professional commercial software (SCADAs and database servers) and with open-source supervision systems. In this study, we have focused mostly on the two parts of the model presented in Fig. 1.

First, on the upper right part of the model, the distributed control system of a hydraulic process is depicted symbolically. The process consists of a main water reservoir, pipes, two tanks, level, pressure, and flow sensors, frequency controlled hydraulic pumps, and control valves. All sensors and actuators' signals are connected to three controllers (PLCs), where local control algorithms are implemented. PLCs communicate with each other through several communication technologies (Profibus, CAN, and Ethernet). Several control concepts can be realised in the process: Two separate level control loops, coupled and decoupled level control of two tank system, flow control, cascade control, etc.

Secondly, on the lower left part of the model, the control system is presented on a three-tank laboratory model. Other processes (distillation process, electric furnace, and heat exchanger), that are also connected to this communication network, are not graphically represented in Fig. 1. We use this model for the realization of the Fault Detection and Isolation (FDI) remote experiment described in Section 4.

All laboratory processes in the LMRDCS enabled online and remote education by using industrial equipment which is supported by web technologies. In the next Chapters two different approaches are given of how we use two parts of the LMRDCS for distance learning.

3. Laboratory process control experiments suitable for remote engineering education

In remote laboratories, real physical processes can be accessed by remote users through the Internet.

There are different didactical applications of online remote experiments possible:

- Teachers can use it during lectures for demonstrations;
- Students can use it during scheduled lab sessions as an experiment sharing tool;
- Students can use it outside class as a self-training tool.

A few years back, for remote experimentation, the process could be controlled via the Internet using a Web-based SCADA technology. Data trend diagrams could be displayed for the observation of different process signals from sensors e.g., level sensors, flow sensors, and pressure sensors. A brief description of existing technology and concept is given next. The user is connected to the process control system (PLC) via OPC technology and CitectSCADA server installed on the main computer. The abbreviation stands for Object linking and embedding for Process Control, originating from Microsoft 90's technology, however achieving Universal Architecture and platform independence is nowadays abbreviated as Open Productivity and Communication. OPC is an established communication protocol/interface in Process Automation for data exchange and can be found on the internet in the form of licensed or free software, or under GPL licence. Fig. 2 shows the communication structure in detail.

The MySQL Connector/ODBC is the MySQL ODBC driver that provide access to a MySQL database using the industry standard Open Database Connectivity (ODBC) API. All data are saved in MySQL database installed on the main computer. The Internet web server (IIS) is also installed on the main computer, and it is used for hosting Graphical User Interface (GUI) as a web application. On the client-side, only the web browser is needed to run the web-based GUI. This architecture ensures scalable and reliable access to our laboratory resources. As shown in Fig. 2, the bridge between client and server-side PCs consists of all professional programme modules and technologies, which are often used in industrial automation projects.

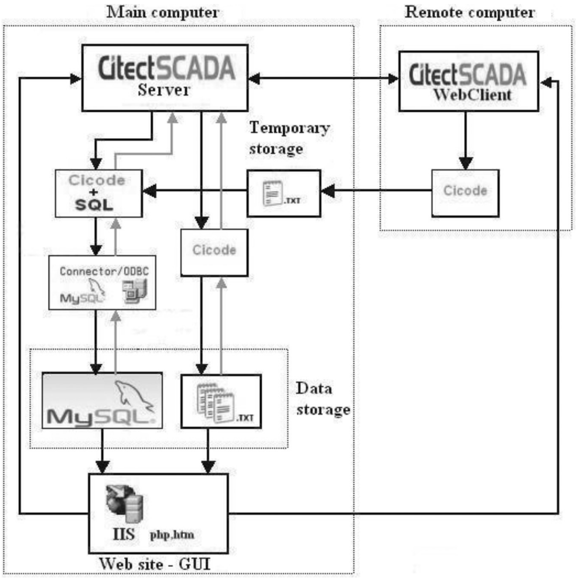


Fig. 2. Block presentation of the information flow between client and server-side PCs with all used technologies.

During an experiment session, users can normally change some parameters, observe the results and download data. A live webcam window is provided in order to make the remote experiment sessions more stimulating. Students can watch the real process responses in the monitor window, to be able to understand the process operation clearly as they would in the laboratory. For video transmission, the web camera software is used, which can display on-line video, and it is not necessary for the user to install special software on the client-side to perform this task. The user interface of such a remote laboratory experiment is presented in Fig. 3. Additionally, the streaming webcam picture is displayed.

This experiment provides different PID controlling techniques to control the water level or flow of the hydraulic system. The aim is to control the tank at a certain level of water height remotely. To achieve this, the students select the control system from different controller structures (PID controller, cascade controller, pump as actuator, control valve as actuator). While the remote experiment is running, the user can change the value of reference input and PID controller parameters, and can observe the reference, process and controller output signals. The live webcam window shows what is going on in the remote laboratory. First the system track needs to be recorded, with the aim to find out what kind of system it is and how it behaves. The next step would be to design an appropriate controller with optimal controller parameters. The Lecturer illustrates the physical model of the process, emphasising its nonlinear dynamics, and then suggesting to the students to use the Ziegler-Nichols controller tuning method. At the end of the experiment it is possible to download data for off-line data processing.

