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Remote Controlled Laboratory as a Modern Form of Engineering Education

ABSTRACT

Technological development enables many benefits and improvements with regard to the educational process. This paper discusses the development of remote laboratory architecture for web-based programming and control of a passenger lift located at the Faculty of Mechanical Engineering, University of Maribor (UM FME). A dedicated web page provides users with the opportunity to learn how to programme and control a programmable logic controller (PLC) from remote sites. Remote-controlled experiments involving additional visual support have similar learning effects compared to practical work in a laboratory, the difference being that students acquire additional technological knowledge in the latter. This paper presents, among other things, the details regarding the development of the respective laboratory for remote control of lift operation. In conclusion, the article critically examines the advantages and disadvantages of the here presented remote-controlled laboratory.

Key words: remote controlled laboratory, passenger lift, laboratory experimentation, mechanical engineering, undergraduate study

Oddaljeni laboratorij kot moderna oblika izobraževanja strojništva

POVZETEK

Tehnološki razvoj v izobraževalnem procesu omogoča veliko prednosti in izboljšav. Prispevek predstavlja razvoj in delovanje daljinsko vodenega laboratorija za krmiljenje, programiranje in nadzor osebnega dvigala kot učnega laboratorija na Fakulteti za strojništvo Univerze v Mariboru. Spletna stran za oddaljeni dostop do laboratorija študentom omogoča učenje programiranja logičnega krmilnika in krmiljenje dvigala. Daljinsko vodeni eksperimenti z dodano vizualno podporo zagotavljajo primerljive učne dosežke kot praktične vaje v laboratoriju, študenti pa pridobijo še dodatna tehnološka znanja. V prispevku so predstavljene tudi podrobnosti razvoja in vzpostavitve laboratorija za daljinsko upravljanje dvigala. Zaključek ponuja kritično diskusijo o prednostih in slabostih predstavljenega laboratorija.

Ključne besede: oddaljeni laboratorij, osebno dvigalo, laboratorijsko delo, strojništvo, dodiplomski študij

Introduction

"Learning is the process whereby knowledge is created through the transformation of experience" is a well-known Kolb's definition which emphasizes several critical aspects of the learning process as viewed from the experimental perspective (Kolb, 1984). Experiential learning focuses on individual learning, and it traditionally plays a central role within science and technology curriculum at all levels of education. Lecturers and teachers are aware of numerous positive effects of practical work and experimental learning of students in laboratories. Research experience obtained in a laboratory is especially efficient if included in the concept underlined in theoretical lectures (Šorgo and Kocijančič, 2006; Mackechnie and Buchanan, 2012). Students often experience problems in understanding abstract subject matter which is being presented in theoretical lectures, so laboratory work in fact connects abstract notions with the real world (Thomson-Jones, 2010).

Today's society faces an immense proliferation of all aspects of knowledge. In order to keep curricula from becoming dated, current research results and applications to "real life" must be incorporated into today's classrooms.

Universities are under constant pressure to reduce the expenses associated with laboratory-based education of undergraduate engineering students. Many alternatives to traditional laboratory instruction have been tested to improve educational benefits and to reduce academic input (Mackechnie and Buchanan, 2012). Additionally, adult and part-time students are becoming important consumers of higher education, requiring methods of educational delivery addressing space and time separation and student diversity. Both lack of financial support as well as demands for the implementation of a study process that is separated by space and time are the main reasons for an intense implementation of e-learning in higher education.

The introduction of e-learning in the higher education system is also an opportunity to raise the quality of the study process. It is necessary to consider adequate preparation of human resources for the technological development. Quality improvement requires a change in the attitude, along with the development of a new philosophy and new concepts. These concepts are simple, but the practice of quality improvement is far from easy (Aberšek, 2004).

E-laboratory is becoming an increasingly popular didactic form of studying in different fields. Šorgo and Kocijančič (2006) thus used computerised laboratory practice to demonstrate biological processes in lakes and fishponds. Kocijančič and O` Sullivan (2004) confirmed the efficiency of a virtual laboratory while studying wave phenomena using sound as well as in a study of motion in one dimension.

