Web-Based Laboratories for Distance Learning*

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Experimental installation of the 'Electrical simulator of typical physical process' exercise in the field of automatic control is developed and presented . The structure of this laboratory exercise includes goals, possible educational tasks, structure and learning objectives. The initial educational results of implementation of web-based laboratory and remotely-controlled laboratory exercise in engineering and control engineering education are also presented. The effect of web-based laboratories is quantified by student feed-back in both organization and effects of implementation.

Keywords: web laboratories; engineering education; remote control; automatic control

INTRODUCTION

A WIDESPREAD TOOL for teaching and learning is the web. It enables more flexible delivery (anytime), distance education (anyplace), new visualization possibilities (interactivity), and cost reduction. In engineering education and control education, the Internet and web technology have increasingly important role, especially in concepts of distant learning. This issue was a topic of a large number of researches and papers [1, 2, 3, 4, 5, 6]. Generally, there are two different concepts of virtual laboratories: the first with simulation and visualization in the concept of virtual reality [7, 8], and the other, the subject of this paper, based on remote control (usually using the Internet) with laboratory experiments [9, 10, 11, 12]. At many universities, remote web-controlled laboratories ensure full accessibility to expensive laboratory equipment, reduce costs, and make time savings and individual usage of laboratory equipment. Computer-aided experimentation has a long and venerable history in many scientific areas, particularly physics and astronomy. Many high school and college physics labs already control experiments, collect and analyze data using laboratory computers like [13]. A large number of very well known universities, starting with MIT (Microelectronics web lab), Chalmers University of Technology in Sweden, Chemical Engineering Department at Cambridge University, and University of Illinois (Integrated Remote Laboratory Environment (IRLE)), University of Siena ACT [4] and Oregon State University [5] (as well as many others) have their own web laboratories. In some of their solutions, remote experiments are controlled by changing appropriate parameters, and some other prefer solution with existence of a control program that changes the dynamic of the system with feedback.

The web laboratory of University of Kragujevac (WLUK) (http://weblab.kg.ac.yu mirror http://www.cqm.co.yu/weblab access upon request) was established at the initiative of a group of professors and associates of the university in order to use laboratory resources more effectively and to improve cooperation between departments, faculties and universities. The educational advantages and limitations of a web-based experimental environment using an example of one web-based experiment that is functioning in WLUK are presented below. A web portal for laboratory and directions of further development are also described (development of the integrated e-learning environment, design of access rights and schedule of usage of laboratory resources, because only one person could control the experimental set-up at the same time). This setup is very cheap; it consists of a PC, A/D and D/A interfaces and physical simulator (electric circuits). Using jumpers and potentiometer, we can control and simulate typical industrial process. The structure and parameters of physical simulators are generally unknown to students so they need to identify them. It is possible to set additive of measurement noise, disturbance effect and transportation delay on system output using an appropriate software solution. A student could develop the algorithm of measurement signal processing, set periods of sample and control algorithm. Therefore, the support is enabled for

fields of modelling and identification, signal processing, real-time programming and design of control algorithms. Some initial educational results in the implementation of a web lab in the educational process can also be seen below.

WEB LABORATORY—EXAMPLE OF A SET-UP

Experimental installation

The university web laboratory was established to improve cooperation between different departments and faculties and to provide unique access to laboratory equipment dislocated on several locations.

The web laboratory offers five exercises in the field of telemetry (TM1 Measurement of electrical signal velocity through the coaxial cable, TM2 Measurement of diode electrical characteristics, TM3 Measurement of transistor electrical characteristics, TM4 Experiment with step plane, TM5 Interactive experiments with linear systems); two exercises in the field of automatic control are in the implementation phase and installation of the necessary equipment (coupled water tanks experimental setup [14] and gantry crane [15]); one exercise in the field of automatic control is developed and available on-line—an electrical simulator of a typical physical process. This laboratory exercise is a part of the educational plan and programme at the department for Automatic Control and the department for Industrial Engineering.

