A LabVIEW-Based Remote Laboratory Experiments for Control Engineering Education

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ABSTRACT: This paper deals with remote access to a real laboratory equipment using contemporary computer and network technology for creating the environment that will enable a remote user to perform the required laboratory exercises and control the laboratory equipment. Architecture and characteristics of WebLab will be described with special attention to the latest implemented laboratory experiment for control of the coupled water tanks (using LabVIEW). This paper will also give results of researches among student population in order to determine advantages and effects of using web laboratory in control engineering education. © 2009 Wiley Periodicals, Inc. Comput Appl Eng Educ 19: 538−549, 2011; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.20334

INTRODUCTION

Much attention has been focused recently on modern control education in Engineering. A leading idea to all educators was given in [1]: "*Educators must have an open attitude towards new technologies. They should sensibly incorporate new technological development to avoid the risk of teaching the students of today, how to solve the problems of tomorrow, with the tools from yesterday.*" The Web influences both the industry and education because it enables supervision and teleoperation of devices (cost reduction).

Recently, Information and Communication Technologies (ICTs) have changed the conception of the teaching process both in the classroom and in the theoretical teaching approaches. Traditional content-oriented teaching approaches are being replaced by student-oriented ones.

The WorldWide Web has provided an opportunity for design and analysis of control systems through the Internet. An increasing number of web-based software packages have been developed to enhance the teaching and design of control systems. Today one of the most popular applications in control systems is web-based educational environments and laboratories [2].

Different designs of web-based control labs are presented in educational practice all over the world [3−8]. The web enables more flexible delivery of teaching materials, distance education, new visualization possibilities, interactivity, and cost reduction.

The underlying fundamental promise of Internet-based laboratory approaches lies in students' abilities to connect to a computer-controlled laboratory setup 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 [9].

The idea of having a remote web-based laboratory corresponds to attempt to overcome different constraints and may be the next step in the remote distance learning [10,11]. Remote web-based laboratories may also allow researchers in different locations to carry out researches 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 website to centrally house various online functions and facilities course management.
- Creating a remote laboratory where multimedia animation or simulations are provided to replace physical experiments.
- Developing a web-based laboratory that enables students to set up parameters and undertake experiments from remote location.

The main disadvantage of distance and e-learning approaches is absence of laboratory work. Multimedia animations or simulations cannot bridge this gap. The only possible solution

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to ensure practical work as a part of concept of distance learning is implementation of web laboratories that consist of remotely controlled experiments with video feed-back. Besides, web laboratories with remote control of experiments could be used as a very useful educational tool in classical or blended (mixture of classical and e-learning approaches) learning environments. In this paper the architecture of web lab will be presented with experiment "Coupled water tanks" that was developed using LabVIEW. Presented solution enables users to design their own controllers using a controller template, to upload them, and remotely control the real laboratory equipment. This paper will also present results of surveys that show effectiveness of implementation of web laboratories in control engineering education.

ARHITECTURE OF WEB LABORATORY

The main goal and significance of the WebLab system [12] is to provide remote access to laboratory equipment and to be as universal as possible for various kinds of laboratory work and experiments. In this paper architecture, and a laboratory exercise of web laboratory (WebLab) developed on the University of Kragujevac, will be presented. WebLab system adds value to e-learning system and enables remote laboratory work, which is not possible with traditional e-learning systems. The basic precondition for the experiment to be available remotely, through the WebLab, is the use of the programmable equipment that manages all the aspects of the experiment. Experiments can be performed completely unattended on the side of experimental equipment, with full and exclusive control from the remote user. Basic configuration [13−16] of the WebLab system consists of the web server and one or more PC acquisition servers that control the experiments. Even simpler configuration is possible with only one PC computer that serves both roles; the one of the web server and acquisition servers that control the experiment. Such simple configuration is limited to cases with small number of experiments where one acquisition server can control all experiments. In general, when there are many experiments, more than one acquisition server is needed. Acquisition servers are PC computers with one or more data acquisition systems (DASs) for measurements of the physical quantities and control of the experimental equipment. Besides DAS, acquisition servers can have also other kind of measurement/control equipments attached, such as digital oscilloscopes for very fast measurements and for laboratory exercises devoted to learning how to use digital oscilloscopes or other kind of programmable equipments. Data acquisition servers are connected to web server by computer network. Such configuration of the WebLab system enables acquisition servers to be placed in any physical location which is provided with Internet access for connection with web server. The actual architecture of the WebLab system is distributed, as it is physically situated in different buildings of the institutions [17,18] that develop the WebLab system.

