REMOTE CONTROLLED LABORATORY EXPERIMENTS ON THE WEB

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The purpose of this paper is to present organization and development of web laboratory exercises in Web Laboratory, University of Kragujevac. WebLab provides remote access to real laboratory equipment using contemporary computer and network technology for creating the environment that will enable the remote user to perform the required laboratory exercises and control the laboratory equipment. This paper presents pre-requests, architecture and software realization of web based laboratory. Using feedback from survey we will present framework for web laboratory and web lab experiment in order to incorporate practical work and laboratory exercises in integrated e-learning environment. Realizations of two laboratory experiments developed using different platforms are presented, compared and contrasted. Finally some educational results of usage of web laboratory in industrial engineering education are presented.

1. INTRODUCTION

The Internet (Web) has become a widespread tool for teaching and learning. The Web enables more flexible delivery (anytime), distance education (anyplace), new visualization possibilities (interactivity), and cost reduction. In industrial engineering education the Internet and web technology have increasingly important role, specially in concepts of distant learning and web based, remotely controlled experiments. This issue was a topic of a large number of researches and papers Ko et al. (2001), Albu et al. (2003), Colace et al. (2004), Book et al. (2004), Casini et al. (2004), Guran-Postlethwaite et al. (2005), Yu et al. (2004), Šafaric et al. (2005), Barrero et al. (2008). Development of web based laboratories enable users to access laboratory equipment and perform experimental tasks on specific aperture at any time from any place.

The main disadvantage of distance and e-learning approaches is absence of practical work. Multimedia animations or simulations cannot bridge this gap. The only possible solution to ensure practical work as a part of concept of distance learning is implementation of web laboratories that consists of remotely controlled experiments with video feed-back.

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 (Casini et al. (2004)) and Oregon State University (Guran-Postlethwaite et al. (2005)) (as well as many others) have their own web laboratories. In some of their solutions, remote experiment are controlled by changing of appropriate parameters, and some other prefer solution with existence of control program that change dynamic of system with feedback.

The web laboratory of University of Kragujevac (WLUK) (http://weblab.kg.ac.yu mirror http://www.cqm.co.yu/weblab) was established at the initiative of group of professors and associates of University of Kragujevac in order to use laboratory resources more effectively and to improve cooperation between departments, faculties and universities. The main goals is a development of a network of laboratory resources for usage of authorized group of users for research, academic and college education, as well as permanent learning. The concept of web laboratories should ensure more efficient exploitation of laboratory equipment. Students also will have opportunity to perform their laboratory exercises from any place and at any time. Finally, the concept of web laboratories should ensure better and more quality education process and should help achieve better educational results.

The Internet web laboratory should be integrated with other forms of e-Learning and other educational services. A wide selection of educational materials could be placed on web pages and connected with the experimental task. The educational materials are sharable, available and organized using appropriate eLMS (e-Learning Management Systems). One of the main ideas is development of integrated, rich e-Learning environment. Exploitation of any particular experimental set up in different fields using e-Learning platform will improve education, and make university and permanent education more coherent, more complete and more convenient.

The underlying fundamental promise of Internet-based laboratory approaches lies in students' abilities to connect to a computer controlled laboratory set-up of interest at anytime from anywhere, thus sharing existing limited resources in a more efficient manner than is possible with the traditional on-site laboratory approach Gallardo at al. (2007). Remote web-based laboratories may also allow researchers in different locations to carry out researcher and design work co-operatively and remotely at the same time.

The Integration of the Internet into education is most commonly achieved through the following methodologies:
- Developing a course LMS to centrally house various online functions and facilities course management,
- Developing a web-based laboratory that enables students to set up parameters and undertake experiments from remote location.

This paper will present pre-requests, architecture and software realization of web based laboratory. Using feedback from survey we will present framework for web laboratory and web lab experiment in order to incorporate practical work and laboratory exercises in integrated e-learning environment. Realizations of two laboratory experiments developed using different platforms are presented, compared and contrasted. Finally some educational results of usage of web laboratory in engineering education are presented.