Experimental installation for this laboratory exercise consists of:

- Physical simulator, presented in Figure 1 a) in the role of plant
- Transformation of A/C of 12, for accumulator,
- 12-bit A/D, D/A interface between plant and computer: card PC ADDA-12 FPC-010 produced by Flytech company,
- PC computer, connected on LAN, for implementation of control.

The physical simulator is an electric circuit with I/O having a voltage signal of 0-9.8V and the supply of alternating voltage of 12V, controlled using a PC computer (See Figure 1). In more detail, the simulator consists of serial coupled electronic circuits, which could perform different transition functions. Different variants of their interconnection produce different plant structures. On the other hand, by changing resistance (using potentiometer and jumpers), it is possible to change parameters of the plant. The input is direct current voltage in the range of 0–9.8V, and output is a voltage on the selected circuit (0–10V) and it presents an output signal of the plant. The simulator covers electronic circuits, whose transfer function could be first, second or third range (alternatively), with an introduction of dynamics in a numerator of the transmission function (where zero of the plant could be placed in the right or left s-half plane, e.g. it is possible to select the plant of a non-minimal or minimal phase). Also, the integral subpart for transmission function plant is available. More exactly, the functional parts of the simulator are designed in order to define following transfer function:

a) $\quad W_a(s) = \dfrac{U_{iz}(s)}{U_{ul}(s)} = \dfrac{b_1 s + 1}{\frac{1}{a_2} s^2 + a_1 s + 1}$

b) $\quad W_b(s) = \dfrac{U_{iz}(s)}{U_{ul}(s)} = \dfrac{0.92}{s}$ (1)

c) $\quad W_c(s) = \dfrac{U_{iz}(s)}{U_{ul}(s)} = \dfrac{K}{Ts + 1}$

By interconnecting and combining different functional sub-parts of the simulator, we can select the structure of the plant (potentiometers define changes of parameters). Note that each of the functional blocks has limited output in range of 0–10V, so it is possible to apply nonlinearity in the specific working regimes (specially considering that in more complex structures of the plant inner-variables could become saturated).

Goals and possible educational tasks

A possible educational task is available to download (http://weblab.kg.ac.yu mirror http://
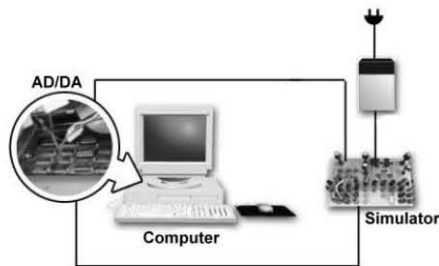
a) Feedback system
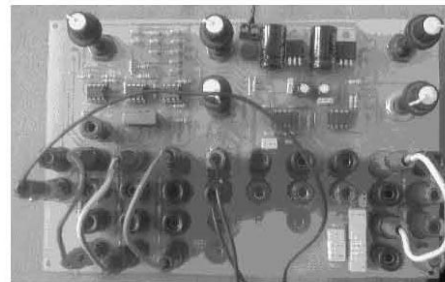
b) Plant – a simple laboratory model
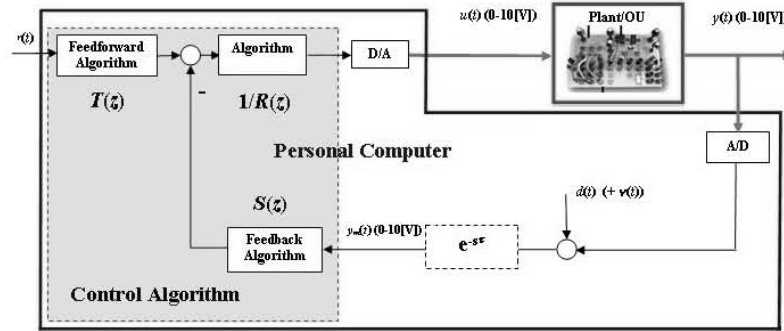
Fig. 1. Experimental installation.
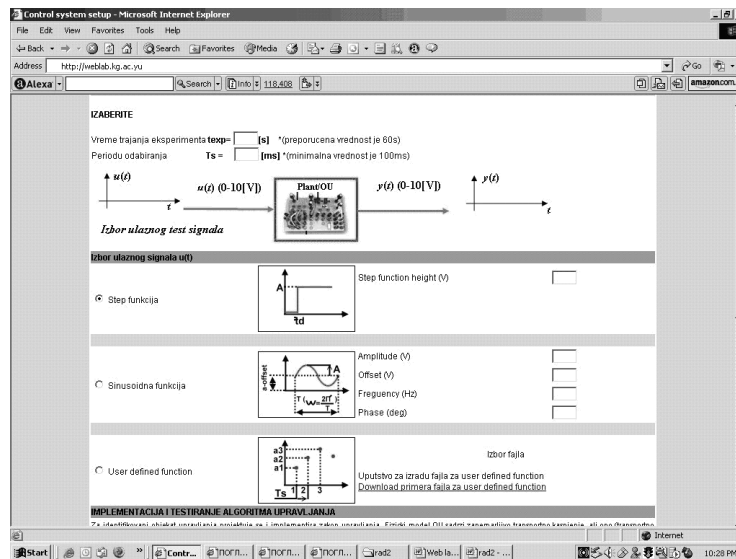
Fig. 2. Block diagram of experimental set-up.