Users of the WebLab access the system by means of the web browsers as the only required tool on the side of the user. Such distributed configuration of the WebLab system is presented in the Unified Modeling Language (UML) node diagram in Figure 1 (see Refs. [19−21]). Each box in diagram presents one physical piece of equipment. PC 1 is web server, while PC 2−PC 4 are acquisition servers that are connected with web servers using Win Sockets. The structure of the WebLab software is presented with components named Web user interface, Experiment and Programmable devices. These software components consist of classes for each experiment. Web user interface consists of classes that are used for communication with remote user.

Experiment component consists of classes that control each experiment in the system. These two components are physically located on the web server. The third software component named Programmable devices consists of classes that are located on acquisition servers and that actually control programmable devices—DASs and digital oscilloscope. Nodes with names DAS and digital oscilloscope represent programmable equipment used in WebLab system. Nodes on the lowest level that are connected just on one side are specific experimental equipment that is controlled by the DAS and digital oscilloscope. Names of those nodes are equal to names of the existing experiments in the WebLab system—Diodes and Transistors, Analog systems, Electrical signal velocity, Steep plane, and Automatic control system.

The node named PC WEB browser represents remote user of the WebLab system. Although it is only one node in the diagram, it represents all users of the WebLab system. Each experiment can be controlled by only one remote user at a time.

All software components are implemented in C++ and C# programming languages using Microsoft platform. Older DAS were programmed in C++ without .NET, while the new DAS and the web server were programmed in C# .NET. Web server was implemented using Microsoft ASPX.

COUPLED WATER TANKS EXPERIMENT

Framework for Experiment

The framework for this laboratory exercise has been designed using LabVIEW for creating flexible and scalable measurement and control applications. Experiment with coupled water tanks was added as a independent hardware/software module to the existing WebLab structure in Figure 1. It is different from the previous experiments (in this web laboratory) as it was fully developed using NI LabVIEW 8.0 software system (http://www.ni.com/labview/). That fact slightly changed the previous general structure of the WebLab given in Figure 1. 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 (http://sine.ni.com/nips/cds/view/p/lang/en/nid/14605). This experimental setup is common and useful in control engineering education [22].
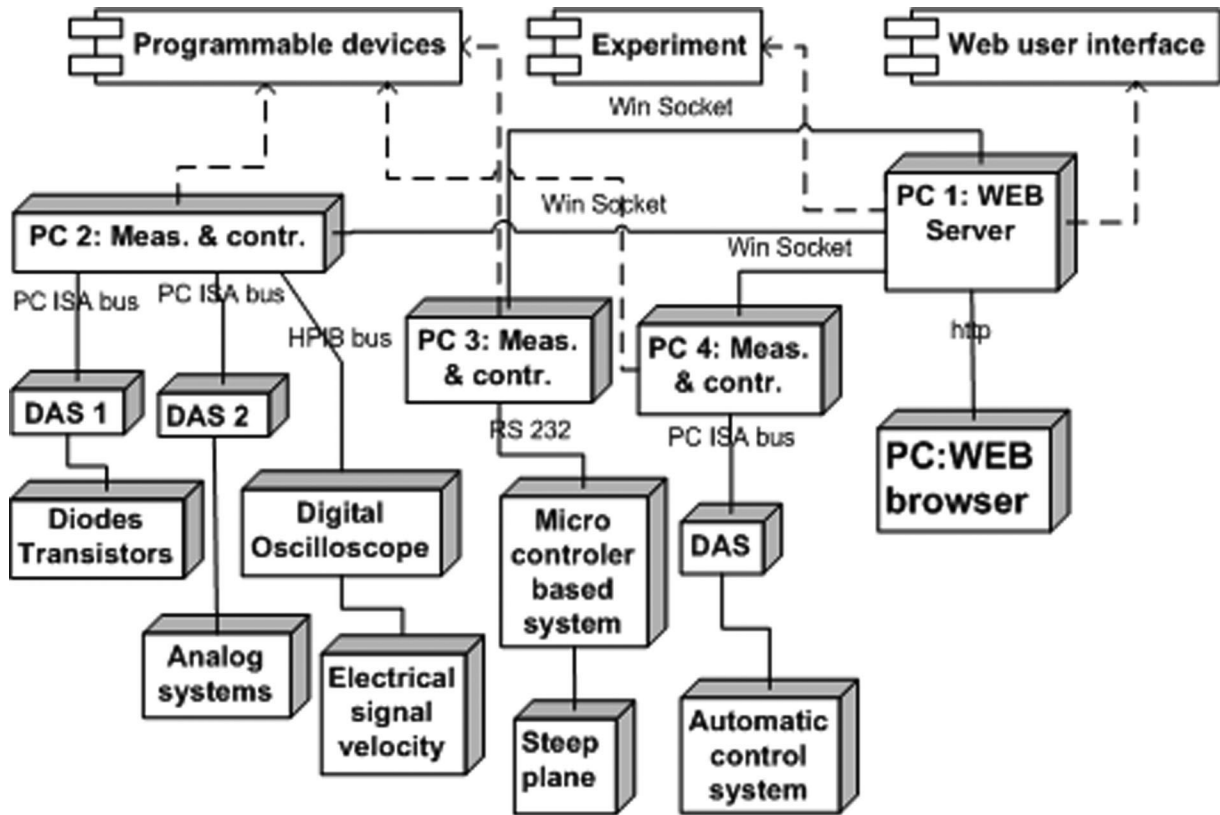
Figure 1   UML node diagram of the WebLab system.