2. PRE-REQUESTS AND ARCHITECTURE OF WEB BASED LABORATORY

Considering other relevant experiences and solutions in development of the web laboratories, Casini et al. (2004), Guran-Postlethwaite et al. (2005), Forinash al. (2005), as well as the character of the planned laboratory exercises, the following requests (during the implementation and validation some additional requests emerged and they are incorporated in this list) for the software infrastructure of WLUK was defined:
1. Requests for web laboratory:

        a. Easy understanding and usage,
        b. Incorporation of traditional didactic materials in new context,
        c. On-line supervision and monitoring of laboratory environment,
        d. Flexible control algorithm,
        e. Flexible and reliable maintenance system and changes,
        f. Open and modular architecture,
        g. Adaptability of physical system, and
        h. Existence of parameters for quality of services.
2. Requests for web lab client:
        a. Multy-platform client software,
        b. Management of changes and distribution of new versions,
        c. Easy installation of client software,
        d. Security of client-side application, and
        e. Free client software.
3. Requests for experiment:
        a. Easy access to library of examples,
        b. Laboratory exercises and all results should be stored in a database,
        c. Storage of experimental data, and
        d. Download of experimental data.

All requests are separated in three categories: requests connected to the web laboratory (software for control server, equipment and procedures), requests connected to the client module software and demands connected to the experiment in narrow sense.

Requests connected to the web laboratory demand that laboratory experiment should be stand alone, intuitive for usage, and equipped with all introduction and explanation material. Control of laboratory equipment must possess certain quality and safety level with indicative parameters that depict the level of service (speed of response of the system etc.). Software and control server, that control experiment must be flexible, modular, and easy to monitor and maintenance.

One of the requests connected to the client side of the system is hardware / software independency. Other demands are easy installation and safety issues on the client side. Classical web browser fulfills much of these demands.

The last group of demands is connected with the experiment in narrow sense and results of experiments. It is necessary to ensure storage of experimental results, and specific example, and download of experimental results for each particular user of the systems. Personal download ensures development of technical reports, and storage of experimental results enables students and teachers to compare different experimental results and develop data base of realized experiments. In addition, some specific control algorithms should be stored in the data base along with parameters that depict specific conditions of the system. Of course, beside these requests listed above, a number of other requests could be included for different conditions and implementation of web laboratories. Listed demands, at least, describe situation of experimentation in engineering education.

In order to achieve listed demands, we selected appropriate software architecture. The software architecture 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 1).

The control server is developed using programming language C#. 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 the fact 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 e-Learning environment are stored in MySQL data base.
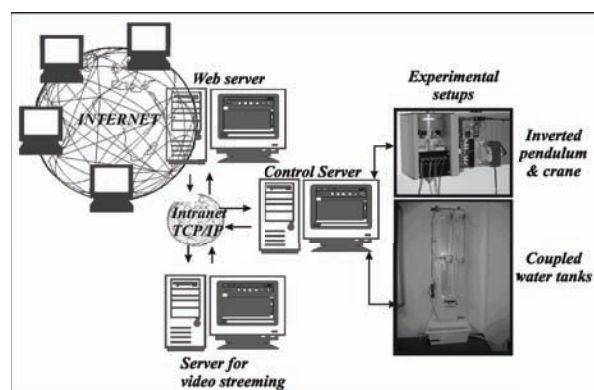
Figure 1. Architecture of the system

It is clear that there is a number of additional important demands and requests for quality organization and development of web laboratories. 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 the engineering education, and it is highly possible that other fields of education have partially different demands.

3. FRAMEWORK FOR DEVELOPMENT OF WEB LAB IN INTEGRATED ELEARNING ENVIRONMENT

When the first version of WLUK was implemented in education on study programs on Faculty of Mechanical Engineering, Industrial Engineering, the feedback from students was collected. Generally focus was on draw backs and problems in functioning of web lab.
All comments were divided into two groups:

- Hardware / software problems (Like: WLUK performs poorly, It is slow, Take to much time)
- Organizational problems (Difficult to handle, No instructions, No FAQs, Options to save both graphical and numerical results – in appropriate files, Ability to import / export from / to Excel and MatLab)

The first set of problems was solved with more powerful servers and limitation of U/I in order to prevent device breakdown. On the other side there was a problem connected with better instructions and lack of supervision when stuck on trivial matters is very frustrating for many students. Online laboratories are not simply replacements for traditional hands on laboratories because students need to deal with many connected problems.