Fig. 3. User interface for identification of plant.

www.cqm.co.yu/weblab access upon request). The same task is a part of the educational programme in the following courses as a part of different educational profiles of academic studies: 'Design of Automatic Controlled Systems' and 'Computer Added Measurement and Control', at the university's Faculty of Mechanical Engineering. This laboratory exercise gives students an opportunity to implement theoretical knowledge from fields of process identification, signal processing, analysis, synthesis and implementation of controlled systems and real-time programming.

When experimenting with a laboratory model over the Internet, a student has no information about the structure and parameters of the plant, so identification is necessary. Hardware possibilities of the laboratory could be more complicated if we accompany transport delay and effects of disturbance and measurement noise on the dynamic of the system (see Figure 2).

The set value of a transportation delay could be unknown as much as the structure and parameters of the laboratory model to the user who is making an approach to the experimental set. However, a user may influence selection or generation of signals r—referent signal, u—control signal, d — signal of disturbance effect on output variable (which could include an additional signal of measurement noise $d+\nu$). A user has the possibility of selecting sample period T. The output file consists of samples of time signal $t = kT$, 'measured' output variables of the plant, plant— $y_m(kT)$, control variables—$u(kT)$, referent signal— $r(kT)$ and the signal of disturbance effects—$d(kT)$. Considering that the largest time constant for the plant is 10s, the recommended duration of the experiment is 60s, the maximum duration of the experiment is three minutes. The time of the experimental probe is selected by the user (maximum three minutes).

So, a student:

1) Defines control variable u and record output variable y_m for identification of the controlled process
2) Writes a part of the interrupt routine, e.g. subprogram that implements control $u = f(r, y_m, \ldots)$—and analyses functioning of the system in different referential trajectories and disturbances.