Engineering education is a specific field just as any other. As said by Golias et al. (2005), engineering education specifically has to address creativity, hands-on learning, and interdisciplinary issues. Creativity and critical thinking can be simulated through teaching techniques, such as problem-based learning and cooperative learning.

The curriculum thus comprises theoretical knowledge that needs to be upgraded and deepened with experimental learning and practical exercises. Korthagen (2006) said that it was crucial to find the right ratio between theoretical knowledge and practice obtained during the study process. Here, we raise the question of whether e-learning is appropriate for engineering education. The fast-moving world of information technology enables different kinds of applications for attaining demanding goals.

Modern Methods in Engineering Education

Information technologies have been changing the practice of engineering, and they offer a new framework for integrating next-generation information technology into the engineering curriculum. Grigg et al. (2005) present a project which shows

how to introduce instruction in systems engineering and how to approach the transformation of courses in physics and electricity, and some effective ways to overcome obstacles in teaching the constantly evolving information technology tools that are available.

Thiriet et al. (2002) describe a European Thematic Network the overall goal of which is to convert the traditional approach to learning—lecture, laboratory, and library—into a European distance-learning concept over the Internet. These authors propose the use of WWW and Web browsers as the platform for virtual and remote laboratories on the grounds that it is easy to use.

The Didactical Aspect of E-learning

Based on a detailed review of the engineering curriculum it has been concluded that from the didactic point of view, the educational process can be divided into three sets: lectures, where the educator imparts theoretical knowledge to students, laboratory work (experimental learning), where students upgrade the theoretical knowledge and combine it with practice, and independent learning. Each set enables different methods of using information technologies which mostly share the following common characteristics, as discussed by Calvo et al. (2009), and Dormido (2004):

- *Flexibility:* Laboratories can remain ''open'' 24 hours a day and every day of the year. Moreover, as students may connect from anywhere via the Internet, laboratories are accessible when physical access is not possible (e.g., working students, or students with disabilities);

- *Maximal use:* In most cases, laboratory equipment is expensive. By providing remote access, laboratories may be available to more students, and it is even possible to share laboratories among different universities and research centers;

- *Real experimentation:* Even though virtual laboratories based on computer simulations and virtual reality techniques provide very valuable experience, nothing can be compared to the interaction with an experimental setup, although it is performed in a remote way. This is especially true when students must be trained to cope with real-life situations;

- *Active learning:* The learning process requires students to be active by doing things that are instructive.

Many universities across the globe provide online video courses. Online courses are appropriate for self-motivated students and self-starters. As the utilisation of online video courses has been increasing, the question which appears to be relevant is whether this method is appropriate to attain optimal goals. There are

numerous tools and systems that enable courses to be delivered online, i.e. via the Internet, transferring theoretical knowledge and acting as a support to lectures. Providing theoretical educational materials is a fairly simple task, as one can use several multimedia tools and editors that are available to create courseware.

Students can gain theoretical knowledge in the classroom but it is only possible to grasp the necessary practical knowledge and experience in a laboratory.

Advocates of practical experiments argue that student engineers have to know how to work with measuring equipment and they should be able to make out wrong and right results, understand the notion of measuring noise, and analyse the sources of measurement uncertainty in the measured values. Student engineers have to be able to identify errors of the measuring system, while practical work also allows them to develop the ability to improvise (Nickerson, 2007).

The biggest challenge both institutions and instructors face is how to place "real" labs on the Internet. Introducing a laboratory learning environment online is a difficult task which is facilitated by the rapid development of communication technology. New possibilities which regard the way laboratory exercises are performed include simulation environment laboratory, automated data acquisition, and remote control of instruments online. According to Balamuralithara and Woods (2009), there are two approaches to conducting online laboratories: (a) Simulation (virtual) and (b) Remote (online) laboratories.

A virtual laboratory is a simulation tool that enables students to conduct experiments on virtual plants. Proponents of simulations argue that the latter save a lot of time and money. Simulations of lengthy processes can facilitate an experiment. Simulations offer an idealised dynamic and visual representation of a physical phenomenon (Nickerson, 2007). Simulations can replace experiments which are excessively expensive, dangerous or undoable within the framework of a specific educational institution.