In the course Process Modelling and Identification, the students use remote experiments to understand process modelling procedures (mathematical modelling, simulation, model verification and data validation), parameter identification and control design. With remote access to the process, they can acquire the open loop transfer functions by

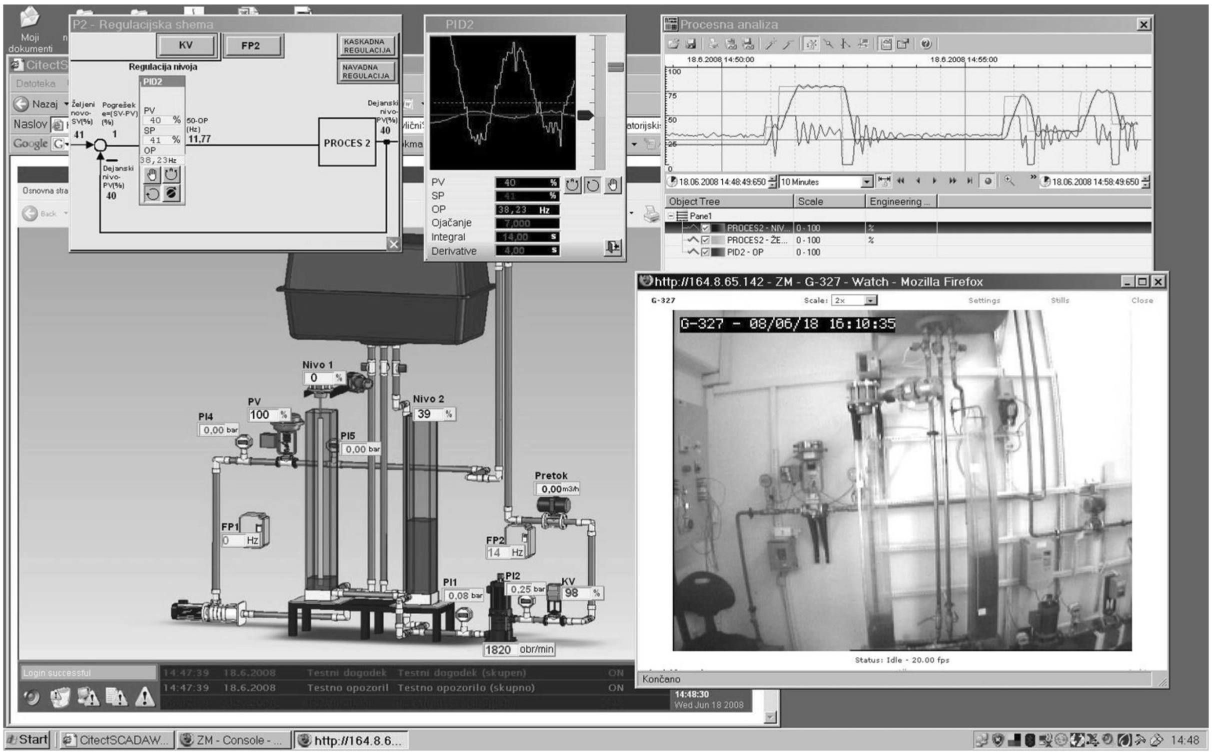


Fig. 3. The user interface of the remote process control experiment.

means of the input-output data. The goals of this experiment are:

- To determine the process (two tanks connected with pipes), sensor (level sensor), and actuator (frequency controlled hydraulic pump) parameters and dynamic characteristics through a combination of analysis and simulation,
- To design an appropriate controller with optimal controller parameters, and
- To compare the response of the simulated control system with the response of a real control system realised with PLC on the laboratory plant.

Response of a simulated closed loop level control can be compared easily with the response of level control acquired on a real process.

This remote experiment has been tested by undergraduate and graduate students at the Faculty of Chemical Engineering and Technology, University of Zagreb, Croatia. It has been used in a Process Dynamics and Control course to demonstrate how to tune a PID controller, quantify a response to disturbances, and to provide experience in data collection, analysis and presentation, and technical report writing. The response of students to the online experiment has been assessed, and it has been favourable in general. We can acknowledge this experiment as a just simple remote based optimization of a real-process towards Industry 4.0 optimization principles.

4. Remote FDI experiment example

The above presented remote experiment from the Control Design course was very well accepted by students, therefore, a more challenging remote experiment was developed for studying fault detection and isolation examples: The laboratory three-tank study model, realised by common industrial equipment (programmable logic controller (PLC), OPC interface) and Matlab/Simulink FDI design evaluation and tests. Low level safety and controller settings were predefined, therefore, the FDI scheme was independent of control parameters' changes. The main task is finding reliable parameters and a scheme for on-line detection of faults upon measured and reconstructed signals under process close-loop operation. The goal was to enable the FDI scheme in Matlab/Simulink to connect with industrial equipment by using industrial communication technologies and remote or web operation.