In order to solve these draw backs a framework for development of web laboratory and web exercises is defined. We adopted ECLASS model and implement in on web laboratories and laboratory exercises (Figure 2).

The eLesson Markup Language (eLML) is an open source XML framework for creating eLessons using XML. It is a "spin-off" from the GITTA project (Grossmann et al. (2008)). The aim of eLML was to offer authors a tool that ensured conformity to pedagogical guidelines. ECLASS is an abbreviation for the following elements:

- Entry: Stands for the introduction into the lesson or a unit (the sub-category of a lesson)
- Clarify: A clarify element is used to explain some theory, models, principles or facts
- Look: Examples that help the student to understand the theory
- Act: This elements animates the student to become act, try out a model or discuss issues
- Self-Assessment: Check if the learning objectives of the lesson or unit were fulfilled
- Summary: Provides a brief summary of either the whole lesson or an individual unit
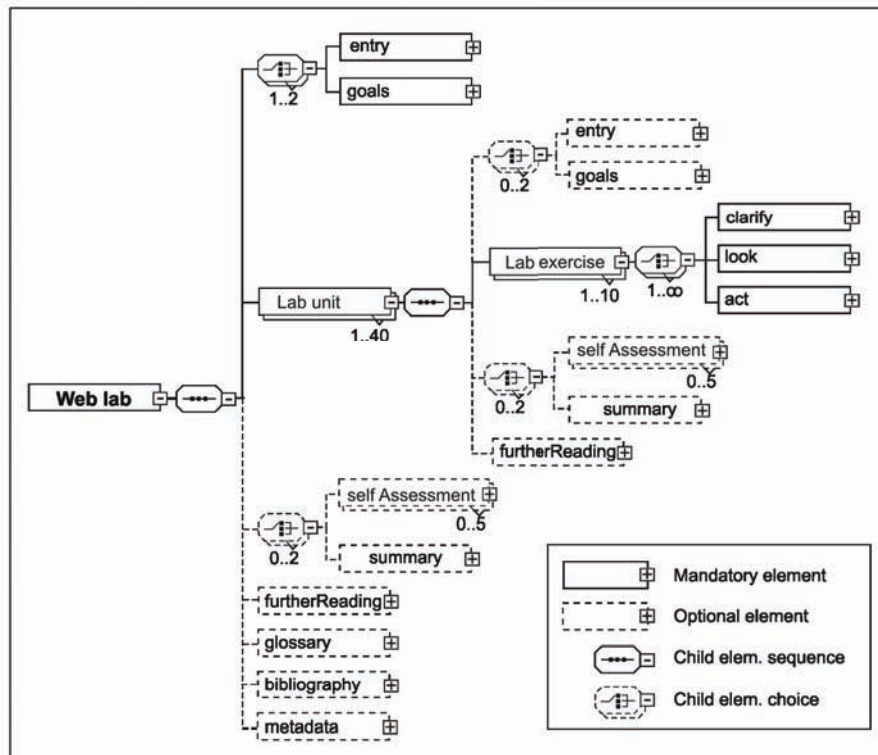
Figure 2. XML schema of WebLab

So, Web lab consists of number of Lab Units (Laboratory exercises: Control: LV1 Electric simulator of typical physical processes, LV2 Gantry Crane, LV3 Coupled Water Tanks Experimental Setup and Telemetric: 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 and TM5 Interactive experiments with linear systems).