a) Input sequence u(KT$_s$)
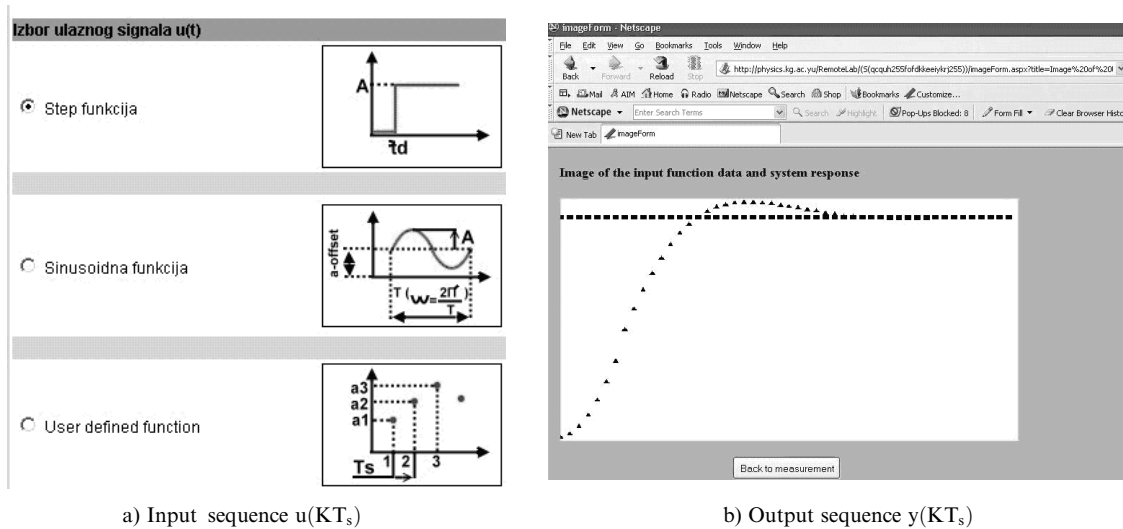

b) Output sequence y(KT$_s$)

Fig. 4. Step response of plant.

3) Analyses in what extension analytic and simulation results are in accordance with recorded experimental results.

Experimental results and user interfaces

Usage of the described laboratory system on the Internet and performance of the experiment has two phases:

1) Identification of the plant
2) Implementation and testing of the control algorithm.

The selected input test signal $u(t)$ causes a change of output signal $y(t)$. Experimentally, based on knowledge of the input signal $u(t)$ and the measured output signal $y(t)$, a user estimates a model of the plant. The user interfaces in the phase of the experiment that deals with identification of a model of the plant is presented in Figure 3.

The button 'Start of experiment' starts the experiment, the button 'End of experiment' could cancel it, otherwise a user is waiting for the defined duration of the experiment t_{exp}.

Fig. 5. User interface for control of implementation and testing of control algorithm.

A user has an indication of the experiment status: start, progress, end or free status. After the experiment, a user has the experimental diagrams $u(t)$ and $y(t)$ in the same or separate graphs. Using the button 'Download of exp. Results', a user downloads file with a header and the explanation, selected parameters (t_{exp} T_s), date, information about the logged user, and the following columns: time t, input samples u and output y.

An example of the experimental results for this phase of the experiment is presented in Figure 4. The section 'Selection of input signal' in Figure 4 defines the needed signal, selection of parameters of one of the listed signals (step, ramp, sinusoid) or defines completely the user-defined signal by uploading a file with a sample of the signal.

For identification of the plant, a user defines and implements a control algorithm. The physical model of the plant has an unimportant transportation delay, but for education purposes, this delay τ can be set using the software, (see Figure 5).

The transportation delay could be set by the user, or stay unknown to the user and become an entity for identification. When the administrator of the web lab allows, it is possible to select the transportation delay of the plant (it is very useful to probe the possibility of design of the algorithm of the control in the following situation:

1) $\tau = 0$,
2) $\tau = \frac{1}{2}$ max. time constant plant,
3) $\tau = 2 \times$ max. time constant of plant, etc . . .).

In practice, the controlled variable is $y_m(t)$— measured value of the output variable, e.g. variable of the feedback, which consists of an effect of the disturbance impact on the system. The effect of the influence of the disturbance on the control variable $d(t)$ could be set using the software. In the control algorithm testing, we control $y_m(t)$, in the function of the controlled variable, $u(t)$ is controlled variable, possible selection of the referential trajectory $r(t)$, $d(t)$—effect of disturbance on the controlled
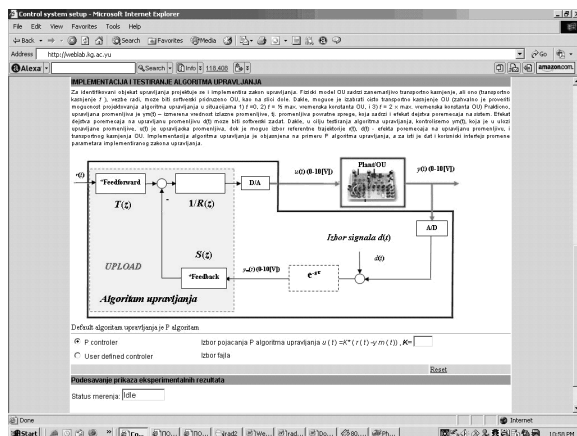
variable and the transportation delay of the plant τ. The implementation of the controlled algorithm is explained in the example of P (proportional) control algorithm, and for that example we presented a user interface for changes of parameters of implemented control algorithm.