Prerequisites to develop an FDI scheme are:

- Sufficient knowledge about the system and its operation;
- Implementation of a control algorithm in the PLC;
- Automatic start-up routine and selection of running regime;
- Upgrade of the system to be able to introduce faults (additional hardware, PLC code changes,

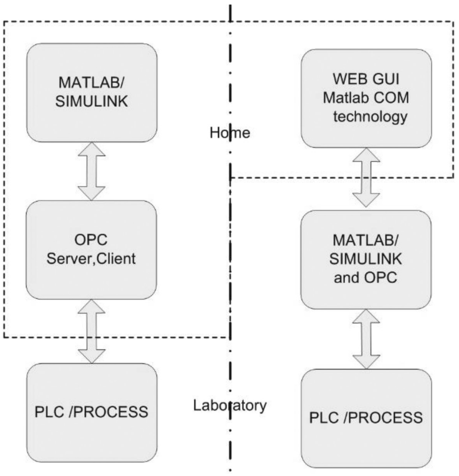


Fig. 4. Comparison of remote experiment communication.

execution on demand or automatic by sub-routines etc);
- Data acquisition support for implementation, model development and validation;
- Development environment with Graphic User Interface, visual support, webcam feedback if possible;
- Analysis of results and report.

Today, many commercial platforms enable realization of remote experiments (LabVIEW, etc), however, rapid development of informatics and telecommunication technologies often faces compatibility issues. Based on different operating platforms, using different database structures and commercial tools, it is difficult to found an optimal platform. Licencing can be an additional reason for introducing open-source platforms to enable web remote laboratories. Control courses are often Matlab/Simulink supported, which was a sufficient reason for setting up an FDI environment based on Matlab/Simulink.

The first task is preparation and modification of the three-tank system for on-line operation with Ethernet and OPC support. The model is controlled locally by a PLC running an appropriate code, so the process is maintained under a controlled steady state regime. By using OPC interface (server and client) a communication between lower level equipment and higher level software is possible, in our case PLC and Matlab/Simulink. Classic OPC interface was having issues with connectivity between different local networks (DCOM, user security policies, firewall), therefore OPC UA can be used instead.

We decided first to set up a platform where the process will be running automatically in normal mode, and remote connection from distant Simulink will be possible by using Ethernet and OPC. In this case, a student can develop an FDI scheme in Simulink and operate the process in real-time to test and conduct the experiment. The experiment is started by the user (Simulink simulation start) and process responses from PLC are saved in Matlab. Safety regulations for normal process operation are implemented locally. Fig. 4 shows newer (on the left side) Vs older communication scenarios.

In the left part of the block diagram in Fig. 4 the Simulink scheme is predefined for FDI purposes so students can focus mainly on FDI tasks. Further brief information of FDI concepts and development can be found in many research and review papers presented by [22–25].

The PLC code had to be altered to enable interaction between Matlab/Simulink FDI schemes and process control. The FDI scheme was developed for additive faults on system outputs (sensors) and inputs (actuators), and system faults, such as tank leakage, body structure damage, etc. The magnitude of faults (big or small) and type (step or drift) can be defined. Planned faults could be introduced automatically or manually to the system.

A set of blocks and functions were developed for Matlab/Simulink to simplify the development procedure of FDI schemes, along with OPC communication and soft real-time block. During the execution of experiments the process variables can be monitored in Simulink, or recorded and plotted after the "simulation" by executing adequate .m function. The results are presented in accordance with the FDI scheme (model-based, data-driven) and can serve for additional optimization or process fault monitoring. Fig. 5 shows detection of sensor faults (level measurement of fluid in the tank) upon model-based FDI scheme and adaptive threshold function. Faults were introduced in the first and second tank, respectively.

A Fault Detection and Isolation remote experiment is still in the development phase, not because of the theory and technical reasons, but mostly due to the concept adjustments to become more educationally functional. The concept of hardware experiment availability only reveals issues with client software installation and development of FDI schemes. Also, the GUI and proper reporting scheme and analysis still need to be realised, whereas webcam support is not critical for setting up these days.