Working on distant experimental setups, however, is enabled only by a remote or online laboratory. The innovative nature and distinctiveness of such a laboratory lies in its ability to implement remote experiments on real machine tools and not only mock-ups that are used to simulate, more or less accurately, the operation of experimental setups. These experiments require space, though much less space than practical experiments. The results of such experiments are real, which means that the actually recorded signals represent the basis for the analysis. They are relatively cheap to implement, the only major cost occurs in the initial phase of setting up the experiment (Nickerson, 2007).

Didactical experiments play and will continue to play an important role in education (Horaček, 2000). New information technologies allow us to upgrade

remote acquisition of theoretical knowledge with remotely-controlled didactic experiments.

For some students, physical presence is not important, as they see it more as a social way of maintaining contacts. For such students, the effects of a hands-on didactic experiment and a remotely-controlled didactic experiment remain approximately the same (Nickerson, 2007). The implementation of remotely-controlled didactic experiments also offers insight into scientific work to students with special needs. Visually impaired students, motor impaired students, dyslectic students, and hearing or speaking impaired students can use a computer screen for remotely-controlled experiments (Jovan, 1996). An additional advantage of remotely-controlled experiments also lies in their reducing the workload of laboratory staff and consequently the costs of a school (Book, 2002).

Related Work on Remote Labs

Literature provides us with numerous examples of remote laboratories being used in engineering education (Prezelj & Čudina, 2009; Castilla et al., 2009; Reynard et al., 2008; Gillet, 2003).

Aziz et al. (2009) describe online learning environments which have been used at Stevens Institute of Technology (SIT) for a number of years to provide undergraduate engineering students with a comprehensive laboratory experience based on content-rich and flexible remote and virtual laboratory experiments. Web-based educational tools have been developed using various open source programming languages and free software applications.

Colton et al. (2004) have designed a new exercise in process dynamics and control, regarding a heat exchanger with the infrastructure. In this case, the plant was locally controlled and broadcast with LabVIEW software by National Instruments. The new experiment could be accessed from any Internet-connected computer upon registration of Java and LabVIEW plug-ins, which allowed students from the University of Cambridge (UK) to use the infrastructure of MIT (US).

The use of these technologies in complex remote laboratories is not a trivial task, as several requisites must be satisfied simultaneously. Calvo et al. (2009) proposes a methodology that eases the creation of remote laboratories, defining the steps required to build up a remote access system. This methodology proposes a set of key components that can be used to define access to a remote plant from a functional point of view. Some of these components are generic and can be reused in most applications whereas others are application-specific.

Gillet et al. (2005) present a case of a collaborative Web-based experimentation environment introduced at the École polytechnique fédérale de Lausanne (EPFL) to

provide more flexibility to students performing laboratory experiments in automatic control, biomechanics, and fluid mechanics.

Dormido et al. (2008) introduce a Web-based control laboratory for experimentation on a nonlinear multiple-input and multiple-output (MIMO) system: a three-tank plant. Using this application, automation technician students can learn many fundamental aspects of control processes in a practical way.

These authors describe remote laboratories where remote access is used to control and manage real processes on scale models, i.e. mock-ups. It is very important to integrate experimental setups into the engineering education concept because faculties should aim at educating future engineers to work in production and not on scale models.

Nickerson (2007) presents a study which compares the learning outcomes and satisfaction of students who participated in two different approaches to implementing laboratory exercises. Twenty-six students were asked to rate the effectiveness of remotely-operated labs in comparison to traditional ones. The results are presented in Table 1.

Table 1: The number of answers to the question: "Are remotely-operated labs more effective than practical labs?" (Nickerson, 2007)

More effective	About the same	Less effective
3	21	2

The students also rated the importance of five specific aspects of laboratory exercises. The results are provided in Table 2. The results show that the aspect rated as the most important in the implementation of laboratory exercises was the preparation to exercises. What students regarded as the most important part was instructions for practical work. A specific aspect of laboratory exercises is writing laboratory reports, which student respondents saw as an important activity, the reason being that it took up a lot of their time, especially if they did not understand the exercise or were not accurate in their measurements. Team work is often implemented in practical laboratory exercises, which the students considered a positive aspect. The students found physical presence to be the least important activity, though this is in contradiction with their desire for team work. Based on those results, the authors of the study concluded that students regarded remote and hands-on laboratories as essentially equally popular and effective methods (Nickerson, 2007).