Figure 3. UML diagram of integrated e-Learning environment of WLUK

There is introduction and goals for both, web laboratory and web exercise (web unit). Each unit, beside practical experiment, is accompanied with elements that explain theory, model and principles, as well as examples. Laboratory exercise is followed by self assessment and summary.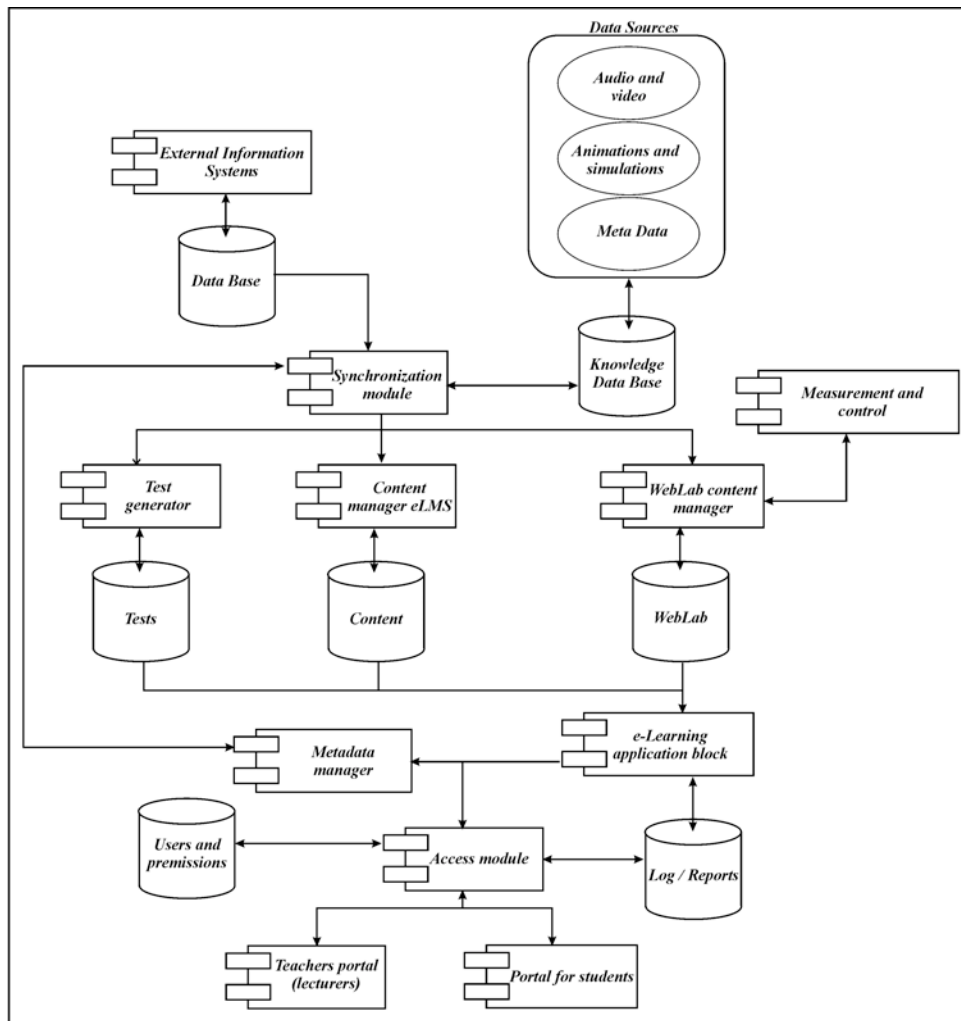 This model of Web lab could be very useful because it provides framework and define elements of well defined web laboratory and enables networking and exchange of web lab experiments between different educational centers. It is clear that full capacity of web laboratories could be used only in integrated e-learning environment. The integrated e-Learning system, with WLUK as an important part is presented in Figure 3.

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); self-evaluation and evaluation using module for e-tests and practical experiments in the web laboratory. Figure 3 depicts position of web laboratory in integrated eLearning environment. There are two possible accesses to the system, through access module: teacher and students. E-learning application block is connected with web laboratory and LMS. Each part of system could be used separately as support to classical learning or together as integrated learning system.
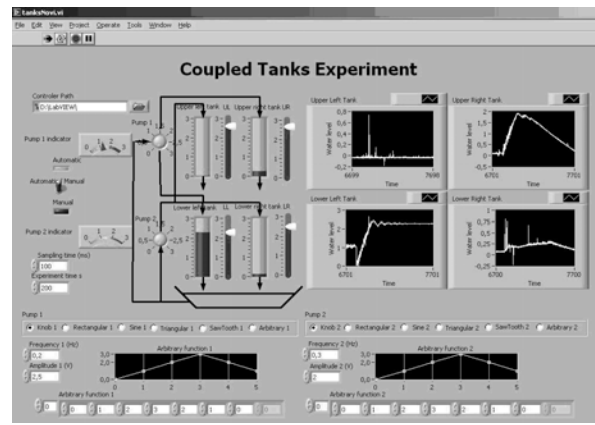
This e-Learning environment improved education processes and produces basis for a "blended" education environment. The combination between the classical education and the e-education on faculty of Science and Faculty of Mechanical Engineering University of Kragujevac. We have also planned a module for synchronization for interconnection of the e-Learning system with other education information systems and extern knowledge basis.

