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# Implementation, Effectiveness and Experience With Remote Laboratory in Engineering Education

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Modern educational methods bring many new challenges from the pedagogical, as well as from the technical aspect. One of the more significant is the integration of information and communication technology into the educational process. These is particularly noticeable in the engineering education where the requests of the industry for a faster and more efficient acquisition of knowledge and practical skills lead to a constant search for new solutions in the learning process which would attract and motivate students, as well as be user friendly. This is especially difficult to be reached with the practical education which is usually composed of laboratory exercises that are bound to a specific time and place. One of the possible solutions are the remote laboratories which offer the possibility of the implementation of real remote laboratory experiments in the educational institutions' laboratories and, therefore, enhance the students' knowledge and capability for dealing with some technical problems without the need for their physical presence in the laboratory. In the article, the example of a successful implementation of the remote laboratory in the field of engineering, developed and operating in the Moodle environment, is presented. The laboratory does not only represent the framework for the experiment implementation, but it also offers courses with complete documentation, therefore courses can be performed on distance. As an example, the case of the most widely used course from remote laboratory is presented, i.e., the "Control of nonlinear mechanism" course. Special attention is given to the description of the booking process for remote experiments, the execution of remote experiments and the applied user interface. The evaluation of the interface usability from the point of view of end users was performed via the acknowledged SUMI method. Additionally, another questionnaire was prepared in order to investigate the students' opinion about working in the remote laboratory. The results have shown that the presented remote laboratory is user friendly and accepted by both teachers and students as a suitable and interesting supplement to the conventional laboratory exercises.

**Key words:** Remote laboratory, Mechatronics, Usability evaluation.

## 1 Introduction

Due to the increasing use of information and communication technology (ICT), modern educational processes bring numerous changes in all areas. These changes are also visible in the fact that we are ever more willing and fast in our transition from the traditional learning to e-learning. E-learning represents the integration of the use of multimedia tools, as well as web media and communication tools (Downes, 2005). Moreover, a transition from traditional learning to constructivistic learning (Huitt, 2003), as well as finding solutions for problems where the importance of the students' own researching and designing their knowledge with practical work, followed by the group discussions of the problems and learning by doing is increasing (Costa et al., 2007; Alterovitz and Ramoni, 2007). In this way the students are learning to manage and solve complex problems from various perspectives.

One of the most important aspects of the designing of a quality study process in the field of technical engineering education is adequately prepared and designed laboratory work. Especially the industry expects from the educational institutions that the students will in the course of their studies gain practical experience by using the systems they will be later on operating with, especially due to the pressure of the market and a fast development of engineering (Åström, 1994). For this purpose, the educational institutions prepare laboratory exercises in such a way that the students have the chance of gaining knowledge by working on experiments and systems and performing the analyses by themselves, (Bauer et al., 2007).

Such laboratory work with concrete experimental devices demands time and physical presence of the students, as well as of the teaching staff. Moreover, suitable adjusting of dates for the live performance of laboratory exercises is necessary. This can be particularly difficult, especially with larger classes of students. Furthermore, the preparation of suitable laboratory experiment for larger classes demands greater financial investments (Nedic et al., 2003). To solve the problems of live laboratory exercises at an educational institution, a need for offering the students additional possibilities for acquiring knowledge of experimental systems outside the real laboratory, i.e., without their direct physical presence, is visible. Thus, the following approaches, which are supported via the World Wide Web, are increasing in use (Bencomo, 2004):

- videos of exercise implementations,
- virtual laboratory experiments and
- remote laboratory experiments.

Despite the constantly increasing popularity of the video in the World Wide Web, the video lacks interactivity and it is for this reason that the students cannot get practical experience, but only the basic insight into the exercises. The other alternative is virtual laboratories which offer simulation environments. These environments offer the chance that the students familiarize themselves with the theoretical aspects and perform experiments in a certain interactive virtual environment that can be two- or three-dimensional.

Although virtual laboratories can be quite attractive (e.g., Boeing 777 flight simulator) (Trego, 1995), they are only a poor substitute for practical work on physical devices, because simulations cannot include all the aspects of the real world. For this reason, remote laboratory experiments which offer practical work on real devices on distance are increasingly being introduced. Among the first remote laboratories were the laboratory experiments in robotics (Taylor and Trevelyan, 1995) and system control (Bohus et al., 1995). For a certain institution, especially in the case where the institutions are cooperating with other institutions in the preparation process of the laboratory experiments, this means fewer investments into the necessary technology.

On the whole, it is being ascertained that planning and development of remote laboratory experiments which are included in the direct environment of e-contents is not a simple process. The materials and equipment, as well as the interaction have to be adequately planned, elaborated and evaluated for their usability.

In our research, we wanted to find the answer to the question of how to design remote laboratory experiments so that they are going to be an efficient replacement of real laboratory exercises. Thus, we were focusing on the following aspects:

- the explanation of the remote laboratory experiment implementation and its learning objectives on an example of nonlinear system control in the field of engineering,
- the explanation of didactical experience in working with the students on distance where it was established how the students accept remote laboratory experiments in comparison with real experiments in the laboratory,
- the description of the usability evaluation of the system for remote experiments which was done via the standardized method SUMI.

