

# Web-Based Laboratory for Engineering Education

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**ABSTRACT:** Laboratory experiments and practical work by their nature are unavoidable, important, and costly in the engineering education environment. The web laboratory is an educational tool for teaching students the basic principles and methodology in performing a series of experiments on different equipment at any time and from any location through the Internet. In this paper, pre-requests, architecture, and software realization of the Web Laboratory at University of Kragujevac are presented. Organization, development, goals, and possible demands of the laboratory exercise: The inverted pendulum/gantry crane controls (with the capability to test different control algorithms) are also discussed. The applications of the web lab have been tested with the students enrolled at University of Kragujevac and the initial educational results of the implementation of this laboratory exercise are presented. © 2009 Wiley Periodicals, Inc. *Comput Appl Eng Educ* 18: 526–536, 2010; View this article online at [wileyonlinelibrary.com](http://wileyonlinelibrary.com); DOI 10.1002/cae.20222

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## INTRODUCTION

The Internet provides a new environment for developing a variety of applications for educational and research purposes. From the educational perspective, it is an enabling technology for the Internet based engineering education and active learning. From the industrial perspective, it is a competitive service for remote measurement, supervision, diagnosis, and control. From the information and communication technology (ICT) perspective, it is a challenging application that pushes research into the web services and communication systems. Experimental work has a special role in the domains where high theoretical challenges and the need for the abstraction must be combined with the engineering applicability and the real-world needs. A university must give students a solid basic engineering education and not only train them for specific tasks. On the other hand, the practical experience provided to students through lab work, along the entire course, is necessary. During those exercises, students solve practical problems and gain experience and practical training

needed for their future career. Therefore, experimental work is necessity for engineering education.

The web enables more flexible delivery (anytime), distance education (anyplace), new visualization possibilities (interactivity), and cost reduction. In the engineering and control education, the Internet and web technology have an increasingly important role, especially in the concepts of distant learning. The Internet (web) has become a widespread tool for teaching and learning. In the engineering education and control education, the Internet and web technology have increasingly important roles, especially in the concepts of distant learning. This issue was a topic of a large number of research articles [1–5].

Virtual laboratories have a very important place in the concept of e-Learning. Generally, there are two different concepts of virtual laboratories: the first one with simulation and visualization in the concept of virtual reality, and the second one, which will be the subject of this article, based on the remote control (usually using the Internet) with laboratory experiments. Development of the web-based virtual laboratories enables users to access laboratory equipment and to perform experimental tasks on specific equipment at any time and from any place. Many universities have developed, or are developing, these laboratories

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for control, electronics, production, engineering, and other scientific fields. At many universities, remote web controlled laboratories: (a) ensure full accessibility to expensive laboratory equipment, (b) reduce costs, and (c) make time savings and individual usage of the laboratory equipment. The computer-aided experimentation has a long and venerable history in many scientific areas, particularly in physics and astronomy [6]. A large number of very well known universities, starting with MIT (the microelectronics web lab), Chalmers University of Technology in Sweden, Chemical Engineering Department at Cambridge University, University of Illinois (Integrated Remote Laboratory Environment (IRLE)), University of Siena ACT [3], and Oregon State University [4] (as well as many others [7]) have their own web laboratories. In some of their solutions, the remote experiments are controlled by changing appropriate parameters, and in other solutions, the existence of the control program that changes the dynamic of the system with the feedback is preferred.

The web laboratory of University of Kragujevac (WLUK) [www.weblab.kg.ac.yu; www.cqm.co.yu/weblab] was established at University of Kragujevac in order to use the laboratory resources more effectively and to improve cooperation among departments, faculties, and universities. The main goals are to develop a network of laboratory resources for the authorized group of users for research, academic and college education, as well as for permanent learning. At this moment, WLUK is using some of the existing laboratory equipment in web experiments (several projects for development of the web-based laboratory installation with an appropriate e-Learning content is planned for financing, or have been submitted for evaluation). The concept of the web laboratories should ensure more efficient exploitation of the laboratory equipment. Students will also have an opportunity to perform their laboratory exercises from any place and at any time. Finally, the concept of the web laboratories should ensure a better quality education process and should help achieve better educational results. The Internet mediated laboratory environment allows students to access the laboratory at any time and from anyplace. While one student works on the connected control apparatus, others can observe this process over the Internet/Intranet. This way of learning also offers an interesting economic potential in certain industrial applications, especially for fault telediagnosis, telemonitoring, and tele-maintenance of equipment, telecontrol of processes, and robotics. In the direct interaction with the devices at the remote location, a large student community can access these experiments. High-cost instruments are shared by many users, emphasizing a more dynamical educational environment. Using this type of distance learning, the total cost for education is reduced. Also, teachers can assign laboratory exercises as homework.

In this article, we will present the educational requests, demands, architecture, advantages, and limitations of a web-based experimental environment using the example of one web-based experiment that is functioning at WLUK (the inverted pendulum and crane). A web portal, for the laboratory and directions of further development, is also described. In this laboratory exercise, students could develop an algorithm of the measurement signal processing, set periods of sample, and control the algorithm. So, the support is enabled for the fields of modeling and identification, signal processing, real-time programming, and design of the control algorithms. Finally, we will present some initial educational results in the implementation of a web lab in the educational process at Faculty of Mechanical Engineering, Kragujevac.

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

Considering other relevant experiences and solutions in the development of the web laboratories [3,4,6,8–10], as well as the character of the planned laboratory exercises, the team which started the development and the implementation of the web laboratory at University of Kragujevac defined the following requests for the software infrastructure of WLUK:

- Easy understanding of the educational tasks and user-friendly interfaces for the laboratory exercises.
- Adjustment of the teaching material in relation to the new context.
- On-line presentation of the experiment.
- Appropriate software platform and the appropriate security measures.
- Client software has to operate on all the available software and hardware platforms.
- Environment for an easy definition of the control algorithms and the control signals.
- Laboratory exercises and all the results should be stored in a database.
- Download of the experimental results.
- Management of the changes and distribution of new versions.
- Modular and open structure so that a new component and the laboratory experiments could be added easily,
- Reasonable security of the system.