Table 2: The importance of specific activities in laboratory work

Activity	Mean	Standard deviation
Preparatory instructions	6.6	1.8
Data acquisition	5.9	1.9
Lab report	6.5	2.0
Team work	6.1	2.2
Physical presence in lab	5.4	2.1

At the end of their studies, the learning outcomes of the students who participated only in traditional laboratories were compared to those of the students who participated in remotely-operated laboratories. The mean grades were very similar and it was not possible to use statistical analysis to prove that the methods differed in terms of their effectiveness (Nickerson, 2007). Based on what has been written on this issue, we can come to conclusion that practical introduction of students to experimental work is not to be avoided. Remote didactic experiments are possible in laboratory exercises where practical implementation of measurements is time consuming. In such a case, a laboratory exercise can be divided into three phases: preparatory instructions, practical introduction of students to the object of measurement and to the measurement system, and the implementation of remotely-controlled experiments.

Case Study: The Laboratory for Remote Control of a Lift

By considering the proposed methodology, we developed a remote laboratory built on experimental setups at the UM FME that is presented in the remainder of the article. A special characteristic of the developed remote laboratory lies in the integration of an external measurement system and a numerically controlled machine tool in the development of an adaptive control system which students can test via remote experimentation.

The remote laboratory enables the implementation of different experiments that are conducted on the basis of the LabVIEW software which is integrated in the Moodle, that is, an open-source virtual learning environment. The article presents the experiment which regards the control of a personal lift.

In accordance with the didactic criteria for quality e-learning material (Dinevski et al., 2006), the documentation on the experiment provides the basic information about the experiment itself: its description, aims, requirements, time required to implement the work, schedule of implementation, etc.

Development of the Laboratory for Remote Control of a Lift

The development of our remote experiment proceeded in several stages, whereby all of them required student participation. The rate of learning tends to increase and laboratory experience is enhanced due to experiments being designed by students and for students; matching students' needs, education, and interests with experiments (Truax, 2007). The students prepared for each phase and planned it as a project task under the tutorship of a professor whose task was to help the students and who was responsible for successful completion of the project of the remote experiment. Working on this project, students acquired theoretical and practical knowledge along with manual skills and learned about teamwork, thus acquiring extensive experience they will need while working for a company. Third-year students of the Mechatronics study programme (first degree) participated in the preparation of the development of the laboratory for remote control of a lift. This was part of the course entitled Logic Control Engineering and Control Engineering. The development of the laboratory involved three phases:

Phase 1: Development of the lift's profile construction with corresponding technical documentation

We designed the lift's engine room above the lift shaft, a system of pulleys and cables, a lift car and a sliding doors mechanism (Fig. 1).
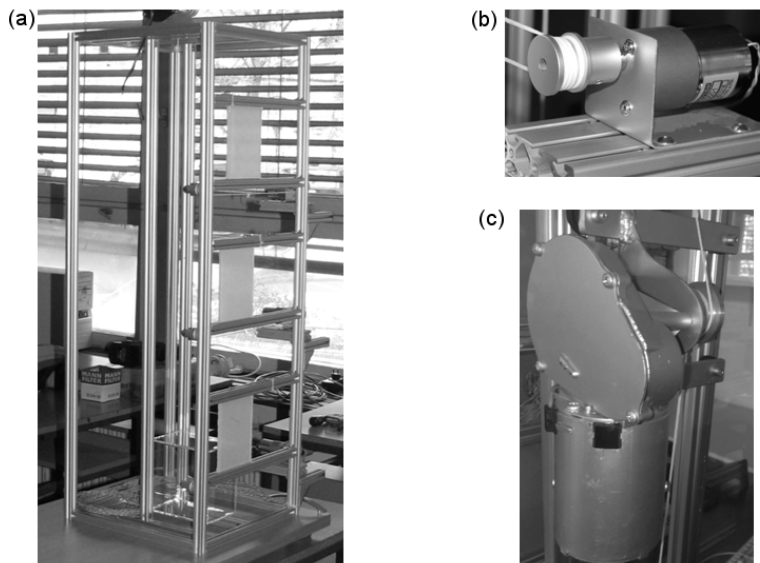

Fig. 1: Mechanic model of the passenger lift: (a) profile construction; (b) sliding doors drive, and (c) main drive of the car with the rope drum and self-locking worm gear

We installed all required drives, sensors and light/sound indicators. Phase 1 took one semester and required the participation of three students.