## 2 Implementation of remote exercises

With distance education, there are, from the perspective of teaching methods, various chances of the implementation of remote exercises, such as individual approaches, approaches one-to-many and approaches many-to-many (Cohen et al., 2004). Individual methods, among other things, include the implementation of interviews, preparation of seminar papers, implementation of various e-contents and other forms where the students perform the tasks individually. The methods one-to-many with distance education usually include the presentation of the assistant with the aid of videoconference, streaming video or webcasting (Reynolds et al., 2008) and lately also with hypervideo technology which enables interactivity within the video (Debevc et al., 2008). With the method many-to-many, we are dealing with discussion groups, debates, simulations, case studies and project work.

Due to the extreme development of the ICT, it is today possible to enable the students a high degree of interactivity and cooperation with the implementation of remote exercises without the physical presence. Despite this, the social contact can be maintained with the aid of adequate communication and remote discussion tools. Nowadays, computer technology offers (Bencomo, 2004):

- better human-computer interaction,
- more natural and intuitive graphical user interfaces,
- high degree of interactivity,
- access to remote computer applications.

In the field of engineering, it is important for the students that in their studies and exercise implementation they get acquainted with the physical laws that describe the operation of these systems. Scientists and engineers usually use computers for calculating and graphical imaging of the responses of these technical systems onto various initial states and inputs. With technical systems, we are thus tackling time responses, spectra, Bode and Nyquist diagrams, etc. The knowledge and comprehension of these basic system descriptions represent one of the important aspects for the comprehension of the operation of technical systems.

The development of ICT and distance education have thus provided the students the chance to get acquainted with technical systems according to an individual didactical method in the World Wide Web and to perform remote exercises independent of time and place, so that they the students are performing the experiments and solving problems. Didactically speaking, it is about the principle of problem learning and learning by doing. These are student-oriented learning processes where the teacher is not in the main focus, but on the side and intervenes only when necessary.

Didactically speaking, the use of remote laboratories provides the students with the access to experiments 24 hours per day and from any location whatsoever. An even greater advantage for the students is that they can, if they want and understand it, perform the exercise quickly. On the other hand, they can also take some more time and repeat the exercise in a greater detail with the goal of improving their comprehension of the system operation and its reactions if they find it difficult. By this, the learning process is improved, because there is constant link between the theory and practice, so that the students on real devices examine theoretical bases and gain the necessary practical experience and skills which are fundamental in the engineering studies.

On the other hand, remote laboratories and the implementation of remote exercises offer an equal inclusion into the learning process also to the persons with special needs. In this way, better position in the modern, technologically-driven society is enabled for them.

## 3 Remote laboratory for automation and mechatronics

As an example, we will present a remote laboratory which is intended for the students in the field of automation and mechatronics and which was constructed at the University of Maribor, Faculty of Electrical Engineering and Computer Science (Hercog et al. 2007). The purpose of the remote laboratory is offering students and lecturers an alternative way of implementing the regular learning process or for its supplementation. In the framework of the remote laboratory, there are more extensive courses at disposal and they cover the basic theory from the field of operation, modeling, simulation, control, design and implementation of electrical and mechatronic device. The courses, which demand on average 50 hours of intensive work from the students, are practially oriented. Focus point of every course are remote experiments.

The web portal of the remote laboratory was designed and constructed in the framework of the Moodle web-casting tool with which the user management and the inclusion of the web learning materials were facilitated (Brandl, 2005). The access to the contents of the remote laboratory is enabled only for registered users. The registration is free of charge and it is possible to register right on the web portal of the remote laboratory. All the data and necessary documentation are at disposal in Slovenian, as well as in the English language which enables the use of the laboratories to foreign students, as well.

The basic, introductory website is designed in such a way that it offers the users by entering into the system


*Figure 1: Introductory website of a remote laboratory*

all the necessary data about the laboratory, this being the description of the remote laboratory, the possibility of logging into the system and the necessary data for the implementation of exercises in the private environment (Figure 1 – functions of the remote laboratory). Additionally, the programs which the students must download on their own computers are also at their disposal. These are the programs which are necessary for the operation of the LabVIEW environment and for the video presentation of remote experiment.

## 3.1 Remote laboratory architecture and principle of operation

Remote laboratory is composed of the laboratory server, DSP-2 control systems and several objects under control (Figure 2). DSP-2 control systems are connected to the lab server which is, in turn, connected to the Internet. Embedded control systems execute predefined control algorithms and through the analogue and digital I/O signals drive the real process (DC motor, nonlinear mechanism, SCARA robot). At the same time, data visualization and parameter tuning program is running on the lab server. This program receives selected data from the control system and displays them in the experiment graphical user interface (GUI). Each experiment GUI also contains controller parameters which can be changed on-the-fly by the user. On each value change event, new parameter value is transmitted to the control system. Experiments GUI, which are created using LabVIEW, are further published on the Web using a LabVIEW built-in Web Publishing Tool. Once the GUI is published, anyone on the Web can access and control an experiment using the standard Web browser.