5. Improved platform of web/remote processes

The existing web and remote laboratory platform received a positive feedback from students and Professors of the undergraduate and postgraduate programmes in the fields of Electrical Engineering, Mechatronics Chemical Engineering at local and

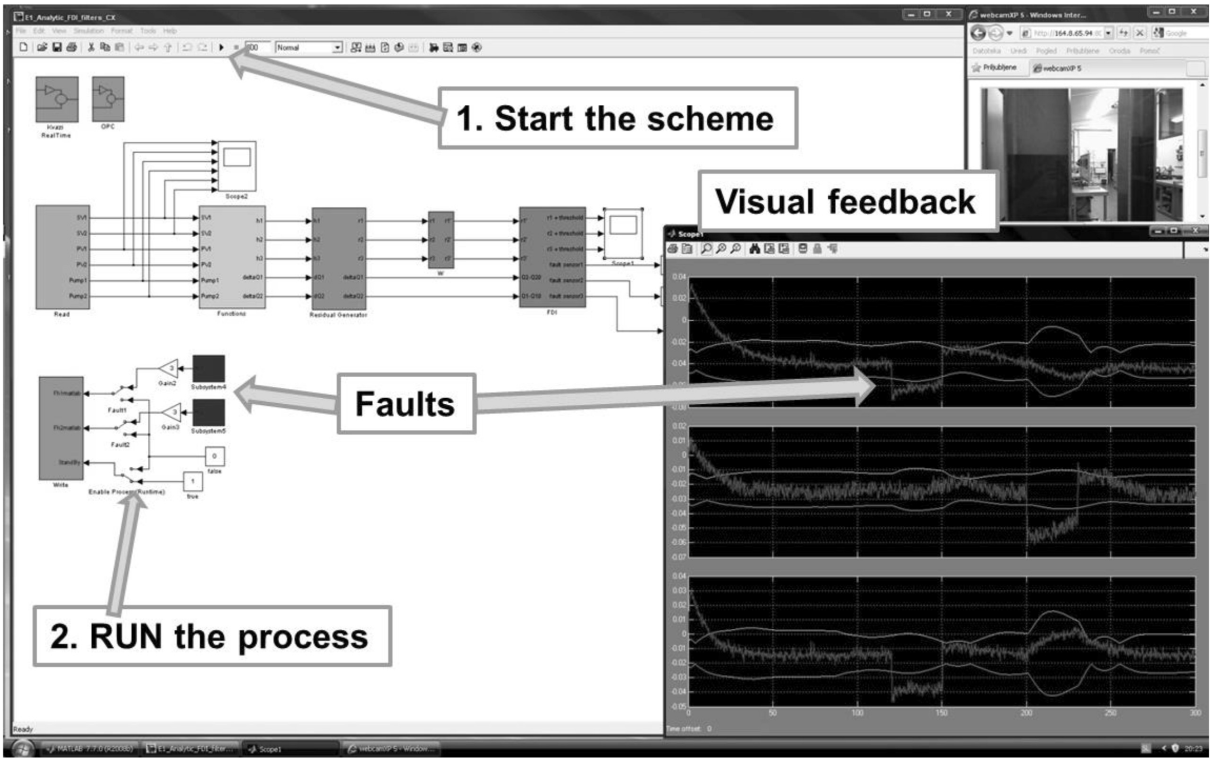


Fig. 5. Matlab/Simulink based FDI remote experiment.

foreign institutions. However, with development of newer communication technologies, an improved platform was designed towards the Industry 4.0 concept. The use of OPC was still somehow mandatory, as it follows the standardised process automation basics of our control and automation courses. The goal of the proposed platform depicted in Fig. 6 is to use most of the open source technology available: Python based OPC client, commercial OPC servers, and an open source database. We relied on existing industrial hardware and software, and introduced newer web technologies for GUI, data handling and analysis purposes.

Most modern PLCs or embedded devices have Ethernet communication where IP based architecture and Ethernet backbone became the base for modern industrial data exchange. Web and database (SQL) servers are considered as the central point of data fusion, whereupon user interaction, an operator screen and code for communication protocol is generated. Graphical User Interface (GUI) is HTML5 and JAVA based, while code for configuration of OPC Client communication is generated on demand. OPC server configuration is fixed, with predefined possible tags of each laboratory model (control, monitoring). That way, the user can define interactively which tags will show in GUI for monitoring of the laboratory process from the database, while data of the monitored process is collected constantly during the operation and stored into the database. Access to a web/remote portal can be by the university's teaching platform (Moodle), or by social profiles from social integrated networks (Facebook groups).

A web-based GUI example (In Slovene language) of a laboratory study model for the Control Engineering course is shown in Fig. 7. The PLC and GUI scheme is preprogrammed for the Control Engineering course that enables manual and automatic