Phase 2: Development of control system

We designed the rectifier, the control relay panel, the circuit for changing the revolutions of the sliding doors drive, the circuit for changing the speed of the main drive of the lift car, and the operating panel in the car (Fig. 2). Moreover, we chose a PLC controller, wired inputs and outputs, prepared a technological scheme, a control block algorithm, a state diagram, a symbol table of inputs and outputs, PLC software, and performed the simulation of the programme's operation on the simulation panel, integration of PLC to a lift model, final testing of PLC on the lift model, and fine tuning of controller parameters. Phase 2 took another semester and required the participation of three students.
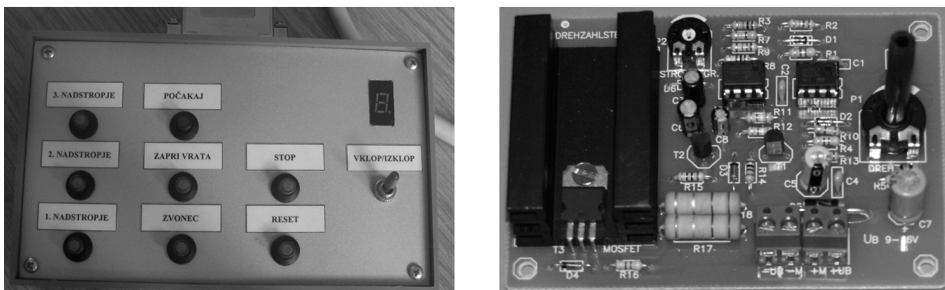

Fig. 2: Operating panel in the lift car

Phase 3: Development of the system for remote control of a lift

We developed a system that enables remote control of a lift.

• Series connection: control unit – laboratory PC,

• human-lift graphic interface with virtual lift and corresponding graphic keys and indicators (LabVIEW),

• PC-controller communication (OPC-server; KEPServerEX),

• website featuring a presentation of the lift, instructions for use, password system to access the lift, and

• Webcam installed.

The aim of the experiment:

Supervision and control of a fully functional model of a passenger lift, knowledge on how to programme a PLC controller, and online testing of its operation.

The description of the experiment:

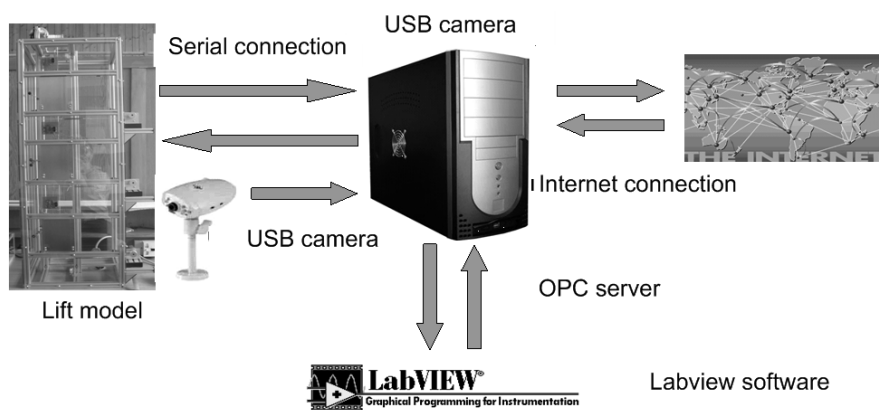The system comprises three parts (Fig. 3):

Fig. 3: System for remote control of the lift

• The first part is a mechanical model of a passenger lift that services three floors. This is a profile construction with drives, the control unit with power supply and sensors. The drives move the lift car and doors, while the control unit represents the logic of the operation. In order to prevent damage to drives, limit switches are installed. Siemens S7-200 controls the lift as programmed.