4. REAL-LIFE EXAMPLE - WEB LABORATORY - UNIVERSITY OF KRAGUJEVAC

In the Web Laboratory University of Kragujevac, there are 5 exercises in the field of telemetry and 3 exercises in the field of control engineering. Here two different experiments are presented: experimental installation of the inverted pendulum and crane (developed in C#), and coupled water tanks (developed in LabView environment; common used solution such Hardison et al. (2005), Kalantzopoulos (2008)).

There are different approaches in development of web laboratories, and they really on different environments Benitez et al. (2004), Gillet (2004), Lindfors (2004) Imbrie (2005), Tröger et al. (2008), Jen (2008).

Figure 4 represents web portal for WLUK, where different exercises could be selected. Figure 5 depicts server part of web laboratory. This control server for web laboratory could be administrated and managed by teaching staff, locally and remotely.

Figure 4. GUI of web lab

Figure 5. Server part of web lab

This is very important because administrator of laboratory has indication of irregular conditions of laboratory equipment so it is possible to ensure safety and quality of functioning of the system.

4.1 Remotely controlled experiments

The first experiment is inverted pendulum. 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 (Figure 6a). 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 6a 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 control server is developed using programming language C#. Using C# we control system for data acquisition using DAQmx software libraries for program approach to data acquisition system.. 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.

The following options are enabled using client side GUI (Figure 7a):

1.   Selection of the sampling period,
2.   Selection of the duration of the experiment,
3.   Selection of the option for the control variable: definition of the user-defined control sequence; definition of the control sequence according to the P control algorithm; definition of the control sequence according to the self-defined control algorithm, and
4.   Start and stop of the experiment, indication of the status of the laboratory set up, video feedback and download of results are available.

a) Inverted pendulum & crane set-up

b) Coupled water tanks experimental setup

Figure 6. Experimental set-ups

a) Client side of the application for the inverted pendulum & crane set-up

b) Front panel of the experiment main VI, coupled water tanks

Figure 7. Client side of applications

The experiment is used for control of the crane/inverted pendulum in order to illustrate:
- Techniques of 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.
- Theoretical basis of the non-linear systems, such as the contiguous circles and descriptive functions.

Experimental results, position of wagon, graphics and data for download are presented on the figure 8a).
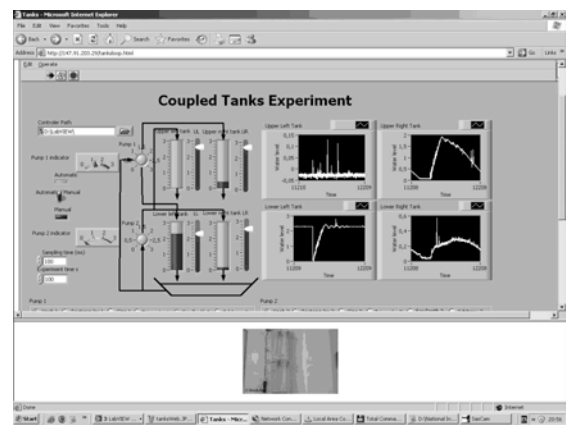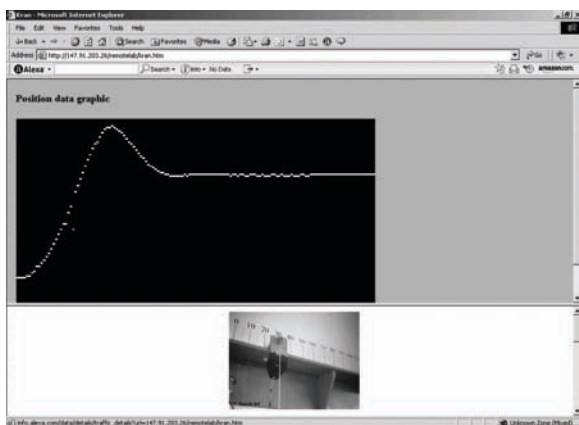
a) Position of the wagon