In order to achieve the listed demands, we have selected the appropriate software architecture. The software architecture consists of two major parts: the first part that controls the physical processes (server—control server) and the second part that controls the user interface and defines the user access (also manages with other functions and parts of the e-Learning environment) oriented towards the user service (the web server) (Fig. 1).

The software solution is a multi-user, client-server architecture developed in the Visual Studio 2003, NET1.1 environment. The control server is developed using the programming language C#. Using C#, we control the system for the data acquisition using the DAQmx software libraries for the program approach to the data acquisition system. The software module—the software interface, for the implementation of the control algorithm and the communication with the web server, is located on the local control server. The system for data acquisition and the D/A converter is connected with this server.

The client side is based on the dynamic pages generated from PHP or ASPX (the reason for this duality is the fact that the telemetric exercises are hosted on the IIS server using ASPX (Faculty of Science), and the laboratory exercises in the field of the automatic control are hosted on the Apache server using PHP (Faculty of Mechanical Engineering). All information about the experiments, user access, and other relevant information connected with the e-Learning environment are stored in the MySQL data base.

The last server is the video server. The video server supports broad streaming of the video signal. This server has a task to establish a visual “feedback” and to create a real impression of an experiment to the potential users of the web laboratory.

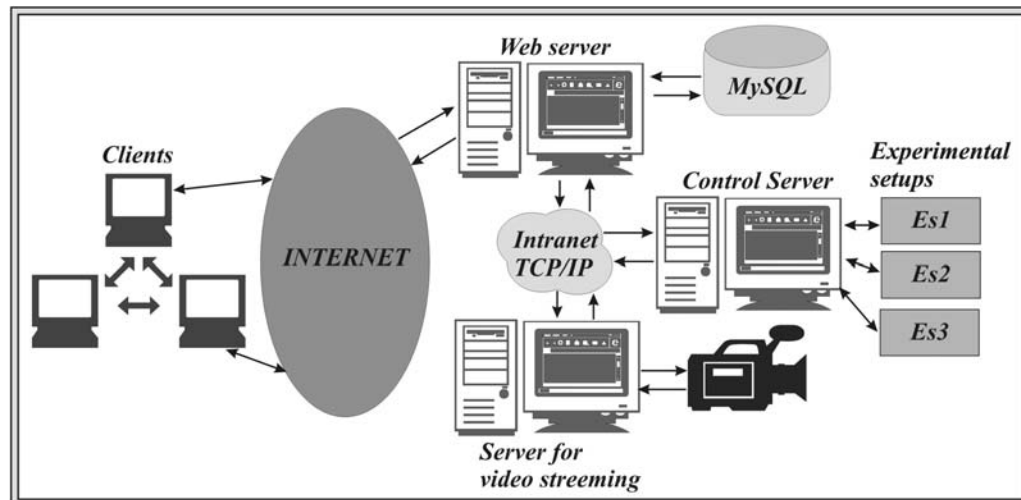


Figure 1 Architecture of the system.

The web lab is an important part of the integrated e-Learning environment. Generally, the negative aspects of e-Learning are: lack of a face to face (direct) contact with the lecturer (or the laboratory equipment), alienation (students perform exercises on their own with no interaction with their colleagues), and insufficient practical work. The web lab has an important role in this concept to provide a platform for the practical laboratory exercises in an e-Learning environment. In the web lab concept, students could have a lack of experience in the formal preparation of the laboratory equipment for experiments. Using a web laboratory, students have a web-based GUI with a visual feedback instead of a real equipment in front of them.

#### WEB LABORATORY—UNIVERSITY OF KRAGUJEVAC—AN EXAMPLE OF A LABORATORY SET-UP

The web laboratory of University of Kragujevac has five experiments (TM1, measurement of the electrical signal velocity through the coaxial cable; TM2, measurement of the diode electrical characteristics; TM3, measurement of the transistor electrical characteristics; TM4, experiment with the step plane; TM5, interactive experiments with the linear systems) in the field of telemetry, and three experiments (LV1, electric simulator of the typical physical processes; LV2, gantry crane; LV3, coupled water tanks experimental set-up) in the field of automatic control [11,12].

We will present a laboratory exercise of the inverted pendulum and crane. The user interface and server side of the application are presented in Figures 2 and 3. From the web portal of WLUK, a user may perform the general operations, such as: reading help files, contacting lab people, sending comments, and viewing the set of processes available for the remote control; and the advanced operations such as: using LMS and taking web-based tests. The security of the web lab is based on the authorization based upon a user's credential (login and password). All information is stored in the MySQL data base. Besides information about the session (session ID), the IP number is stored in DB to ensure the tracking and security of all potential users of the system (it enables a scenario that only a computer with the IP from the university could use the web lab).

The experimental installation of the inverted pendulum and crane is a popular laboratory model that is used for the demonstration of the convention and the advanced control concepts, based on the linear and non-linear control algorithms (Fig. 4). It is a very useful laboratory set-up for education, but it is also very useful for testing different control skills, as well as the implementation of software tools for the measurement and control. The exercise will be predominantly used as the laboratory model of crane. The technical specifications are clear: the weight should be moved (removable weight) from the point A to point B, as fast as possible with the minimal oscillation of the weight. The oscillation of the weight is unavoidable and appears as a result of the acceleration during the movement, and it is clear that it is an unwanted side-effect (safety reasons, functionality, unwanted wearing caused by the vibration).

The experimental set-up is presented in Figure 5, and it is a part of the equipment in the web laboratory of University of Kragujevac. The set-up consists of a laboratory model of the inverted pendulum and crane, AD/DA interface web camera and a PC computer.

The following options are enabled:

1. Selection of the sampling period (default value is  $T = 0.05$  s, but this value could be set differently) (Fig. 6).
2. Selection of the duration of the experiment (default value is  $t = 10$  s, maximally up to 60 s) (Fig. 6).
3. Selection of the option for the control variable (in each sampling period voltage is set on the D/A converter in the range of 0–5 V, that is, in the range of  $-2.5$  to  $2.5$  V towards the laboratory model, that is, voltage of  $-12.5$  to  $12.5$  V in the winding of the motor).