The user interface in this phase of the experiment is presented in Figure 5. Using this interface, a user could adjust following parameters:

- Duration of experiment t_{exp} = _____ [s] *(suggested value is 180s)
- Sample time T_s = _____ [ms] *(minimal value is 50ms)
- Transportation delay of plant τ = _____ [s] *(default value is 0s)
- Referent trajectory $r(t)$—on click 'Selection of signal $r(t)$'
- Disturbance effect $d(t)$—on click 'Selection of signal $d(t)$'
- Control algorithm—on click 'UPLOAD'—explanation and upload of file
- Default control algorithm is P algorithm, and selection of gain of P algorithm $u(t) = K*(r(t)-y_m(t))$ K = _____ *(input field for K).

As well as the controls mentioned above, there is additional material for download for further explanation of the synthesis of the controlled software and definition and implementation of the file for the control algorithm, for P control algorithm and simpler forms of PI and PID control algorithms.

An example of the experimental results for this phase of experiment, with P controller as a control algorithm is presented in Figure 6.

The experimental result in Figure 6 is expected, as well as the error of the stationary stage; with the increase of gain of P controller, the error of the stationary stage decreases, but increases the oscillatory of the systems, (depicted in Figure 7).

An important characteristic of this experimental set up is that a student has to write a software routine for definition of the controlled variable:

$$u_k = f(r_k, y_m k, \ r_{k-1}, y_m k - 1,$$
$$u_{k-1}, r_{k-2}, y_m k - 2, u_{k-2}, ...)$$

in absolutely the same way as he/she should with a PC, laboratory model and appropriate interfaces. In this case, a user does not use software for rapid prototyping—it is common practice for a student to be able to explain possible structure of a software solution as a whole (not just the software routine he needs for implementation of the control algorithm),

PRE-REQUESTS, ARCHITECTURE AND SOFTWARE REALIZATION OF WEB-BASED LABORATORY

Considering other relevant experiences and solutions in development of the web laboratories [4, 5, 16, 17, 18, 19, 20], as well as the character of the
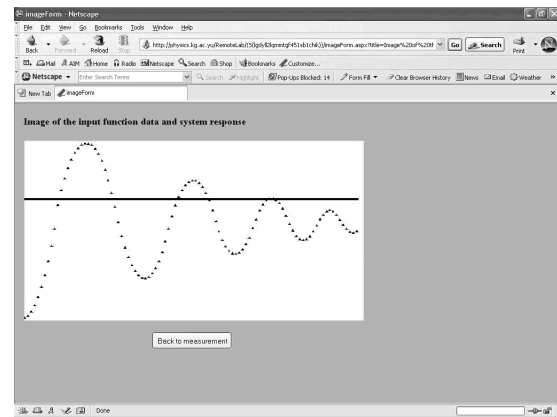

Fig. 6. Step response of system with feedback and P controller as control algorithm, gain three of P controller.
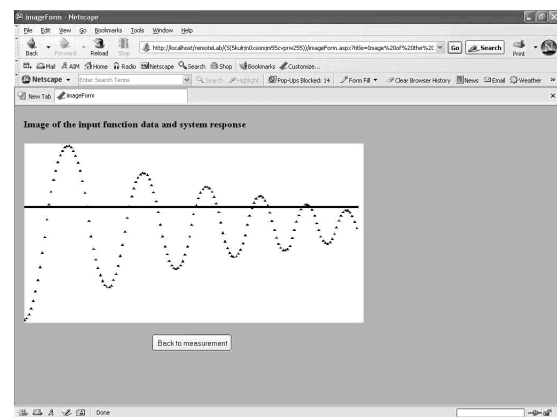