Two additional servers are also running on the labs server: (1) Web server and (2) visualization server. The first one is responsible for displaying remote laboratory web pages while the latter enables live video broadcasting. Visualization solution is based on client-server architecture (Gergič and Hercog, 2006). Server application grabs the images from FireWire cameras, located inside the remote laboratory, and sends JPEG (Joint Photographic Experts Group) compressed images to the client application which decompresses and displays the received images to the remote user.

## 3.2 Courses in remote laboratory

When the student logs in the system, groups of courses appear. For each course, adequate documentation is prepared in the remote laboratory, as well as remote experiments. In the documentation, all key data for teachers and students are stated, together with those that are necessary for the informing about the course and for a successful implementation of the course. Inside a specific course, the following is at the ones' disposal:

- Course Overview,
- Course Objectives,
- Documentation,
- Execution,
- Authors,
- Poster, Photo Gallery and other materials.

In the "Course Overview" section, the data of the course, the necessary entering conditions, the structure of the course and the evaluated time demandness are stated. The description of the course includes a short summary of the course and a description of the main chapters. Its basic purpose is to provide the user with a basic description in a few sentences. The necessary entering conditions include the description of the necessary knowledge which are the basis for the comprehension and implementation of the course. The conditions are stated as concrete conditions in the sense of the knowledge which is required. Thus, the knowledge of, e.g., physics at the high-school level can be required, the knowledge of the linear algebra basics, etc. Also the requirements concerning knowledge of programming in specific programs are stated here. The course structure shows logical units or modules which the course is composed of. Usually, one logical unit corresponds to one chapter in the documentation. The structure of the course is sometimes presented in the graphical form, so

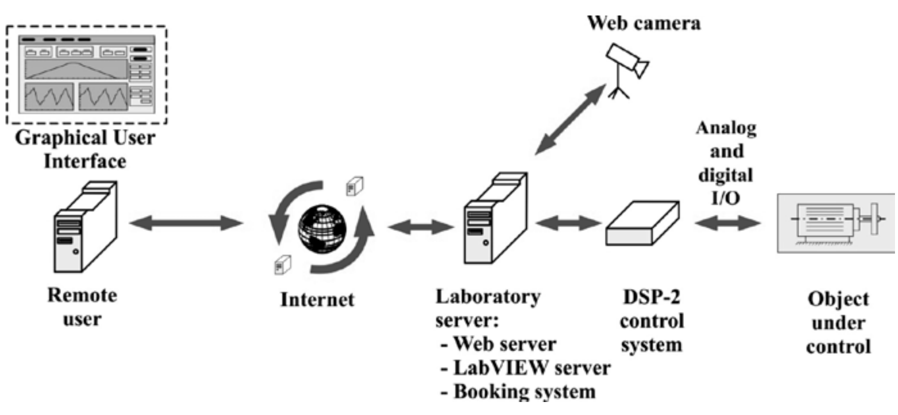


*Figure 2: Block scheme of remote laboratory*

that it is visible how the individual modules are combined and in what order they can be performed. Time demandness defines the necessary average time for each logical unit or module of the course, as well as the total time which is needed for the entire course execution.

In the "Course Objectives" section, course objectives are concisely stated, together with the expected learning outcomes and the suggested method of achieving the desired learning outcomes. The expected learning outcomes relate to a gained knowledge or skills, while the suggested method of achieving the learning outcomes describes the related procedures.

In the "Documentation" section, all theoretical background of the course is stated, together with the necessary literature for additional studying. The theory is combined with the exercises for students which can be theoretical, computational and simulation exercises, or remote experiments. With each task, it is specifically stated what the task of the student is and what results, together with their comments, must be in the report which the students should provide their mentor with.

Furthermore, there is also documentation for the teacher at disposal. Besides the key to the exercises, it also offers advice on how to include the course into the study program, as well as the description of the most common problems that appear with the practical implementation of the course. This documentation can be provided on a specific demand from the author of the course and is not posted on the website of the laboratory.

In the "Implementation" section, all the necessary data which are needed for the practical implementation of remote experiments are collected. Besides the short description of the experiments and the instruction for the implementation of experiments, also the necessary software, is available (See Figure 3).

On the website, there is also the link to the booking table for the reservation of dates of the remote experiment implementation (See Figure 4). With the aid of this table, the users can make a reservation of a date which suits them best for the implementation of the remote experiment. The booking table is one of the most important elements for a successful use of the remote laboratory, because it regulates the access to the experiment in such a way that only one user can use it on the reserved date and time. The user simply clicks on the desired date and time and the colour of the date and time change, adequately. Those, marked in green, are still free, while those, marked in red, are occupied.