Laboratory Model and Experimental Apparatus

Water level in each tank is measured by the hydrostatic pressure using voltage measurement transducer. Voltages on the output of transducers in each tank are measured by DAS. Diagram with principal schematic arrangement of the coupled water tanks is presented in Figure 2.

Experimental setup for coupled water tanks is presented in Figure 3. 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 a 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 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 that goal, the design of the experiment with coupled water tanks is divided into two independent tasks:

- Development of WEBLab environment.
- Development of controller for automatic control of tanks system.

Development of WEBLab Environment. 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. Development of the complete user interface (with following functions: different ways of driving the water pumps, indication of current water levels in tanks, drawing water level/time diagrams, saving measured data and output data in files for online overview and analysis) is also included in that task. The upper part of Figure 4 presents the user interface (UI) for coupled water tanks experiment. Before the start of the experiment, duration in seconds and sampling time interval in mS should be set up by writing the values in cor-responding text boxes. Experiment can be performed in two working modes, manual and automatic, which are selected with the switch Automatic/Manual. In the manual mode, pumps 1 and 2 can be controlled by selection of the continuous manual control from min to max with the rotating knob or one of the periodic functions: rectangular, sinusoidal, triangular, saw tooth, and arbitrary function that is defined with array of values. For any of the mentioned periodic functions, frequency in Hz and amplitude in V can be set. Manual mode is used for various purposes such as testing of the experimental setup working condition, setting the initial water levels, identification of the system parameters, or demonstration of the system operation. Water level for each tank is measured by the DAS and represented by an indicator in the form of vertical tank where the height of the blue colored column represents water level in the real tank. On the right side of each tank water level indicator is a blue control for setting the water level with white arrow that can be moved vertically. Positions of the white arrows determine maximum water levels in the upper tanks, and beside
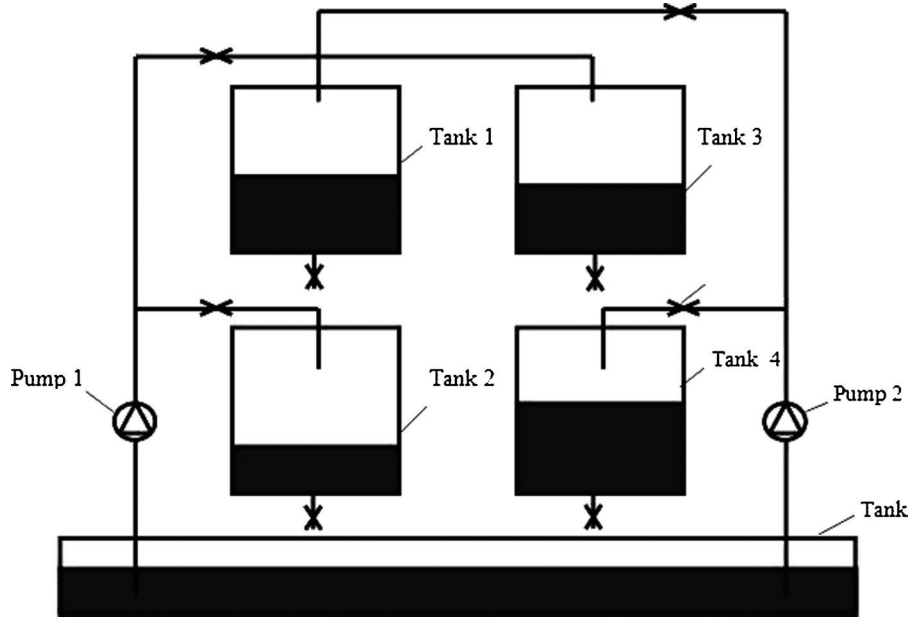
Figure 2 Diagram of coupled water tanks.