The following options are enabled:

- a. Definition of the user-defined control sequence  $u(kT)$ ,  $k = 0, 1, 2, \dots, 0 \leq kT \leq t$ .
- b. Definition of the control sequence according to the P control algorithm. The feedback is closed by the position of the wagon  $x$  for the realization of the position servomechanism (the goal of the control: the fact and the punctual positioning of the system

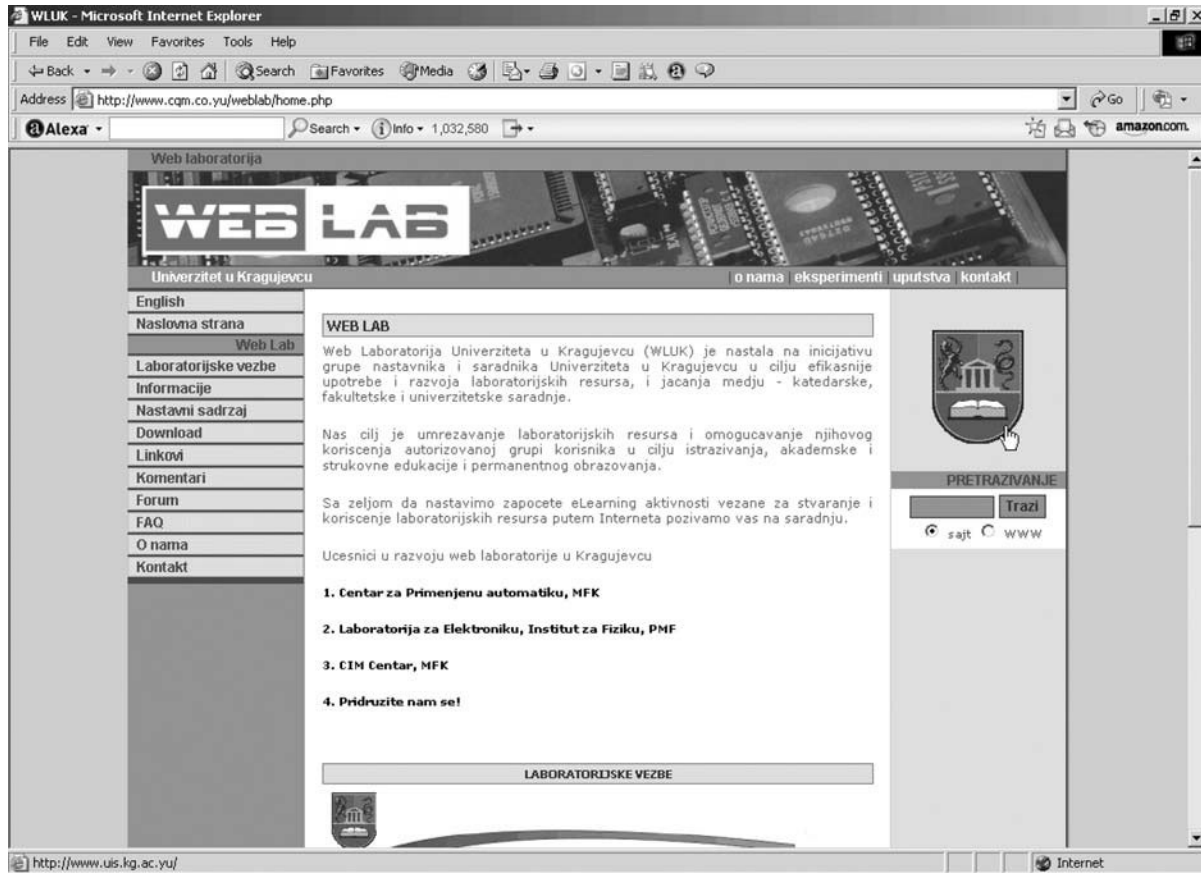


Figure 2 GUI of web lab.

- with the minimum swinging of the weight). The allowed selections: (1) defined values for the position of the wagon (default value is  $x_z = 60$  cm, but this value could be changed in the range of 0–120 cm) and (2) value of  $K$  (default value is  $K = 1$  and could be changed).
- c. Definition of the control sequence according to the self-defined control algorithm. It is allowed to upload the software routine for the realization of any control algorithm.
  4. Start and stop of the experiment and the indication of the status of the laboratory set-up are available. The user of the experiment has up to 5 min of the continual access to the experimental aperture. During those 5 min, the user could perform more than one experimental probe. The potential user should be registered in order to use the laboratory set-up.
  5. Experiment is monitored by a web camera. This service has a task to establish a visual “feedback” and to create the real impression of the experiment to potential users of the web laboratory.
  6. After the experiment is performed or after the defined time of the experiment  $t$ , a user could observe the experimental results in two modes: (1) the diagrams of the change of the relevant variables during the time and (2) available file with the tables and numerical presentation of the results

with the following variables: time  $t$ , current in the motor  $i$ , position of the wagon  $x$ , velocity of the wagon, angular position of pendulum  $\varphi$ , angular velocity of pendulum, control variable  $u$  (voltage of the motor). (Fig. 7: Graphical results—position of the wagon)

7. End of the experiment—it is activated by the button “End” or by the end of the selected duration of the experiment. The end of the experiment starts the control procedure that turns wagon into the initial position  $x_0 = 0$  cm.

After selecting a laboratory experiment, one can view a page describing the physical system and mathematical model. Besides, all experiments in the web laboratory can be controlled according to two modes: pre- or user-defined. In the first case, the default values are already set, and in the second case, students assign the values of the typical parameters.