Fig. 7. Step response of system with feedback and P controller as control algorithm, with increase of gain five of P controller.

planned laboratory exercises, the team that started development and implementation of the web laboratory of University of Kragujevac, defined the following requests for the software infrastructure of WLUK:

- Easy understanding of educational tasks and user friendly interfaces for laboratory exercises.
- Adjustment of teaching material to the new context.
- Online presentation of an experiment.
- Selection of appropriate software platform and appropriate security police.
- It is necessary that client software operates on all available software and hardware platforms.
- Environment for easy definition of the control algorithms and control signals.
- Laboratory exercises and all results should be stored in a database.
- Download of experimental results.
- Management of changes and distribution of new versions.
- System must posses modular and open structure so new component and laboratory experiments could be added easily.

It is clear that there are a number of additional important demands and requests for quality organization and development of web laboratories.
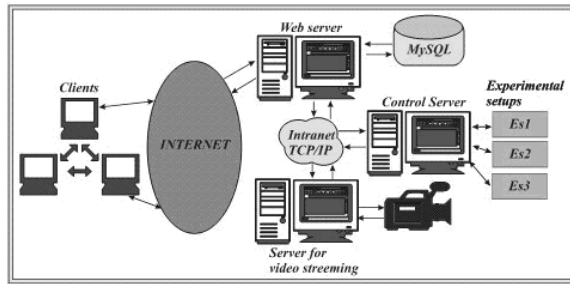
Fig. 8. Architecture of the system.

The listed demands were a starting point of this group of authors in organization and development of this specific web laboratory. These demands are possibly the most appropriate to engineering education, and it is highly possible that other fields of education have partially different demands.

In order to achieve listed demands, we selected appropriate software architecture. The software architecture of web lab consists of two major parts: the first part that controls physical processes (on the server side server—Control Server) and the second part that controls user interface and defines user access (also manages with other functions and parts of e-Learning environment) oriented towards user service (Web server) (Figure 8).

The control server is developed using programming language Delphi. The software module— the software interface for implementation of the control algorithm and communication with the web server is located on the local control server. The system for data acquisition and D/A converter are connected with this server.

The client side is based on dynamic pages generated from PHP or ASPX (the reason for this duality is that telemetric exercises are hosted on the IIS server using ASPX and laboratory exercises in the field of automatic control are hosted on Apache server using PHP). All information about experiments, user access and other relevant information connected with the e-learning environment are stored in MySQL data base. The last planned server is the video server (in the implementation phase right now). The video server supports broad streaming of the video signal. This server has to establish a visual 'feed back' and to create a real impression of an experiment to potential users of the web laboratory. The main idea is the development of the integrated e-learning solution which enables management with the educational materials and presentation of the course using LMS (Learning Management System). and self-evaluation and evaluation using the module for e-tests and practical experiments in the web laboratory. This e-learning environment improved education processes and produced a 'blended' education environment (combination of classical education and e-education) for the Faculties of Science and Mechanical Engineering at the University of Kragujevac. We have also planned a module for interconnection of the e-learning system with other education information systems.

INITIAL EDUCATIONAL RESULTS

The e-learning concept is mentioned as a very important cornerstone of education in all important declarations of the European Union. The main recommendation is the connection between concepts of e-Learning, web laboratories and permanent education and distant learning.

The main purpose of the development of this concept of the web laboratories and e-Learning environment is realization of the following goals:

- connection between e-learning and permanent education,
- realization of better incorporation of ICT in the Bologna concept of education,
- improvement of the quality of academic education,
- realization of the concept of 'virtual' mobility,
- extension of the concept of quality insurance and accreditation of e-learning concept,
- resource insurance, financial and technical support for e-learning,
- promotion of cooperation between universities in e-learning concept.