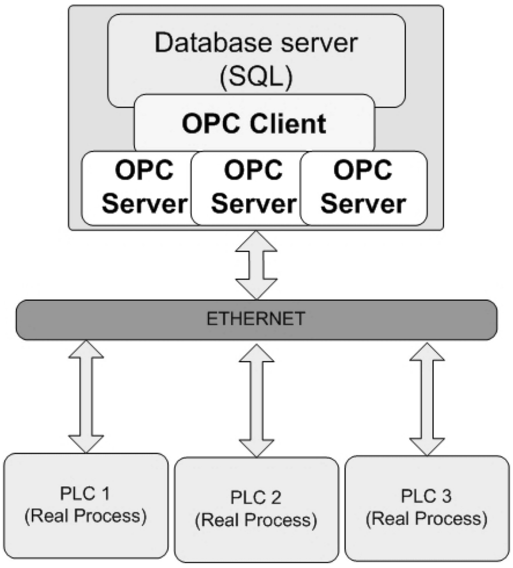
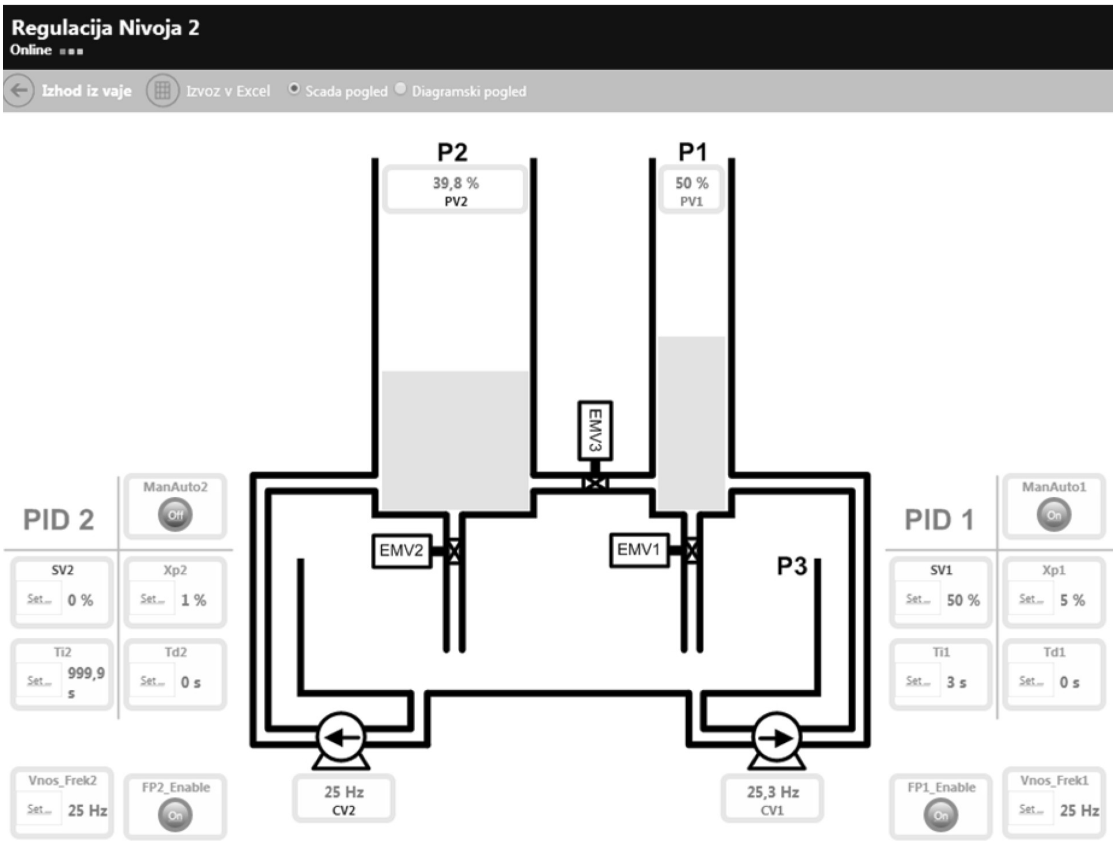


Fig. 6. Improved web and remote laboratory platform concept.