#### GOALS AND POSSIBLE DEMANDS OF THE LABORATORY EXERCISE

The experimental set-up is actually a computer-supported system with a feedback that could be used for better understanding of the abstract theory of signals and systems during the teaching process. This system could also be useful in: (a) developing some students’ skills in the field of design of mechatronics systems, (b) implementation of different control techniques, (c) real-time



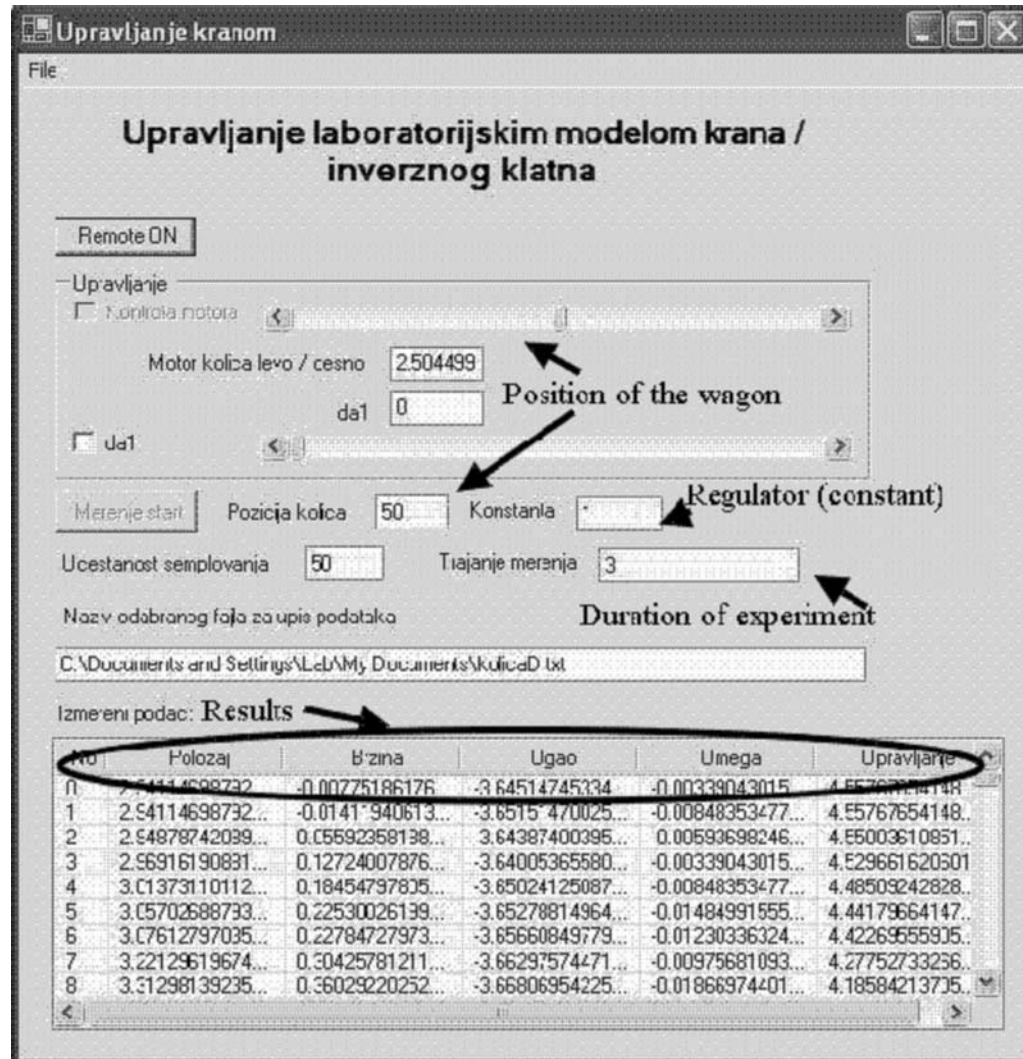


Figure 3 Server part of application.

programming, and (d) using different functional elements, sensors, computer hardware and software.

The experiment is used for the control of the crane/inverted pendulum in order to illustrate:

- Techniques of the development of the dynamic model (especially in the state space),
- control techniques, such as the cascade control, using the feedback according to the state and techniques for adjustment of poles, and
- theoretical basis of the non-linear systems, such as the continuous circles and descriptive functions.

So this experimental set-up has a capacity to cover a wider theory in a number of the linked courses, which deal with the analysis of the dynamic systems and control in order to:

- Illustrate general theoretical ideas and concept of the signals and systems,
- consider technical specifications of the elements and systems, and the integration of the functional architectures,

- perform measurement using a computer, with the procedure of calibration, and identification of the characteristics of used measuring converter,
- use different software tools for measurement, control, and analysis of the results,
- identify the static characteristics, dynamic responses on the different input signals, verification of the different mathematical and simulation models for the specific elements and the whole system, as well as the illustration of the dynamic and static properties of the dynamic systems,
- use the process and a PC computer in the measurement and control systems, and achieve the improvement of skills of the real-time programming,
- demonstrate strengths of the automatic control comparing with the manual control, and the implementation of different control techniques, and adjustment of regulators, and
- test different forms of the control algorithms, system identification, theoretical concepts for analysis, and evaluation of the quality of the behavior of system.

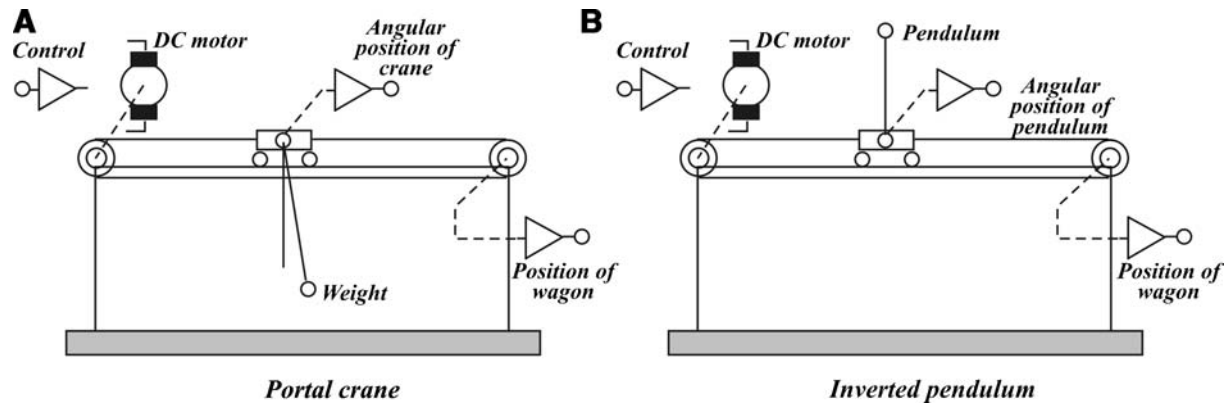


Figure 4 General schemas of the standard laboratory models.