that, water levels that are to be regulated and maintained in the lower tanks. Water levels are regulated only in the automatic mode of operation, and not in the manual mode. UI in Figure 4 which is Front Panel (FP) of the main Virtual Instrument (VI) can be accessed locally from the same PC and also remotely (Internet) from any PC by web browser using the LabVIEW built in web server.

Remote access to any VI by web is very simple to setup, and web pages for VI can be customized in standard way like any other web page.

Figure 3 Coupled water tanks experimental setup.

FP of the VI is the same in the web browser window as it is on the local computer. In the lower part of the web page in Figure 4 is real-time live video from the web cam following the experiment. Only one user can control the VI, while others can observe the experiment from the VI and web cam live video.

Development of the Controller. The second task of the software support for this experiment is the design of the system controller template that can be used for implementation of any type of controller.

The basic role of a controller is to enable the maintenance of liquid level in the given tanks using two pumps to fill the tanks. Different types of controllers could be used to control the level of fluid in tanks. Therefore, VI for this instrument is designed in such a way that the controller is not necessarily fixed, but it is possible to use a special controller implementation VI, that is, sub which is a exchangeable module in the VI for the control of the experiment. Template controller is designed as a separate sub VI that is connected with experiment main VI, FP of which is given in Figure 4, using the strictly specified interface. Any sub VI serving as a controller that has the same interface can be inserted and connected with the main VI.

VI that represents the controller for this experiment must have a standardized interface that is connected with the rest of the system. Any VI with required interface can be dynamically linked with the rest of the system that provides a working environment for the controller. Dynamic linking is a possibility to change module controllers without restarting development and execution environment—LabVIEW. Previously implemented controller in the form of VI with required interface loads as a VI file from FP VI using control field for the selection of VI entitled "Controller path" in the top left of Figure 4. The main task of the working environment is to bring all the necessary signals for the work of controllers, as well as to accept signals generated by the controller, which are used to control pumps. In the experiment with tanks, signals that are brought to the controller represent current value of liquids in all tanks, then the required values to be
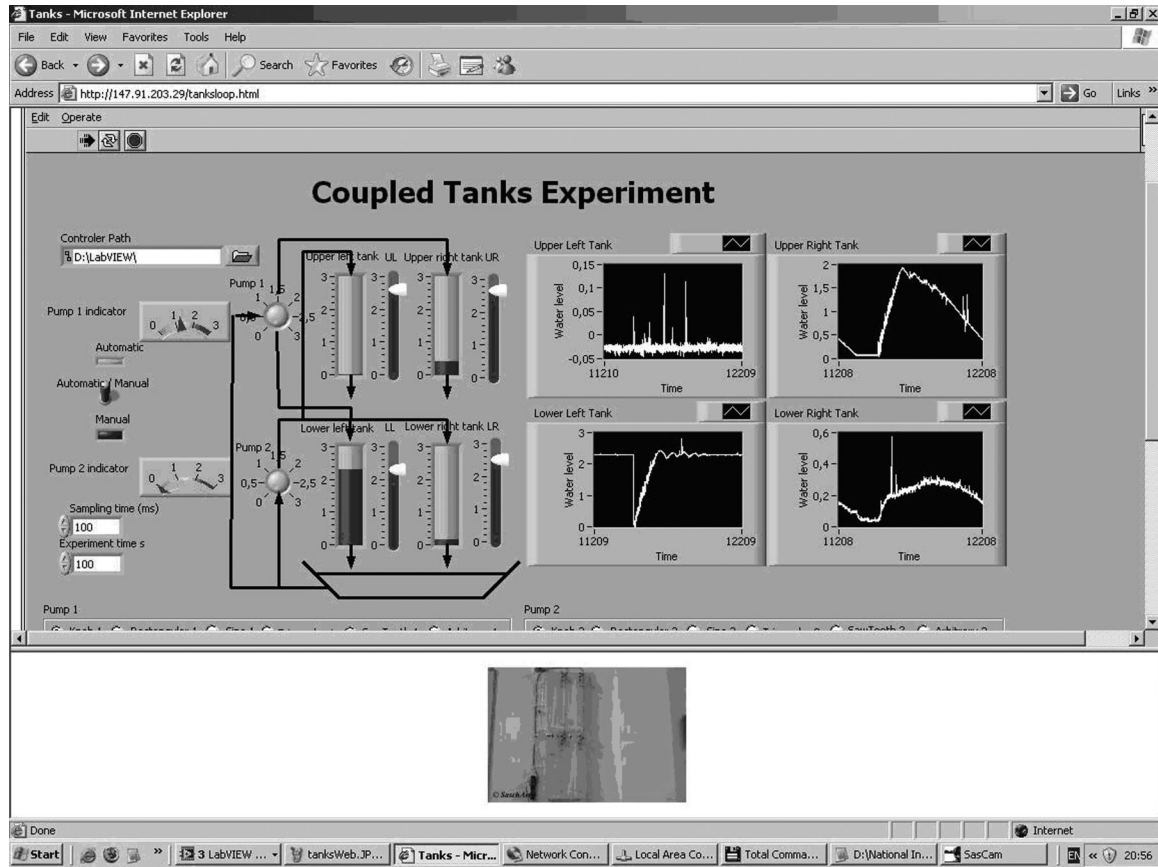
Figure 4 Front panel of the experiment main VI—water tanks experiment.