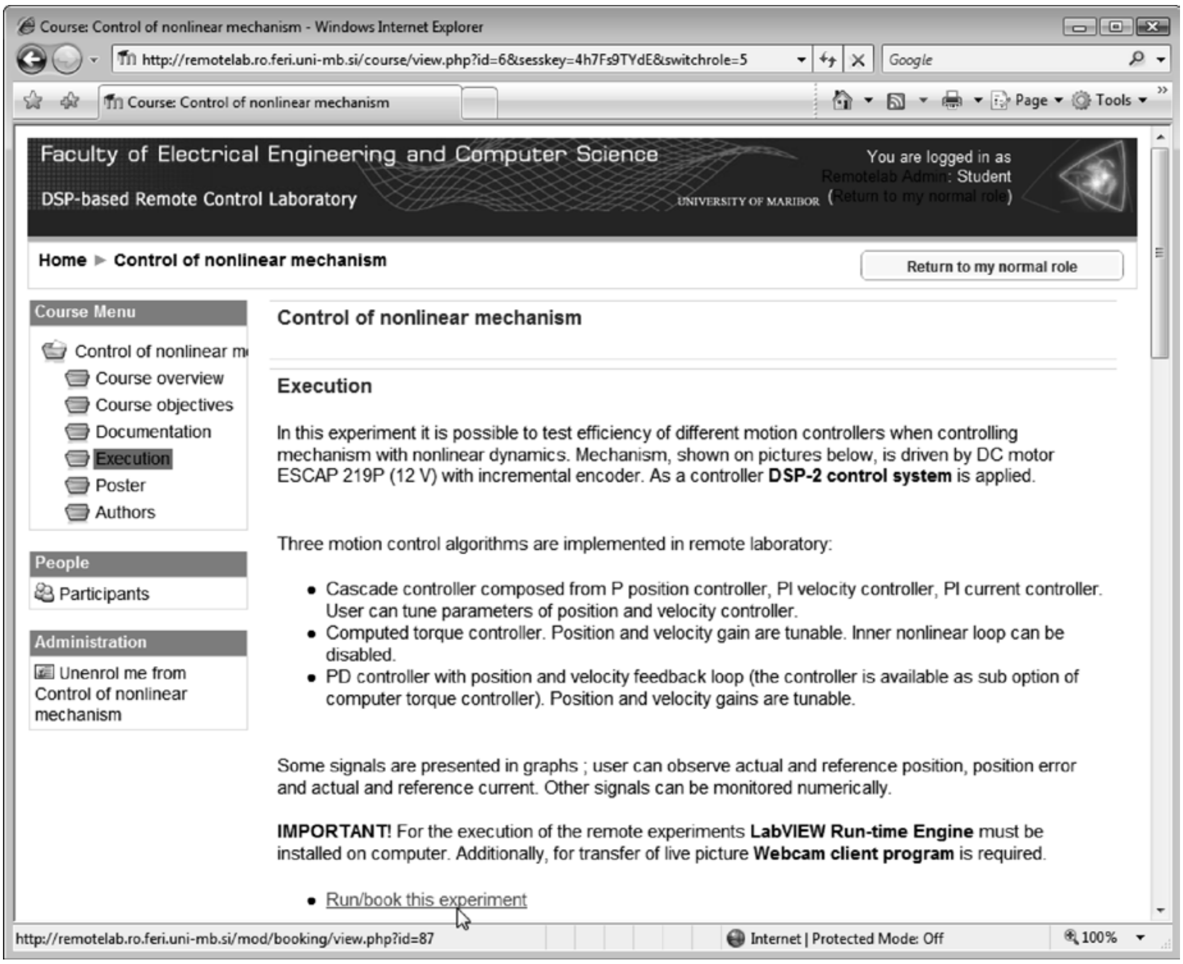


*Figure 3: Implementation of a remote experiment, website*

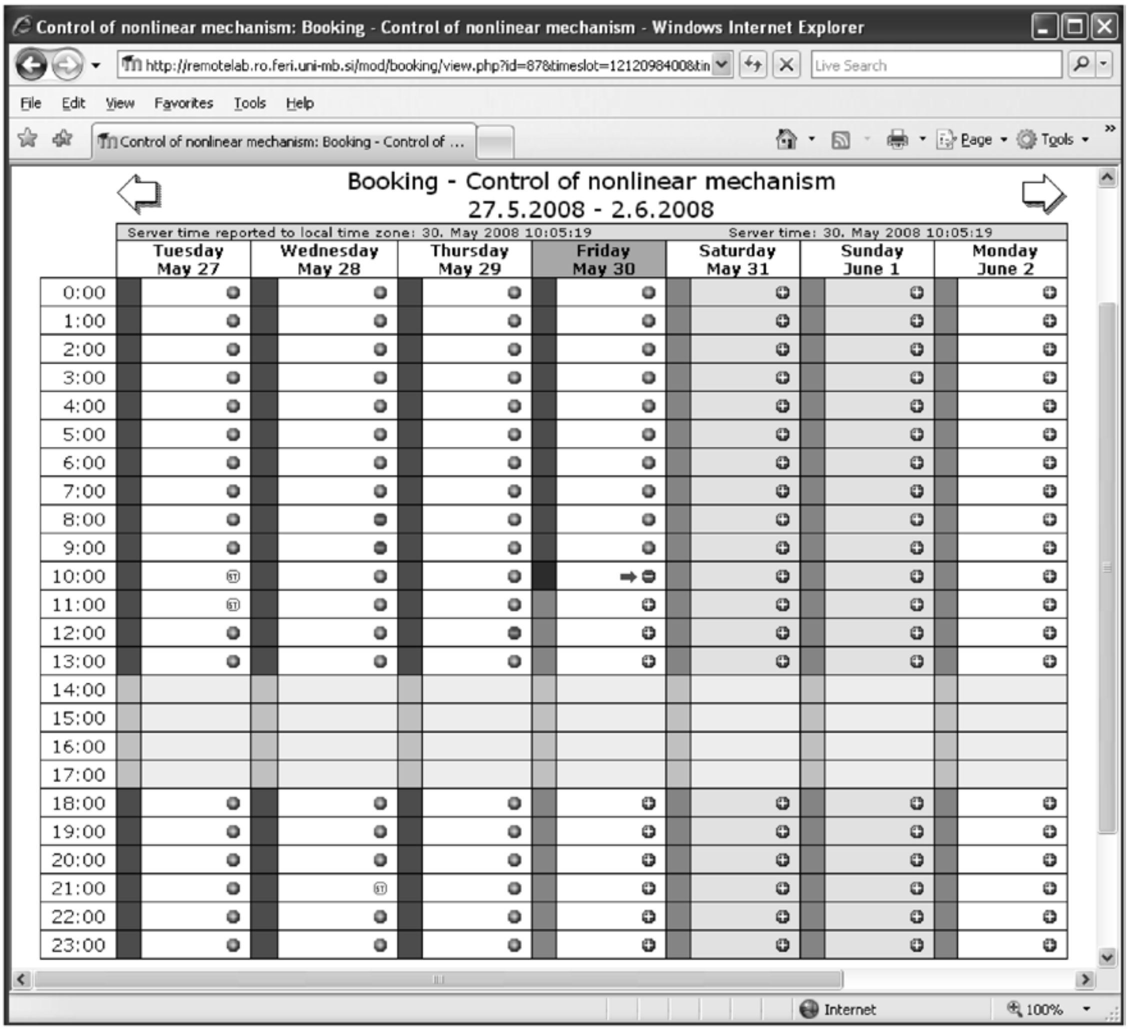


*Figure 4: Booking table*

## 4 The "Control of nonlinear mechanism" course

The most widely used course which was constructed in the framework of the remote laboratory is the "Control of nonlinear mechanism" course which covers an extensive topic of modeling, simulation, planning and practical implementation of the motion control of mechatronic device with nonlinear dynamics. All this is an important part of the modern education of electrical engineers, machine engineers and mechatronics engineers. In the course, all basic elements are included which enable the student with adequate pre-knowledge an insight into the problem, an acquisition of some new knowledge and practical experience.

Learning objectives of the "Control of nonlinear mechanism" course are the following:

- Modeling of the mechatronic device with the nonlinear dynamic of mechanical work.
- Planning, implementation and optimization of the linear regulator with the cascade structure (cascade P position, PI speed and PI current controller) for the position control of the mechanism with nonlinear dynamics.
- Planning, implementation and optimization of the nonlinear position controller based on the mechanism dynamic model.
- Understanding the reasons for variations in efficiency of the use of linear and nonlinear control methods in the case of nonlinear mechanism control.

As a practical example in the course and an experimental device in the remote laboratory, the mechatronic device called mechanism with a spring with a DSP-2 control system is used (Hercog and Jezernik, 2005) (Figure 5).

The first part of the course is intended for familiarization with the theory and it is in each chapter supplemented with an example that represents the use of theory on a practical example of the mechanism with a spring. Thus, in an example of a basic dynamic mechanism model, the dynamic model of the mechanism with a spring is explained, as well as the construction of the suitable MATLAB/Simulink simulation model and the simula-