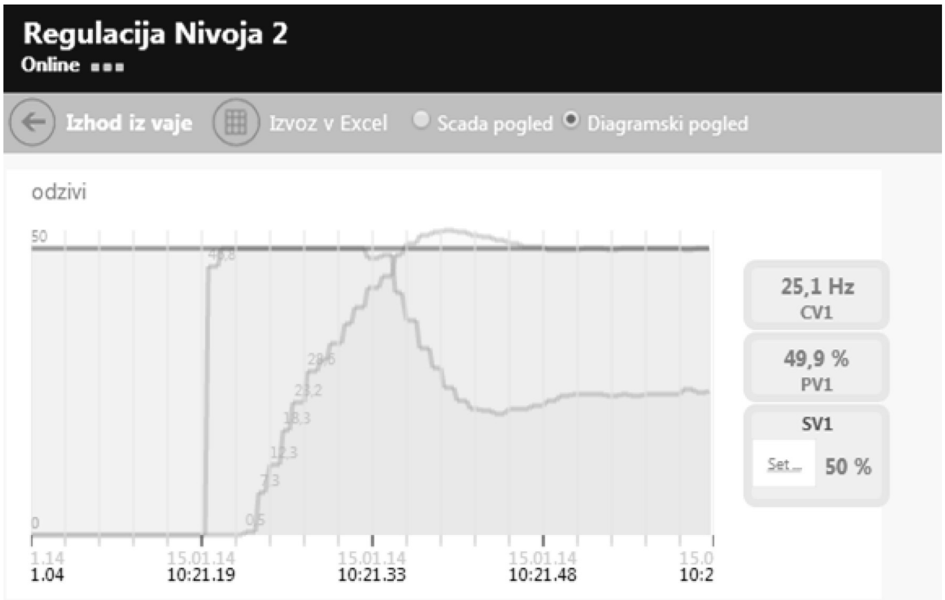


Regulacija Nivoja 2
Online

PV2: 39,8 %
PV1: 50 %
SV2: 0 %
Xp2: 1 %
Ti2: 999,9 s
Td2: 0 s
Vnos_Frek2: 25 Hz
FP2_Enable: On
ManAuto2: Off
CV2: 25 Hz
CV1: 25,3 Hz
SV1: 50 %
Xp1: 5 %
Ti1: 3 s
Td1: 0 s
ManAuto1: On
FP1_Enable: On
Vnos_Frek1: 25 Hz

Fig. 7. Graphic user interface for online operation of the laboratory model based on SVG objects.

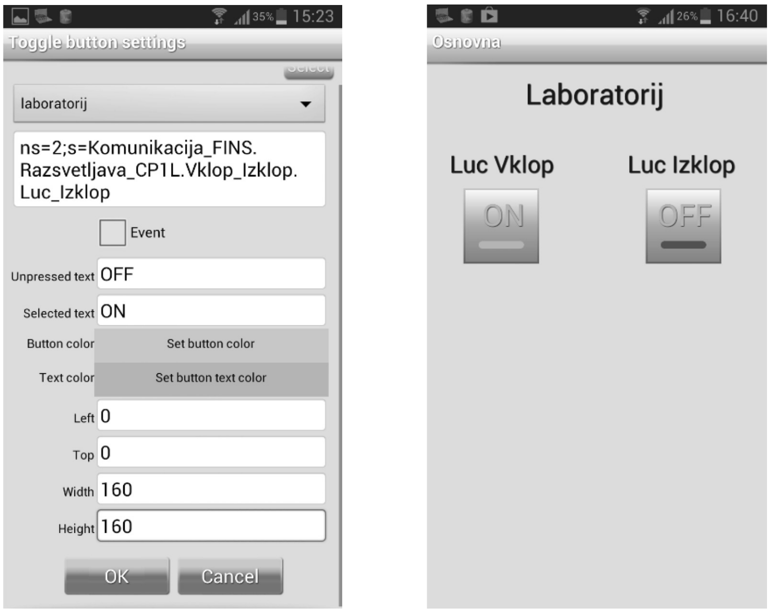
operation of level control in the three-tank system, recording trends and PID tuning. Access and the booking system restrict the use of the study model (device) to one user. The operation is in real-time; however, delays can occur between web service and remote user. Fig. 8 shows the system's closed-loop response (set, process and control value; level and frequency of the pump) that can be recorded into trend graphs and exported into a CSV file for PID tuning tasks.



Regulacija Nivoja 2
Online

CV1: 25,1 Hz
PV1: 49,9 %
SV1: 50 %

Fig. 8. Online trend function with Excel support.



laboratorij

ns=2;s=Komunikacija_FINS.Razsvetljava_CP1L.Vklop_Izklop.Luc_Izklop

☐ Event

Unpressed text: OFF

Selected text: ON

Button color

Text color

Left: 0

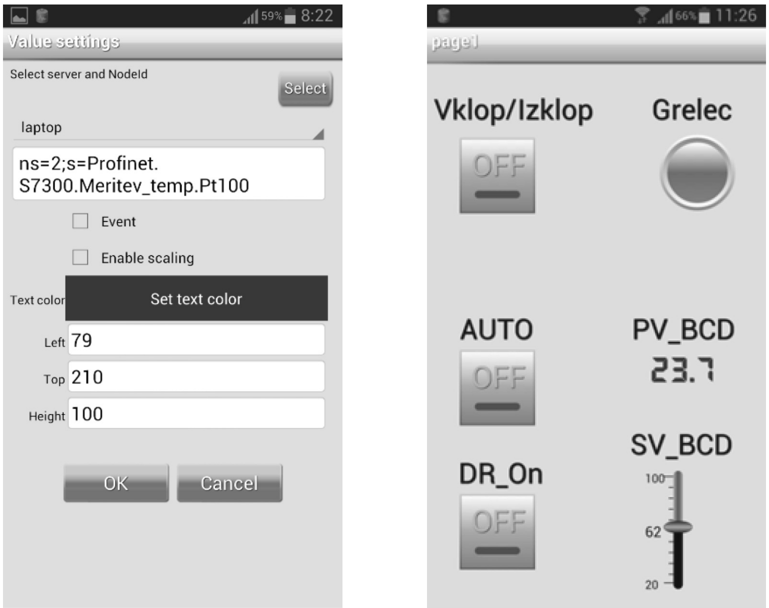
Top: 0

Width: 160

Height: 160

(a) (b)

Fig. 9. Mobile application for laboratory lights. Interface for configuration of OPC UA tag (a) and GUI for control the lights (b).