• The second part of the system is a personal computer (PC) – server and software enabling remote control of the lift. The PC serves as an interface between a student and the lift model. LabVIEW is the human-machine graphic interface for remote control. A virtual lift is programmed in LabVIEW software which together with installed graphic keys controls the lift and graphic doors which open every time the doors on the lift model open. The remote control system further includes a website with the presentation of the lift, instructions for use, and access to lift control (Fig. 4). Live video stream shows the condition of the lift. A security system involving protective passwords, firewalls, and certificates protects the system from unauthorised use and computer viruses.

• A webcam is installed, which monitors if the lift is responding correctly to remote control
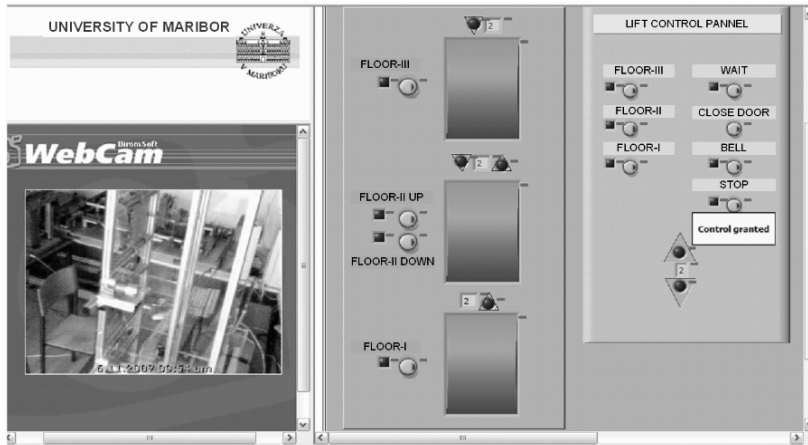
Fig. 4: Website for remote control of the lift

The progress of the experiment:

A student can access the machine's control panel in a booked time slot. In the student's browser, a window with the main panel of the experiment opens (Fig. 4). The main panel represents the user interface through which the student controls the remote machine. The student takes over control of the machine. The user interface comprises three parts. The left part of the screen displays the visualisation of the experiment over the webcam. The central part is the control area with the animation of the lift's operation. The student remotely controls the lift through switches on individual floors and position indicators. In this section, the opening and closing of the doors is animated in real time simultaneously with light and sound indicators. The control part with indicators in the lift car is on the far right side of the panel of the user interface. It includes three buttons for three floors and additional buttons to control the door.

In the second step, the student checks the operation of the user interface by testing all of the lift's functions.

In the third step, the student downloads the original PLC programme from the control unit to his computer and saves it.

As part of the next step, the student develops his own PLC programme, debugs it, removes syntax errors, sends it to the controller, runs it on the controller and tests it on the lift model. He repeats the procedure until the lift is fully functional and there are no errors. In the last step, the student returns the original programme to the PLC, logs off, making the lift available to the next user. He prepares a report on the conducted experiment and submits it to the assistant.

The result of the experiment:

The main anticipated results of the experiment are as follows: to recognise the construction, the components and the principle of operation of a passenger lift, to control the lift with programmable logic controller, to remotely control the lift via a website, to study the animation of the lift's operation in LabVIEW, to learn how to handle Siemens 200-series controller (programming, debugging, sending the programme to PLC, running the programme), to get acquainted with a programmable unit using Step 7, and to activate a webcam.

Conclusions

This paper describes the development and setting up of a remote laboratory for conducting remote experiments. This laboratory has been included in the work of UM FME. As regards education in automation, we have to enable students to acquire not only theoretical knowledge but also practical experience, experimental learning, manual skills, skills in working with plants, and the bases of teamwork. In conventional education, practical training is conducted within the framework of obligatory laboratory work that requires students to be present in a laboratory. Due to a large number of students, the unavailability of laboratories, and the Bologna structure of study, distance learning is gaining in importance. Compared to traditional hands-on experiments, distance learning has the potential as learning that is flexible in time, place and pace, providing access to a large number of experiments and enabling cost savings through experiment sharing. 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. In remote experiments, the presence of an assistant at a machine is not necessary. Hence the assistant is less burdened, fresh, concentrated and finds it easier to supervise experiments.