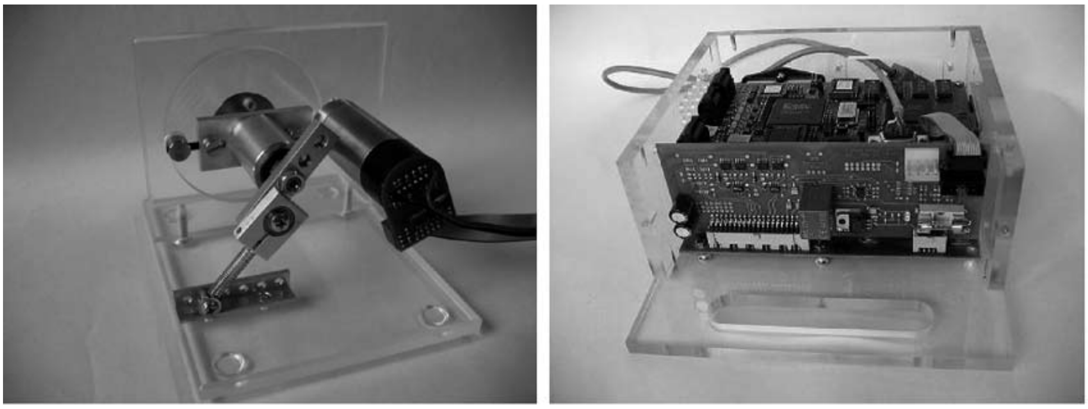

*Figure 5: Mechanism with a spring and a DSP-2 control system*

tions results. After that, the theory on the motion control follows, together with the design of suitable controllers and their implementation for the motion control of the mechanism with a spring. After the theoretical part with the simulations, the experiments in the remote laboratory follow. The user interface with which the students perform remote experiments enables the implementation of three various control methods, the setting of their parameters and the presentation of the measured results. This is presented in Figure 6. The image of the live experiment is also possible to see via the webcam.

## 5 User responses in remote laboratory work

After the implementation of the "Control of nonlinear mechanism" course, the students have filled in an anonymous questionnaire in which we have asked them about their opinion on the performance of remote experiments and its inclusion into the regular study process. 18 students answered the questionnaire.

It was shown that all the students have the necessary equipment for the performance of remote laboratories from their home (personal computer, fast Internet connection), so there were no limitations in the case of equipment.

94 % of students think that remote laboratories are a useful addition to ordinary laboratory exercises, while only 22 % are of the opinion that remote experiments could entirely replace ordinary laboratory exercises.

94 % are of the opinion that remote experiments are suitable for the strengthening and repetition of knowledge which they have already gained. 72 % have the opinion that remote laboratories are suitable also for gaining new knowledge.

For 39 % of students, it was in the "Control of nonlinear mechanism" course in which they performed remote experiments for the first time and this shows quite a low representation of this kind of work in the regular teaching process.

Despite the fact that remote experiments can be performed independently of the place and time, 61 % of the students prefer performing the experiments in the laboratory to remote experiments, 33 % could not decide for one option, 6 % (i.e., 1 student) prefer remote experiments.

As much as 78 % of students have the opinion that they learn more in laboratory work than in remote experiments. The other 22 % could not decide for one option.

## 6 The evaluation of the usability of the remote experiment interface

One of the more important characteristics of the remote experiment system is system usability, because it highly influenced the acceptance of the system with users (Holzinger, 2005). Furthermore, the usability is one of the important factors of evaluation of e-learning technologies and systems. There are more definitions of usability. All include many factors, such as gaining skills, facilitated use, efficiency of the system, and contentedness of the end user. Moreover, there are many evaluation techniques at our disposal which are useful in the evaluation of usability. The choice is dependent upon what we are evaluating, which software and computer equipment we are using, which users we are testing, and what our financial resources are.

For our project, we have, due to the facilitation and fast acquisition of the first impression on the usability, used the Software Usability Measurement Inventory (SUMI) technique (Kirakowski and Corbett, 1993). The tool, which is considered to be standardised in the framework of the ISO 9241 [BEVAN] standard, is composed of the printed-out questionnaire with 50 questions on which those who are being questioned reply in such a way that they choose the answer on a three-grade scale (I agree, I neither agree nor disagree, I do not agree).

The questionnaire is composed in such a way that it measures five main aspects, which are:

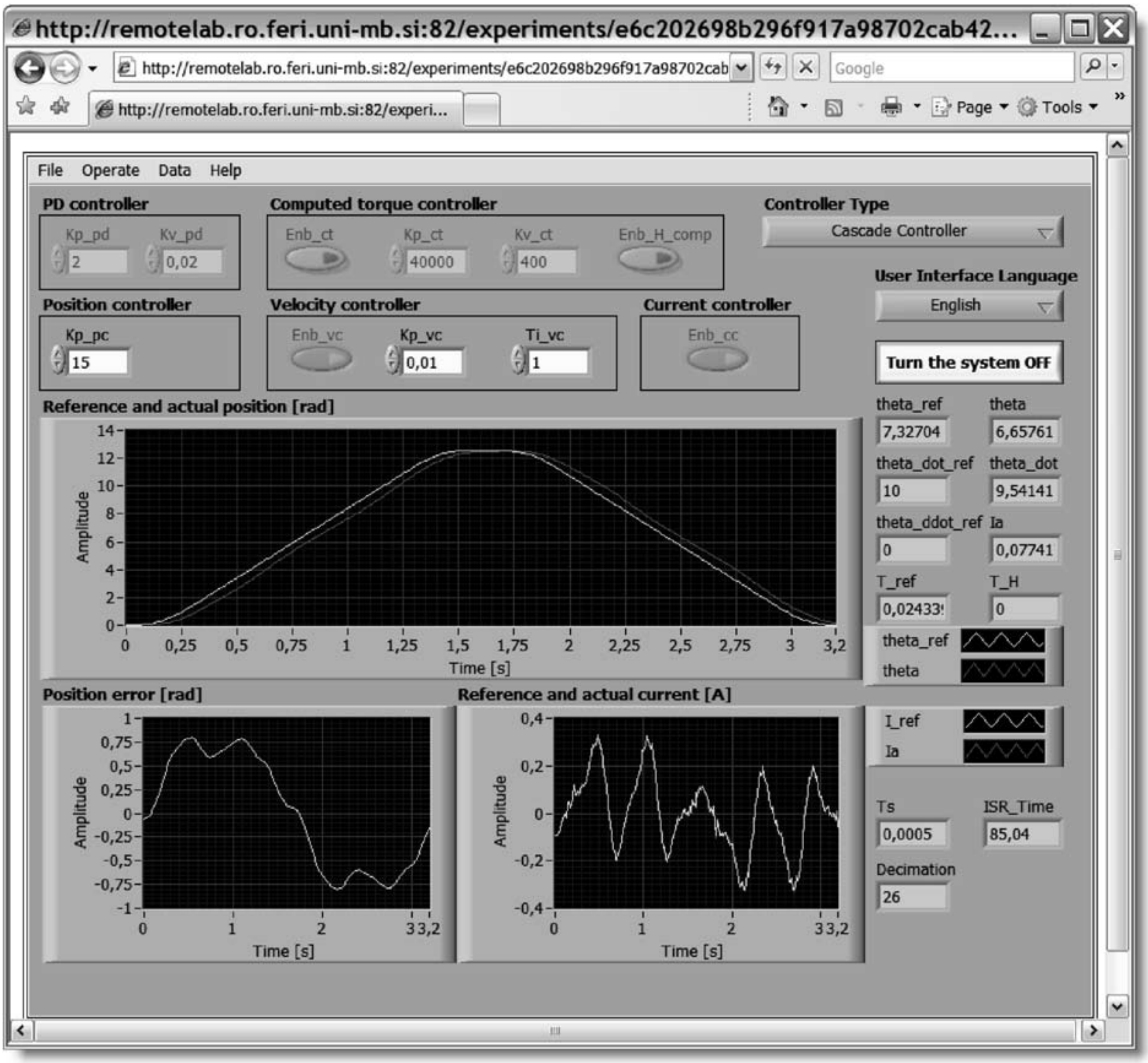


*Figure 6: User interface for the implementation of remote experiments*

- **effectiveness;** represents the feeling of the users that they managed to perform the task fast, successfully and economically. The extreme opposition is that the program impedes the performance of the task.
- **affect;** represents the psychological expression for the description of the feeling which in this context combines the feeling of the users when working with the program – stimulative and pleasant.
- **efficiency;** we are evaluating if the users have the feeling that the communication with the program is easy and clear, as well as if the program is willing to "help" them solve the problems.
- **control;** we are evaluating the feeling in users whether the program is consistently responding to their commands and the input data.
- **learnability;** (ang. learnability) represents the feeling of the users that it was relatively easy to learn using the programme and that the instructions and other materials were readable and useful.

The gained data are processed with the SUMISCO programme, which evaluates the results of the questionnaire and compares them to the standardized database. In Table 1 and Figure 7, quantitative measurements of the system usability which were gained with the aid of 18 students who have performed the test remote experiment are presented. The Median is the middle score when the scores are arranged in numerical order. It is the indicative sample statistic for each usability scale. The Ucl and Lcl are the Upper and Lower Confidence Limits. They represent the limits within which the theoretical true score lies 95 % of the time for this sample of users. From Table 1 and Figure 7 is thus seen that the area that defines the aspect of usability (aspect Global in Figure 7) is in our case completely above the median 50 and with a low dispersion of answers (from 55 to 63). This information tells us that the system was successful in the usability aspect.

*Table 1: Statistical values of certain usability aspects of the materials*

| Scale | LCL | Median | UCL |
|---|---|---|---|
| **GLOBAL** | **55** | **59** | **63** |
| Efficiency | **53** | **58** | **62** |
| Affect | **56** | **60** | **64** |
| Helpfulness | **57** | **61** | **64** |
| Control | **45** | **50** | **54** |
| Learnability | **50** | **56** | **61** |

If we take a closer look at the other aspects in Figure 7, we notice the following:

- the "Effectiveness" aspect is almost identical with the aspect Global; however, there is a slightly lower value which tells us that the system was usable.
- the "Affect" and "Efficiency" aspects have proven to be the best aspects, as well as the answers have proven to be uniform due to the fact that the dispersion of the answers was similar and small.
- the "Control" aspect with the mean value lies exactly on the mean value and due to the greater dispersion under the mean value, which means that the usability interface was not completely satisfactory from the perspective of control. This aspect was expected, because the system, still being in the initial implementation phase, has stopped working. The students had to wait for the intervention of the administrator who has re-enabled the system.
- the "Learnability"aspect presents us with the information whether the students had some problems with their comprehension of how to handle (manipulate) the system.