The general education task in the presented experimental set-up could be defined as:

1. Identify static and dynamical characteristics of the system and/or their functional elements.
2. Implement and test adequate control algorithm according to the set technical requirements design, compare different control algorithms or different methods of adjustment of

- the same control algorithm, suggest a specification of the rational technical demands according to the functionality of the systems, perform an analysis of the comparable simulation and experimental results and make a conclusion how experimental simulation confirms the theoretical consideration. If a deviation exists, explain the reasons.
3. Develop the software support for control and monitoring.

We could suggest the following assignments for students:

**A**



**B**

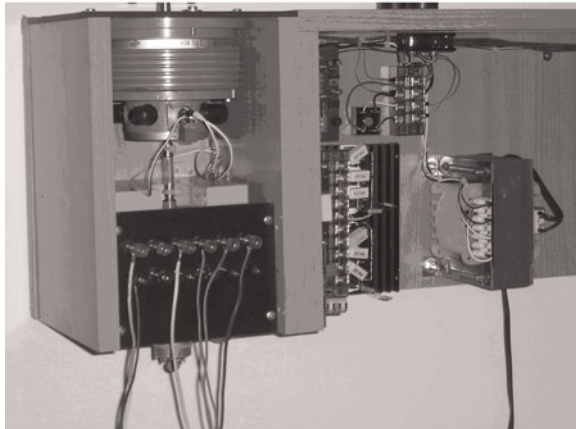


Figure 5 Experimental set-up.

1. The goal is the realization of positioning the servosystems with as much as possible precision positioning of the wagon with the pendulum, but in the shortest time with the minimal oscillation of the pendulum. The measurement of success is the preciseness of the positioning, time, and integral of the absolute value of deflection of the pendulum (angle  $\varphi$  in Fig. 4).
2. Software implementation of the concept of the manual control: (a) starting an experiment (the set of the referential position of the wagon), time starts, user controls with a joystick or keyboard (left or right, and increase or decrease of the intensity of the input voltage of the motor) and (b) pressing "Enter" and the key experiment stops. Relevant signals are saved in a computer, which is also a part of the software solution.
3. Design and implement the control algorithm (e.g., the PID control) for the system with the feedback (design of the position servo system) and compare the results with the results of the manual control.

The expected results will present to students the obvious advantages of the automatic control. For educational purposes, it is possible to divide students in two groups (after appropriate theoretical presentations and exercises with the simulation tools such as Mat Lab) that could compete and research dynamic characteristics of the controlled objects and, on that basis, develop their own control algorithms.

The details of the specific task for students (with the detailed procedure of the experiment performance and precise presentation of the results) will be a result of the specific education goals as a part of the specific curriculum. Professors have an opportunity to give a definition of the laboratory tasks to their students using the web laboratory portal [www.weblab.kg.ac.yu](http://www.weblab.kg.ac.yu) (mirror [www.cqm.co.yu/weblab](http://www.cqm.co.yu/weblab)). Anyhow, a student's report should consist of:

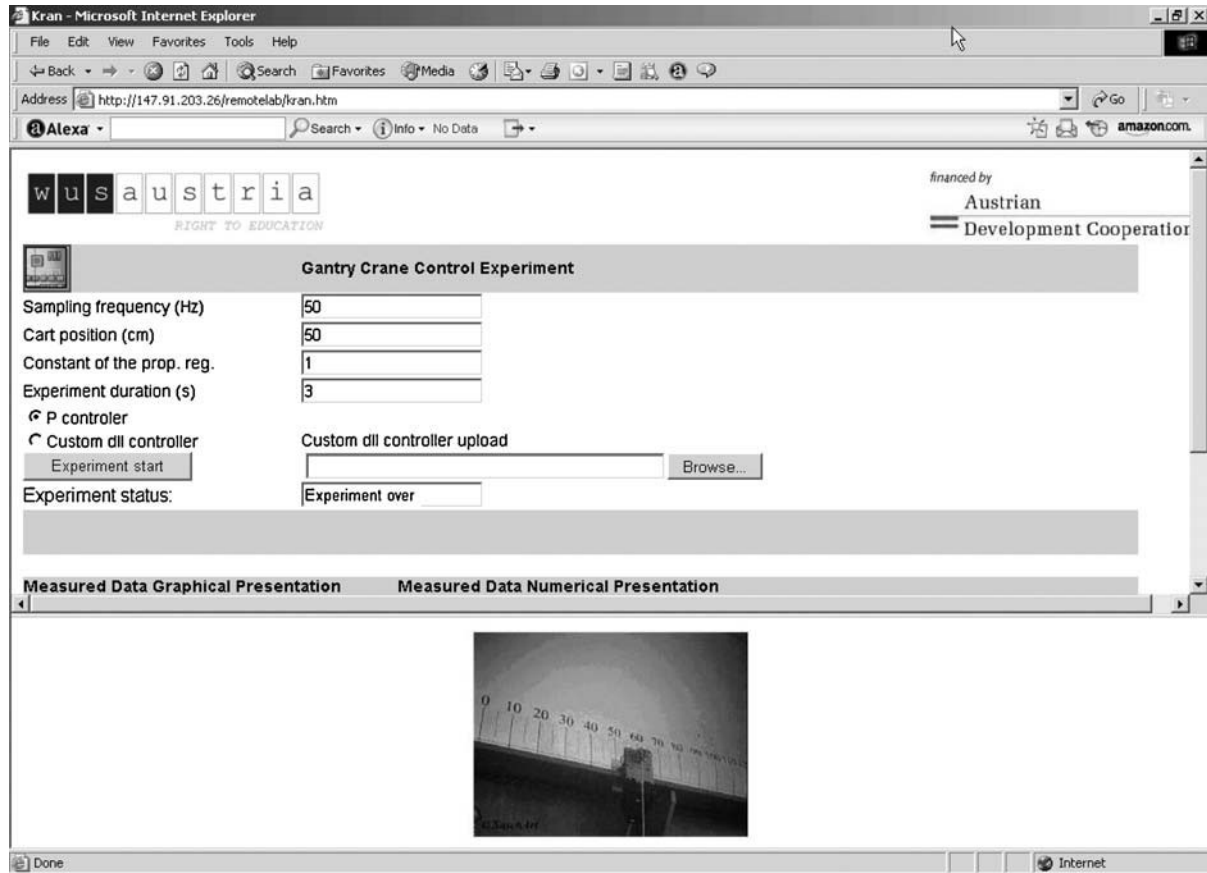


Figure 6 Client side of the application for the inverted pendulum and crane set-up.

- Short abstract about the experiment,
- all drawings and the experimental data,
- answers to all questions about the experimental procedure and result analysis,
- answers to the fundamental theoretical issues, connected to the theory which supports the experiment, and
- short conclusion based on the simulation and the experimental results.

Students also have to use the Internet based testing system developed as a part of WLUK in order to enable educators and trainers to author, schedule, deliver, and report on surveys, quizzes, tests, and exams. This system is used for testing students before and after an experiment. The presented experimental set-up should be used step by step: first, students should control the crane, and then, they could use the options with the inverted pendulum. For example, we will present the experimental procedure for both cases.

The first used concept of control is the usage of the feedback according to the state, so the vector of the states is  $x = [x \dot{x} L \phi]^T$ , in the feedback realized amplification vector is  $K = k_1, k_2, k_3, k_4$ , and the developed component of control is a  $v = -Kx$  using the feedback according to the state. It is necessary to correctly adjust the amplification factors  $k_1, k_2, k_3$ , and  $k_4$ .

In an experimental procedure of the control of the crane, the following steps could be suggested:

- Identification procedure in order to verify a mathematical model of the plant in a wider sense. Record appropriate static characteristics, define constants of the model, and estimate the friction force according to the velocity of the wagon.
- Design position servo by setting  $k_1 = 0.45, k_3 = k_4 = 0$  and change  $k_2$  in order to get the critically damped response of the wagon (movement of the pendulum could be ignored). Previously calculate and confirm by simulation the appropriate values for  $k_1$  (suggested value  $k_1 = 0.45$  is wide) and  $k_2$ . Present the representative output on the ramp input.
- For previously selected values for  $k_1$  and  $k_2$ , continue the experimental procedure increasing  $k_3$  from zero value and monitor the responses. Spend about 5 min in the variation of  $k_3$  and  $k_4$  in order to minimize the oscillation of the pendulum. Record the best result and compare it with the theoretical presentation of distribution of poles using software Mat Lab. Discuss the transition process according to the position of the poles.
- Using the method of adjustment of the poles, select the magnification of the feedback according to the state in order to achieve that all poles in the system, with the closed feedback, have the value  $\omega_1$ . Record the response and connect it with the theoretically obtained distribution of the poles using the software Mat Lab.

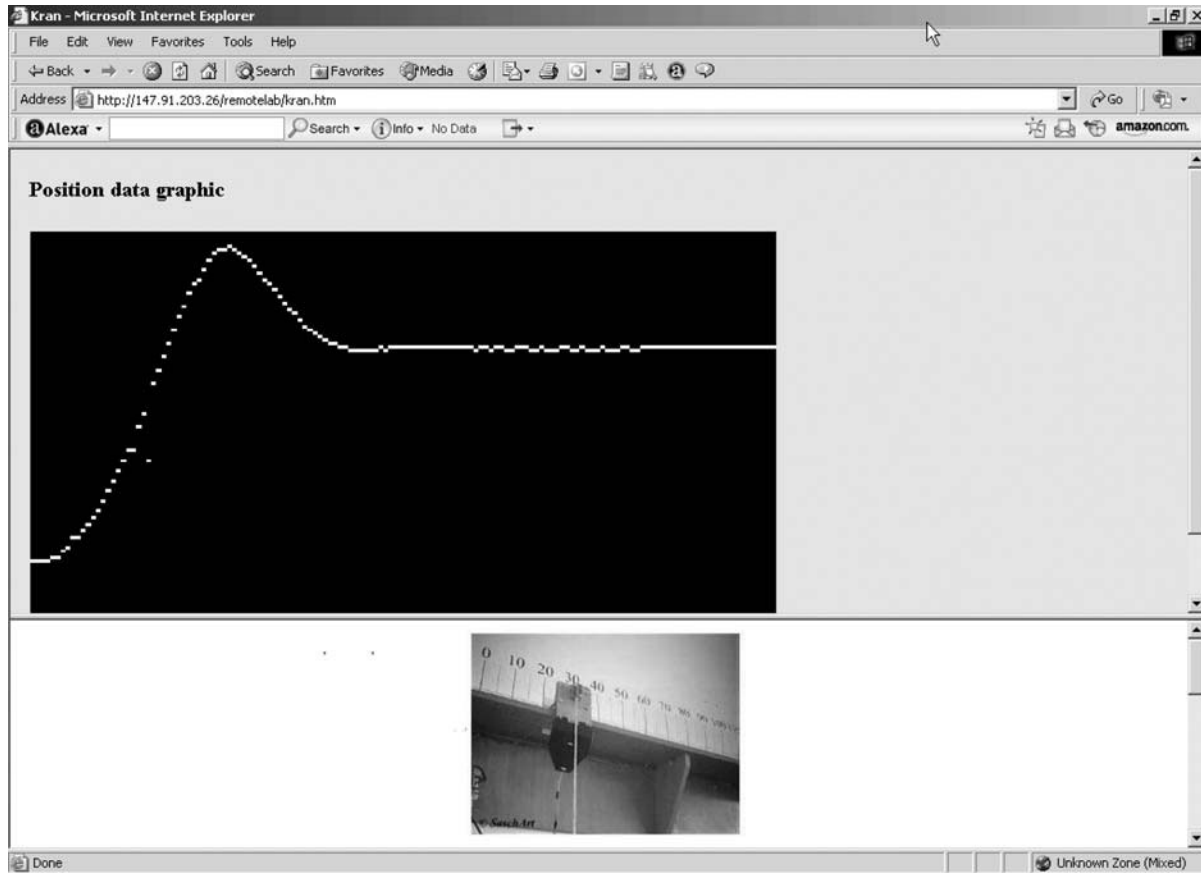


Figure 7 Graphical results—position of the wagon.