b) Water level in tanks

Figure 8. Experimental results

Experiment with coupled water tanks was added as independent hardware/software module to the existing web lab. Problems of coupled water tanks, regulation and flow levels, are frequent in the water supply systems and sewage, biosystems (some problems of medical physiology), as well as in many systems of processing industries. For instance, in process industry (paper production industry, petrochemical industry, etc.) problems of fluid transport, storage and fluid retention in tanks, and transfusion into the tanks are a common case. General goal is obvious: use one of the control techniques to control and regulate height levels in coupled tanks / or ensure that controlled levels follow set trajectories. The framework for this laboratory exercise has been designed using LabVIEW for creating flexible and scalable measurement and control applications. It is different from the previous experiments (in this web laboratory) as it was fully developed using NI LabView 8.0 software system. That fact slightly changed the previous general structure of the WebLab. As it was developed with LabView software system, integrated LabView web server was used on the acquisition server. No web server programming was required with LabView, as it directly supports web access to experiments. Once the experiment is developed in LabView on the local PC, it is immediately available through the web with simple LabView setup procedure. When using LabView for development of the remote experiments, web server and acquisition server run on the same PC.

The role of the central web server is changed in that case, as it serves as the main and central web location that directs the user to other web server running on the acquisition server that controls the selected experiment. In that way, even with the changed configuration, WebLab system remains fully modular and compatible for different implementations with programming languages or LabView software system. Experimental setup for coupled water tanks consists of four water tanks arranged in two levels and two water pumps controlled by DAS. Used DAS is NI USB 6009. Water level in each tank is measured by the hydrostatic pressure to voltage measurement transducer. Voltages on the output of transducers in each tank are measured by DAS.

Experimental setup for coupled water tanks is presented in Fig 6b. Control of such coupled tanks system can be quite complex as the tanks are interconnected so that water from the upper tank goes down in the corresponding lower tank and water pumps simultaneously pump water in the diagonal tanks. As the control task for such system of coupled water tanks

can be formulated in many different ways starting from the simplest version with only one pump working and controlling water level in only one tank – corresponding lower tank, to cases where both pumps are working and with controlling water levels in more than one water tank, the goal of developing such remote experiment is to make the universal environment in which any control task can be performed.

In order to achieve educational goals, the design of the experiment with coupled water tanks is divided in two independent tasks:

1. The first task was to develop working environment in LabView software system that will manage all the functions for measurements on the experimental setup and for controlling the water pumps.
2. The second task of the software support for this experiment is design of the system controller template that can be used for implementation of any type of controller.

Template controller is designed as separate sub VI that is connected with experiment main VI which FP (Front Panel) is given in Fig. 7b., using the strictly specified interface. Results, diagrams and experimental results are presented on the figure 8b.

4.2 Comparison of different implementations of experiments

In development of web laboratories and remote controlled experiments different implementations are possible. In this paper two possible implementations are presented: one, based on C#, and other based on LabView environment. Both implementations have their advantages and disadvantages. Generally we could analyze these implementations from three points of view: students (users), teachers and developers (developers of web lab applications for web experiments. A survey was performed among students, and questionnaire among teachers and developers, results are presented in table 1.

Table 1. Different implementations of experiments

	Implementation in C#	Implementation with LabView
Students	Fast loading of front panel. Fast execution of the experiment. "Poor" user interface. Stabile environment. Better opportunities for advanced development of control algorithm.	Better user interface. Easier development of control algorithms. Export and import of results to Excel, LabView and MatLab. Good visualization, intuitive front panel. Slow loading of front panel. Students need to download LabVIEW 8.0 run time engine lv80runtime.msi.
Teachers	Appropriate for more advanced courses. Students could develop more advanced control algorithms using their programming skills. Faster and more reliable environment.	Appropriate for lower courses in control education, intuitive GUI, possibilities for import / export of data. Students do not need to know advanced programming in order to develop control algorithm. More intuitive and more user oriented environment.
Developers	There is important role of control server. Functions are separated on client and server side of application. Harder to develop, more flexible.	The role of the central web server is changed in that case, as it serves as the main and central web location that directs the user to other web server running on the acquisition server that controls the selected experiment. Easy to develop but less flexible.