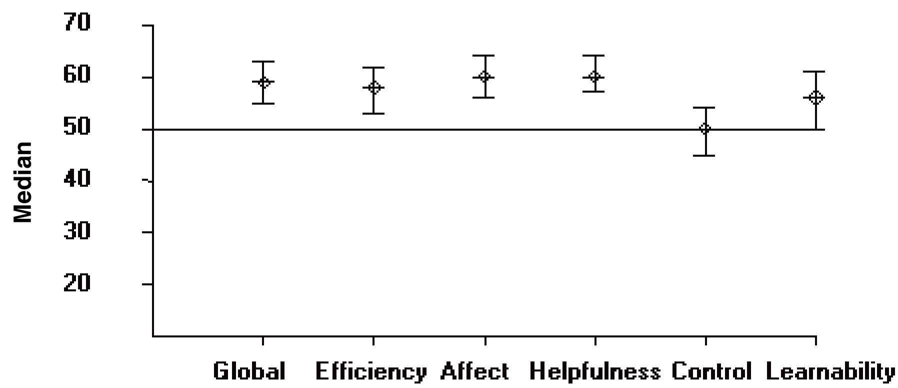


*Figure 7: Graphical comparison of certain usability aspects with the SUMI evaluation*

With the joint results and the results of specific aspects separately, the SUMI approach offers the information about specific questions of the questionnaire. This analysis is called Item Consensual Analysis. SUMISCO compares the results of each individual item with the anticipated value in the standardized database with the use of $\chi^2$-test. Those items which are most deviated are marked in the print-out, separately.

Among the individual questions which had the greatest deviation from the mean value out of all (with more than 99.99 % reliability) are some positive opinions, e.g., "Documentation is informative" and "I know what I have to do in the next step".

It is visible from the results that the user interface was on the whole extremely successful and that the students were extremely in favour of remote experiments. The only improvement that must be done is improving the system stability and increasing the aspect of control.

## 7 Conclusion

In this article, a state-of-the-art approach to engineering education where the ordinary laboratory experimental work is supplemented or entirely replaced with remote laboratories is presented. Such a way of work has numerous advantages, because it enables the students and the teachers a greater flexibility as far as the time and place of the implementation are concerned, as well as solves the problem of lack of experimental devices and/or larger classes of students. Furthermore, it is essential to realize what limitations such an approach has, because working with remote experiments does not completely equal practical experience which direct laboratory work with devices produces. Moreover, the students' answers which were gained via the questionnaire show that although the students find the remote experiments useful and an interesting supplementation of regular laboratory work, there is just a few of those who are of the opinion that such an approach could entirely replace laboratory work. Likewise, a great majority of students are of the opinion that they learn more in laboratory work than in remote experiments.

In the framework of this article, the evaluation of the usability of the remote experiment interface was also performed and it showed that the user interface was user friendly, but there is greater cautiousness necessary with enabling a better stability of the system. For this reason, it is highly important to place greater emphasis on the further development of remote laboratory technology, by chance also in the way that various institutions form connections into a unified system of remote laboratories. With this, the offer and quality of remote experiments for the students of a certain institution would improve.

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**Implementacija, učinkovitost in izkušnje z oddaljenim laboratorijem za poučevanje tehnike**

Sodobni izobraževalni procesi prinašajo s seboj nove pedagoške in tehnične izzive, pri čemer je posebej zahtevna učinkovita integracija informacijske in komunikacijske tehnologije v učne procese. Zaradi zahtev in potreb industrije po hitrejšem in učinkovitejšem pridobivanju praktičnih izkušenj se iščejo nove rešitve, ki bi pritegnile in motivirale študente za dodatno pridobivanje znanja. Ti procesi so posebej izraziti pri poučevanju tehnike. Največjo težavo pri tem predstavlja izvajanje laboratorijskih vaj, ki zahtevajo uporabnikovo prisotnost v laboratoriju. Ena od rešitev so oddaljeni laboratoriji, ki nudijo izvajanje laboratorijskih eksperimentov preko spleta, kar zmanjša potrebnost neposredne fizične prisotnosti študentov in povečuje možnosti za izboljšanje znanja študentov za reševanje določenih tehniških problemov. V članku je predstavljen primer uspešne izvedbe oddaljenega laboratorija za področje tehnike skupaj s tečajem, ki deluje v okolju Moodle. Podrobneje je opisan tečaj 'Vodenje nelinearnega mehanizma'. Laboratorij namreč ne predstavlja samo orodja za izvajanje oddaljenih eksperimentov, pač pa ponuja celotne tečaje s popolno dokumentacijo, ki omogoča učenje na daljavo. Posebej je izpostavljen postopek prijavljanja na izvajanje oddaljenih eksperimentov ter sama izvedba vaje skupaj z opisom grafičnega uporabniškega vmesnika. Izvedena je bila tudi evaluacija s priznano metodo SUMI za ocenjevanje uporabniške prijaznosti sistema. Prav tako se je ugotavljal odziv študentov na delo z oddaljenim laboratorijem. Rezultati raziskav so pokazali, da je v delu predstavljen oddaljeni laboratorij ustrezno uporabniško prijazen in s strani študentov in učiteljev sprejet kot primerna in zanimiva dopolnitev klasičnih laboratorijskih vaj.

**Ključne besede:** Oddaljeni laboratorij, Mehatronika, Ocenjevanje uporabniške prijaznosti.