- Continue with the experimental procedure by increasing the speed of the response by selection of the four poles of the system with the closed feedback  $-\alpha$ ,  $-\beta$ ,  $-\omega \pm j\omega$ . Each student selects the appropriate values  $\alpha$ ,  $\beta$ , and  $\omega$  for himself/herself, and performs the method of adjustment of poles, implements the algorithm for the feedback according to the state and records the response and makes the appropriate discussion.
- For the previously obtained results, students continue with the experiment by the variation of  $k_2$  until unstable behavior of the system. Record the response of the system which starts to oscillate in the border of stability and compare the specific  $k_2$  and the resonant frequency (experimental values) with the values obtained using the linear model. Students could use any stability test in their calculation (e.g., Routh Hurwitzov, which is very appropriate for this case or any other).

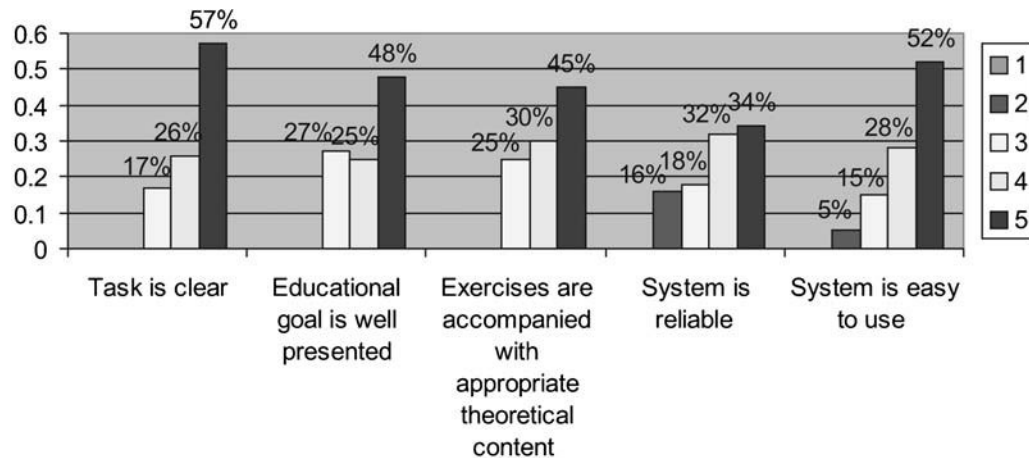
On the other hand, in the experimental procedure for the control of the inverted pendulum, the following steps could be suggested:

- Placement of the pendulum near the unstable state could be simply avoided, if we want to directly use the control algorithm which is derived based on the liner mathematical model. The wagon should be placed in the middle of the path, and the pendulum should be

lifted in the vertical position. In the same time, the experiment should be activated and the pendulum released.

- Set a  $k_1 = k_2 = 0$ , and select  $k_3$  and  $k_4$  in order to stabilize the dynamics of the pendulum (e.g.,  $k_3 = 0.5$ ,  $k_4 = 0.2$ ). The pendulum should be kept in the vertical position and the wagon should stay in the stationary condition. In order to put a slight pressure on the pendulum (by hand), the wagon starts to move. But if we replace the pendulum from that influence, the wagon will aggressively move in order to get into the stabilization position of the pendulum. Students should be able to discuss and explain this behavior of the system.
- By the method of adjustment of the poles  $k_i$  should be calculated in order to set all poles in the system with the feedback on  $-\omega_1$  value. The response of the system should be recorded.
- If students implement the previous task with the exception  $k_3 = k_4 = 0$ , what will happen?
- Illustration of the border circles. Using the method of the pole adjustment, students should select  $k_i$  to produce the stable response. Then, they should decrease  $k_i$  until the oscillation with the considerable amplitude appears. The response should be recorded. Then, they need to increase  $k_i$  until the system becomes almost unstable. The response of the system on a very small input should be recorded. The obtained results should be compared with the theoretical





**Figure 8** Students' questionnaire---Character and organization of the web laboratory (Mark 1-5; 5 the highest grade).

results of the frequencies and amplitudes of the border circles of the calculated function.

The obtained results should be analyzed very carefully. The positions of the poles of the linear model and the experimental responses of the systems should be compared. Generally, the experimental and simulation results should be compared with appropriate comments and discussions.

### INITIAL EDUCATIONAL RESULTS

The e-Learning concept is mentioned as a very important corner stone in education in all important communiqués and declarations of European Union [12]. The main recommendation is the connection among the concepts of e-Learning, web laboratories, permanent education, and distant learning.