The demanding shift from the remote control of a mock-up to the control of a real machine tool is complex, as it requires a scientific approach. The development and implementation of a laboratory as presented herein is rather demanding from the educational, technical, security-related, and organisational aspect. A special characteristic of the developed remote laboratory lies in the integration of an external measurement system and a numerically controlled machine tool which students can test via remote experimentation.

The mentioned concept of experimenting can be transferred from laboratories to production with experimental setups without any additional costs, which represents major savings with regard to laboratory equipment.

Managing a remote laboratory should be easy for students to the extent that conducting the experiment does not deal with the technical background, but the implementation. In this approach, students can alter various physical characteristics and have the opportunity to obtain the corresponding changes in solutions to other parameters instantly. The boundary conditions to which students can change parameters are preset in the programme. The machine is protected against damage which is a result of mismanagement, as the slightest error or inconsistency in experimenting can damage a tool or a machine, incurring costs which are immense compared to the costs of damage occurring on a mock-up.

Due to thorough planning of the booking system, remote experiments enhance the utilisation rate of the machine and reduce energy costs. At the same time, the costs of tools and processing material are reduced, as human errors are eliminated.

During remote experiments, no one is allowed to be in the machine's working area. As students are not near the machine, they are 100% safe.

Building remote laboratories is more complicated that setting up local laboratories. The implementation of a laboratory, however, represents only some initial effort, as further maintenance is minimal.

The aim of future research is to expand the system of remote experimenting to CNC lathes and CNC grinding machines.

DALJŠI POVZETEK

Tehnološki razvoj je v zadnjem desetletju s svojim napredkom postavil popolnoma nove smernice izobraževalnega procesa. Ključni del učnega procesa naravoslovno-tehničnih ved so laboratorijske vaje. V članku je predstavljeno, kako lahko izboljšamo proces vaj, ko študentom omogočimo daljinsko izvajanje posameznih vaj na resničnih strojih in napravah. Za izvajanje laboratorijskih vaj na daljavo sta na razpolago dve možnosti: virtualni laboratorij in oddaljeni oz. spletni laboratorij. V članku smo podrobneje predstavili spletni laboratorij (angl. remote laboratory), ki omogoča delo na resničnih strojih in napravah. Razvoj in izdelava takšnega laboratorija sta s pedagoškega, tehničnega, varnostnega in organizacijskega vidika zelo zahtevna. Prispevek predstavlja razvoj in delovanje daljinsko vodenega laboratorija za krmiljenje, programiranje in nadzor osebnega dvigala kot učnega laboratorija na Fakulteti za strojništvo Univerze v Mariboru.

V Laboratoriju za mehatroniko na Fakulteti za strojništvo Univerze v Mariboru smo začeli s projektom integracije spletnega laboratorija v redni pedagoški proces. Spletni laboratorij je namenjen za oddaljeno poučevanje proizvodne tehnike (obdelovalne tehnike), logistike in mehatronike.

Študenti se na spletni strani za oddaljeni dostop do laboratorija učijo programirati logični krmilnik, krmilijo dvigalo in opazujejo dogajanje. Daljinsko vodeni eksperimenti so nadgradnja praktičnih vaj in po svoji verodostojnosti in predstavnosti prekašajo simulacije, saj omogočajo analizo realnih procesov in od študenta zahtevajo razlago rezultatov itd. Daljinsko vodeni eksperimenti z izdatno vizualno podporo dosegajo enak učni učinek kot praktično delo v laboratoriju, študenti pa pridobijo še dodatna tehnološka znanja. Z uvajanjem daljinsko vodenih eksperimentov torej lahko skrajšamo potreben čas, ki ga mora študent preživeti v laboratoriju, zmanjšamo potrebno število laborantov in sprostimo ure za delo z industrijo.

V prispevku so predstavljene tudi podrobnosti razvoja in vzpostavitve laboratorija za daljinsko upravljanje dvigala. Zaključek pa ponuja kritično diskusijo o prednostih in slabostih predstavljenega laboratorija.

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