Web experiments developed using LabView environment have more user oriented interfaces (with interface that is much alike of standard interfaces developed in LabView), options for export and import of results in similar environments LabView, MatLab and they are not so demanding for development. Solutions developed in this environment need LabVIEW 8.0 run time engine, so they need more time for installation and upload of front panel.

Experiments developed in C#, with defined control server, are faster, more stable and suitable for advanced users. This environment does not offer rich user interface.

From educational point of view experiments based on web lab are more suitable for lower courses, and exercises based on C# are more suitable for more advanced courses because they open possibility for implementation of more advancing programming options (development of more complex controllers, and connection with different software solutions).

5. EDUCATIONAL RESULTS

The e-Learning concept is mentioned as a very important corner stone in education in all important combines and declarations of European Union. Different laboratory exercises are developed to support courses in different study programs and different levels in order to achieve defined educational goals (Zhuang (2006))

The main recommendation is connection between concepts of e-Learning, web laboratories and permanent education and distant learning. The main purpose of 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 on e-Learning concept,
- Resource insurance, financial and technical support for e-Learning and
- 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 the year of 2006 on Faculty of Science and Faculty of Mechanical Engineering. The web laboratory is presented to students from departments of Automatic Control and Industrial Engineering form Faculty of Mechanical Engineering. Students used the web laboratory during the educational process and filled on-line questionnaire in order to present their experience and evaluate benefits from the web laboratory, the results are presented in Table 2. During two years 146 students took questionnaire. 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 main answer that the web laboratory fulfilled planned educational goals, and they completely

understood laboratory experiments goals and tasks of exercises. The students also pointed that the system is user-friendly, and easy to use.

Table 2. Students' questionnaire– Character and organization of web laboratory (% of students out of 146 persons)

No	Question	Mark (1-5) 5 the greatest				
		1	2	3	4	5
1	Task is clear			17%	37%	46%
2	Educational goal is well presented			27%	35%	38%
3	Exercises are accompanied with appropriate theoretical content			25%	30%	45%
4	System is reliable		16%	19%	41%	24%
5	System is easy to use		5%	20%	33%	42%

Table 3. Students' questionnaire – Effects of implementation of web laboratory

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

The students were also encouraged to give their conclusion about the effects of implementation of the web laboratory. The results are gathered, grouped and presented in Table 3. It is important to emphases that there was no negative reaction, and more important conclusion is that the web experiment could contribute to better and more quality understanding of the educational material.

6. CONCLUSIONS

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, a web laboratories have an important place. These web laboratories increase availability of the laboratory equipment to students and decrease maintenance costs.

This paper presents pre-requests and exploitation issues in development and implementation of web laboratories. We advocate idea of necessity for definition of web lab framework in order to ensure operability and exchange of laboratory exercises. It could be very useful to integrate different, geographical distributed, laboratory exercises for different educational or research purposes. We presented one possible definition of web laboratory based on eLML.

Two laboratory exercises implemented using different approaches are presented, compared and contrasted from different points of view (students, teachers and developers).

There are few interesting features in WLUK: control server is self developed solution, users can design their own controllers developing appropriate dll file. Exercise based on LabView uses run engine, and users can develop their virtual instruments VI.

Finally some educational results of usage of web laboratory in engineering education are presented.

The achieved goals of education using web laboratories are:
1. To provide the basis for lifetime learning.
2. To establish and maintain high standards of excellence for the experience of learning the foundations of control and industrial engineering.

The implementation and usage of web laboratory improved education process in many different ways:
- Laboratory is accessible 24/7.
- Physical presence of students is not mandatory in the laboratory building.
- Optimal utilization of resources.
- Better preparation for experiment.
- Web lab is a very important for the concept of permanent education for all employed and unemployed persons.
- Initial results of the implementation and usage of the web laboratories have shown that this education approach has great motivation and education effect, and improve organization and quality of education (table 2-3).
- Web lab allows students to operate real processes without being physically present in the lab.

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

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

We believe that Internet networked laboratories offer unique educational opportunities but must be simple and inexpensive for instructors to develop while clear and flexible for students to use.

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