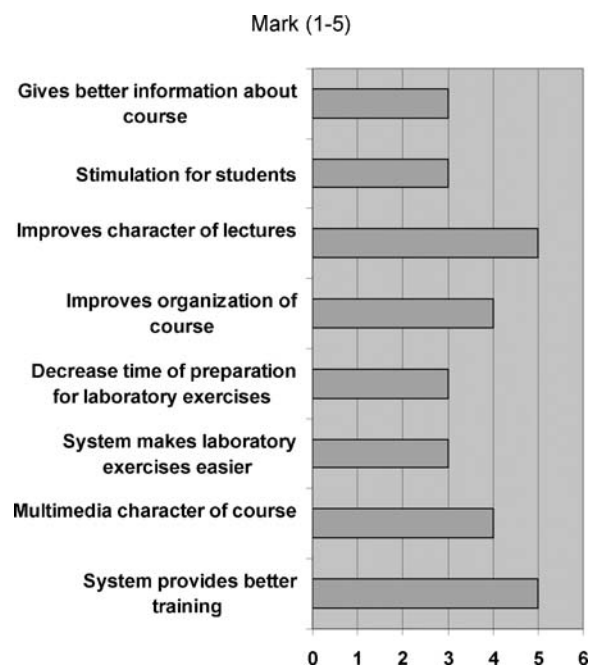
The presented web laboratory, with other parts of the integrated environment for education, became a part of the education process during 2006 at Faculty of Science and Faculty of Mechanical Engineering. The web laboratory is presented to students from the departments of Automatic Control and Industrial Engineering from Faculty of Mechanical Engineering. Students used the web laboratory during the educational process and filled on-line questionnaires in order to present their experience and evaluate benefits from the web laboratory (the results are presented in Fig. 8). The positive response from the student population was undivided; they highly evaluated organization and character of the web laboratory. The students accepted this educational tool and responded with the response that the web laboratory fulfilled planned educational goals, and that they completely understood the laboratory experiments' goals and tasks of exercises. The students also pointed that the system is user-friendly and easy to use.

Students' questionnaire---character and organization of the web laboratory (Mark 1–5; 5 the highest grade).

The students were also encouraged to give their conclusions about the effects of the implementation of the web laboratory. The results are gathered, grouped, and presented in Figure 9. It is important to emphasize that there was no negative reaction. A more important conclusion is that the web experiment contributes to better understanding of the educational materials.

Other similar researches have similar results. For example, Universities Australia concluded: "Virtual experiences are valued for their flexibility of use, availability for revision, and provision of additional information, whereas real experiences are valued for the hands-on, 3D nature but also for their 'reality'" [13].

This approach to education was accepted and highly evaluated by students (results are presented in Table I). Compared to the findings of Austria University and Oregon Institute of Technology, the Serbian students satisfaction was found to be better, but this is a result of the perceived higher motivation of the Serbian students because they usually do not work with modern on-line educational resources, so the students highly evaluated the initial steps in that direction.



**Figure 9** Students' questionnaire---effects of implementation of the web laboratory.

**Table I** Indicators of Usage of Integrated Environment for e-Learning

Title	Number of access to WLUK	Average mark of users' satisfaction WLUK (1–5)	Average mark of users' satisfaction Austria [14]	Electronics Engineering Technology Oregon Institute of Technology [4]
Web laboratory	873	4.07	2.99	3.00
On-line testing	4,318	3.85	—	—
On-line material	—	3.31	3.03	—
Virtual seminar	—	—	3.07	—

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

## CONCLUSION

The expansion and development of information technology enables usage of new, highly quality education systems much different than the traditional systems. In the concept of e-Learning, virtual laboratories have an important place. These virtual laboratories increase availability of the laboratory equipment for students and decrease maintenance costs.

This article describes some education advantages, organization, realization, and educational effects of one laboratory exercise in the web laboratory of University of Kragujevac. It is interesting to mention that the experimental set-up is very cheap and based on the legacy equipment, but in the new environment it presents a very useful education tool for training and education in several courses at University of Kragujevac (modeling and identification, control engineering, and real-time programming). The web lab allows students to operate real processes without being physically present in the lab. There are few interesting features in WLUK: control server is self-developed solution and users can design their own controllers by developing appropriate dll file. During the laboratory experiments, students are also stimulated to design the best possible controller.

The following goals could be achieved in the field of engineering education (control engineering) using web laboratories:

1. Development of the basis for lifetime learning so that new control problems could be tested.
2. Establishment and maintenance of the high standards of excellence for the experience of learning the foundations of control.

The implementation and usage of the web laboratory improved some aspects of the engineering education in different ways:

- Laboratory is accessible 24/7. A student's time is personalized, for example, students may freely plan their experiments. The analysis of the access information of the web lab shows that students have an access to the web lab at any time, a maximum between 10:00–10:59 and 10.2% of the total visits, and a minimum between 06:00–06:59 and 0.2% of the total visits to the web lab.
- Physical presence of students is not mandatory in the laboratory building. This is very important because enables

a concept of distant learning and enables permanent education of people who are dislocated from university and educational centers. Almost 1/4 of accesses to the web laboratory were made out of the region of Kragujevac, where the university is located.

- Better utilization of resources. Increasing availability of the laboratory equipment and full access to the laboratory no matter of the location leads to better utilization of the laboratory resources. The analysis of the accesses to the web lab shows that 38% of the accesses were made from the academic network and 62% of the accesses were made from the outside access nodes. This rationalization in the utilization of the laboratory resources leads to lower expenses.
- Better preparation for an experiment. The access to the laboratory equipment and theoretical content, as well as the previous experiments, offer better preparation of students for the experiment. Student could individually try and repeat experiments as many times as they need to prepare. According to the analysis of the access information, we determined that each student performs a specific experiment 5.8 times in order to improve his/her knowledge or to check his/her results.
- Web lab is important for the concept of permanent education for all employed and unemployed persons. People with special needs could use resources of the web lab and have the same opportunities as all others. Distant learning and the web lab makes them equal in the educational process.
- Initial results of the implementation and usage of the web laboratories show an improved motivation of students and indicated possible improvements of the organization and the quality of laboratory exercises in the engineering education (Figs. 8 and 9, Table I). The analysis of students' feedback shows that students evaluate this approach in the engineering education. The feedback from users has been quite positive, and the convenience and ease of use of the system have been universally appreciated.

One great advantage of this web lab is a fact that this lab is a part of the integrated e-Learning environment. Students have the theoretical content, practical work in the web lab, and an opportunity for self-evaluation using the *e*-tests. Everything mentioned above emphasizes the importance of the dynamic e-Learning environment and a high potential of the web laboratories.

Nevertheless, the Internet mediated experimentation does have some drawbacks, such as the following: (1) no direct physical contact with the experiment, (2) unpredictability and instability of the transmissions, and (3) a need for a change in the teacher and student mentalities.

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