The presented web laboratory, with other parts of the integrated environment for education, became a part of the education process during of 2006 in the Faculties of Science and Mechanical Engineering. The web laboratory is presented to students from departments of Automatic Control and Industrial Engineering In order to have quantitative results we introduced pre and post testing for students. Students have multiple choice tests before and after the laboratory exercise. In the first year students have 7.33 average (6–10 scale, grade 10 excellent, 6 is the lowest passing grade) in pre testing and 7.96 in post testing (comparing to 7.40 average in same test last year, when web lab was not introduced).

Students using the web laboratory completed an online questionnaire in order to present their experience and evaluate benefits of the web laboratory; the results are presented in Table 1. The positive response from the student population was undivided; they highly valued the organization and character of the web laboratory. The students accepted this educational tool and responded with the main answer that the web laboratory fulfilled planned educational goals, and they completely understood what the laboratory experiments had been designed to do. The students also pointed out that the system is easy to use.

The students were also encouraged to give their opinions of the effects of implementation of the web laboratory. The results are presented in Table 2. It is important to emphasise that there was no negative reaction; an equally important conclusion is that the web experiments contribute to better

Table 1. Students' questionnaire—Character and organization of web laboratory (grades 1–5, where 5 is the highest grade-excellent, 3—good, 1—insufficient)

No	Question	Mark				
		1	2	3	4	5
1	Task is clear			17%	26%	57%
2	Educational goal is well presented			27%	25%	48%
3	Exercises are accompanied with appropriate theoretical content			25%	30%	45%
4	System is reliable		16%	18%	32%	34%
5	System is easy to use		5%	15%	28%	52%

Table 2. Students' questionnaire—Effects of implementation of web laboratory (grades 1–5, where 5 is the highest grade- excellent, 3—good, 1—insufficient)

Effects of implementation of web laboratory	Mark				
	1	2	3	4	5
System provides better training					
Multimedia character of course					
System makes laboratory exercises easier					
Decreases time of preparation for laboratory exercises					
Improves organization of course					
Improves character of lectures					
Stimulation for students					
Gives better information about course					

and higher quality understanding of the educational material.

These results encourage us to continue to develop the web laboratory and to interconnect our lab with similar labs (we plan to increase the number of experimental setups and to integrate web laboratory with other e-learning resources.

The implementation and usage of the web laboratory improved the education process in many different ways:

- Laboratory is accessible 24/7
- Physical presence of students is not mandatory
- Optimal utilization of resources
- Better preparation for experiment.

CONCLUSIONS

The developed web laboratory exercise offers help to students in learning materials, science concepts and procedures for control engineering. Considering the character of the planned laboratory exercises as well as other relevant experiences and solutions in development of the web laboratories, we defined requests for the software infrastructure of web laboratories.

Experimental installation, goals and possible educational tasks, experimental results and user interfaces presented could serve as an example for development of other web laboratory exercises. It is worth mentioning that the experimental setup is very cheap and based on the legacy equipment (the simulator consists of serial coupled electronic circuits, which could perform different transition functions), but in the new environment it presents a very useful educational tool for training and education in several courses at University of Kragujevac (Modeling and Identification, Control Engineering, Real-Time Programming).

A laboratory exercise has been included in the process of education so that some initial results of usage are presented. Results from the student questionnaires after they had performed the experiment showed that learning objectives were met and that the web laboratory can be effective as a learning enhancement and additional practical tool in a distance learning environment. Students valued both the character and organization of the web laboratory as well as the effects of its implementation.

Controlling real instrumentation has many advantages over virtual simulations. Students have visual feed-back and video streaming and real impression of an experiment. Practical experience on the real model is very useful for work in an industrial environment. Finally, students get comprehensive knowledge from many disciplines when they work with a real model (knowledge of hardware, software, communications, control engineering). Our results show that web-based experiments designed to be interactive are effective in distance education.

The expansion and development of information technology enables usage of new, high-quality education systems that are very different from traditional systems. In the concept of e-learning, web laboratories have an important place. They increase availability of laboratory equipment to students and decrease maintenance costs. However, these technology tools should be student-centered and pedagogically based.

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