Select server and NodeId

laptop

ns=2;s=Profinet.S7300.Meritev_temp.Pt100

☐ Event

☐ Enable scaling

Text color

Left: 79

Top: 210

Height: 100

(a) (b)

Fig. 10. Mobile application for HVAC. Interface for configuration of OPC UA tag (a) and GUI for control the HVAC (b).

Beside classic SCADA systems, remote or web distributed SCADA systems, future automation engineers also have to be familiar with development, design, use or deployment of GUIs on tablets or mobile devices. Modern web technologies enable responsive and scalable templates to avoid some design and deployment issues. However, the industrial part lacks basic communication drivers, poor support etc. OPC UA has been recognised as the most important part for universal communication, therefore, many vendors offer OPC UA SDKs and toolkits with ANSI C, .NET, C++ and JAVA support. Figs. 9 and 10 show mobile phone captured screens of an exercise for students, where they have to integrate existing PLC and programme for operation of laboratory systems (HVAC, lights), configure OPC UA server and client, and design simple mobile GUI application over WiFi communication. The exercise was accepted very well by students.

Also, OPC interface maintained its position as one of the key technologies for industrial IoT scheme support on the lower level. Therefore, it is also being integrated massively by many software development companies. With improved OPC UA (Unified Architecture) architecture that introduced encryption and security of data over communication channels, it also became an important part of Industry 4.0. Safe data transfer between remote facilities, cloud storage or management level also introduced a newer communication approach, so Publish/Subscribe principle is also used instead of Master/Server principle use.

6. Example of the industrial internet of things

Industrial Internet of Things (IIoT) systems can be used successfully to create effective smart factories in which higher levels of efficiency can be reached. IIoT smart objects can be used pervasively to collect data on the field with the aim of improving productivity through advanced automatic processes, safety through a deeper knowledge of workers’ positions, and by reducing equipment faults through fast event detection capabilities. Within the industrial domain, most IoT applications address logistic and product lifetime management, in which assets diagnostic is a key application. As is shown in [26], these data analytics and computation applications typically feed data to servers for subsequent offline analysis, and do not provide direct feedback in real-time back into the actuators of devices in a closed-loop control. In the framework LMRDCS, we can assemble an example of an IIoT system quickly. The architecture of such system is presented on Fig. 11, which enables various experimentation with older/newer communication technologies, to be able to derive specific solutions under industrial demands for emerging Industry 4.0 integration, such as universal connectivity between devices (IIoT). By realisation, students are faced with the specific automation domain constraints explained in [27] and which imply specific challenges they need to cope with when deploying industrial IoT solutions.

7. Challenges in education for Industry 4.0

The innovation and development of Industry 4.0 applications will require computer scientists and network professionals to work with experts in various disciplines. Innovative use of the available big data, and turning analytical knowledge to competitive advantages, are some of the key competencies needed to orchestrate Industry 4.0 networks successfully. The challenge lies in preparing students and workforce to cope with breakthroughs of technologies, new decentralised control paradigms, enhanced roles of artificial intelligence, large amounts of uncertainty, and other ongoing changes.

The way courses of study are currently accredited, and competencies are assessed have to be rethought. Furthermore, tomorrow‘s teachers need technological competencies in order to interact

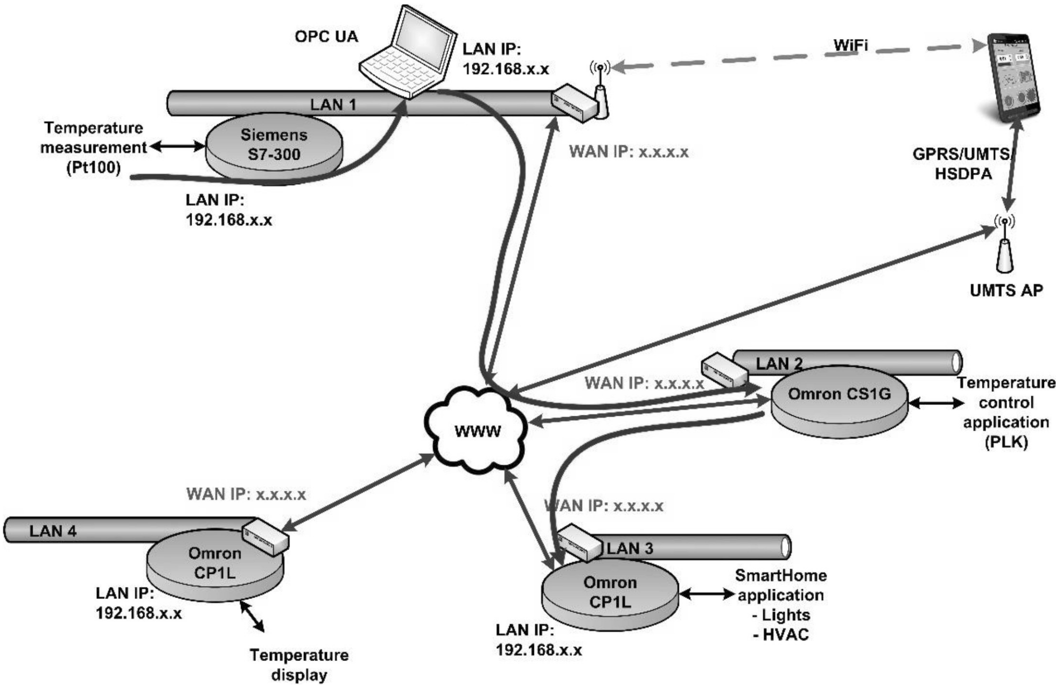


Fig. 11. Example of IIoT system realised in LMRDCS.

with students in virtual and real Industry 4.0 factories. The understanding and empirical insight in these teaching and learning processes is one first step on the way to Education 4.0. Companies will become a more and more important educational partner in academic and professional education systems. The possibility of continuing professional development and learning on the job becomes more valued than ever. Lifelong Learning and the accreditation of qualification and competencies will become of the greatest importance.

In engineering education, collaborative learning in virtual environments is highly important, e.g., by analysing a defective machine, coming up with a logistics concept for a virtual production line, or designing a virtual new product. Working in interdisciplinary teams situated all over the world will be standard practice. In times of Industry 4.0, physical reality will meld with virtual reality. Serious games offer the possibilities to learn in a playful manner, in single-player or in multi-player mode. Innovative virtual knowledge spaces therefore offer all kinds of possibilities for learning and working in times of industry 4.0. Soft skills competencies, which will gain more and more importance, will be the ability to solve problems by virtual teamwork, and to be able to work in hybrid teams consisting of humans and robots, working together indispensably.

Virtual learning platforms like Moodle can be linked systematically to virtual or remote laboratories. Every student gets the opportunity to experiment with physically real equipment without the necessity to be physically present at the location of the production line, industrial process or machine. In order to use the remote lab technologies for engineering education in a proper way, deeper insights in reception, cognition and communication in virtual environments are necessary. Simply providing the technical infrastructure doesn't automatically guarantee successful collaboration.

The Industry 4.0 factory didactic model, as is presented in [6], is probably the best way to teach about Industry 4.0 technology. The philosophy is that the learning factory could be used as an effective preparatory training ground for real-world factories. The complete realisation of the Industry 4.0 learning factory's full potential comes only when the concept is implemented in cooperation with an enthusiastic and willing industry partner.

8. Conclusion

As industrial applications are becoming more and more complex, industries need engineers with new competences and skills that cross a variety of disciplines. Challenges and future perspectives in education for the forthcoming applications and demands of Industry 4.0 are described in this paper. Several web-based remote experiments are presented for real-time control, process modelling, FDI and IIoT. The first method uses commercially accessible technologies of the remote and distributed control systems. The use of professional web-based control technologies has enabled the experiments to be run securely, safely, and from remote locations. The implemented experiments were evaluated positively by students in a study process and have been introduced into lectures Control System Components, Industrial Automation, Process Modelling and Identification, and Process Control Systems. Overall, the student experience has been very positive, and the stated goals of improving learning and enhancing student motivation have been achieved. The educational benefits of the proposed laboratory implementation are that more students can be exposed to comprehensive experimental experiences, asynchronous student learning is supported, and self-learning of the students is promoted. However, further development is necessary to optimise the experiments fully.

The newest technologies, such as the Industrial Internet of Things, Cloud Computing and Industry 4.0, create opportunities to meet the needs of development of design processes, production processes, logistics and supply chains' management, and also the need for new innovative engineering educational processes. Highly educated skilled effort is needed to establish Industry 4.0 concepts. To ensure that the industry of tomorrow has enough employees for the transformation of Industry 4.0 concepts, the educational system must focus more closely on Science, Technology, Engineering, and Mathematics, and establish the importance of Industry 4.0 relevant technologies in unbroken education chains from preschools to universities. Future manufacturing systems will require extremely flexible, high-grade distributed automation systems that are networked through new communication technologies and control concepts.

One of the major activities of our group involves the development of new control and networking concepts based on standard interfaces, which enable web-based control services from the cloud, and satisfy the growing demand for flexibility. Our future work will focus on realisation of the idea that real industrial process control experiments could be used for education purposes, for example, to retrieve data for the modelling and parameter identification, and FDI applications of the real industrial process. Next, we focus our work on the development of a pilot industrial facility based on Industry 4.0. Industrial and academic partners are involved in the development. The facility will be dedicated to the demonstration of Industry 4.0 technology and for educational purposes. Our role in the project is to use the mentioned remote lab technologies, and to upgrade them in the sense of Industry 4.0 Remote Laboratory.

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