held in all the tanks, the previous value of the liquid from the previous measurements, as well as previous values of control signal. Current value of the signal is marked with N, while the previous values in that case with $n-1$. Number of signals that are brought to the controller can be reduced using differences in signals. In this case $e(n)$ and $e(n-1)$ signal errors are used and where $e(n) =$ desired level $(n) -$ measured levels (n) index (i) indicates tanks and i-1, 2, 3, 4. There are also used $u(n-1)$, previous control signal $j=1$, 2. Controller generates two signals $u(n)$ which control the pumps. This means that the controller should have 4 inputs $e(n)$, 4 inputs $e(n-1)$, 2 inputs $u(n-1)$, a total of 10 inputs and two outputs $u(n)$.

Interface for connection of VI with other VI is defined by analogy in definition of prototype of functions in programming languages, C, for example. Prototype should determine the exact type of data for each input and output. Prototype or interface VI is defined as "connector VI." For each VI input, there must be the appropriate input control, and for each output there should be one indicator. These controls and indicators are necessary elements of the interface, and if there is no need for these controls they must be created for the purpose of connecting with the rest of the system. This is developed for the liquid-level controller, where the text boxes are used for input control, while the numeric indicators are used as indicators. Figure 5 depicts a BD for one version of a simple controller. Icons of input controls are shown on the left side, while the indicators are on the right side. Previous value of $n-1$ is marked as "old."

Rectangles are features that can assure input of code in syntax very similar to C programming language.

While designing controller, attention is devoted strictly to controller, while all technical details concerning DAS, timing, experiment duration, connections with experimental setup, and other specifics are handled by the main VI.

Figure 6 presents the FP of the sub VI that implements PID controller. In the upper part of Figure 6, above T are controls and indicators that serve as interface connections, while T and controls below serve for setting the constants for the controller. Controller in Figure 6 has two independent sections for each pump. As all constants for the controller for pump 2 are 0, that controller is turned off.

Figure 7 presents the water level/time diagram for lower left tank which gets water from pump 1 directly, and which level is maintained by PID controller with FP in Figure 6.

EDUCATIONAL GOALS AND TASKS OF LABORATORY EXERCISE

Educational Goals

Laboratory experiences, which imitate the complexity of real life practices, are essential elements in engineering education. In practical sessions, students learn not only by listening, like in theoretical courses, but also through "learning-by-doing."
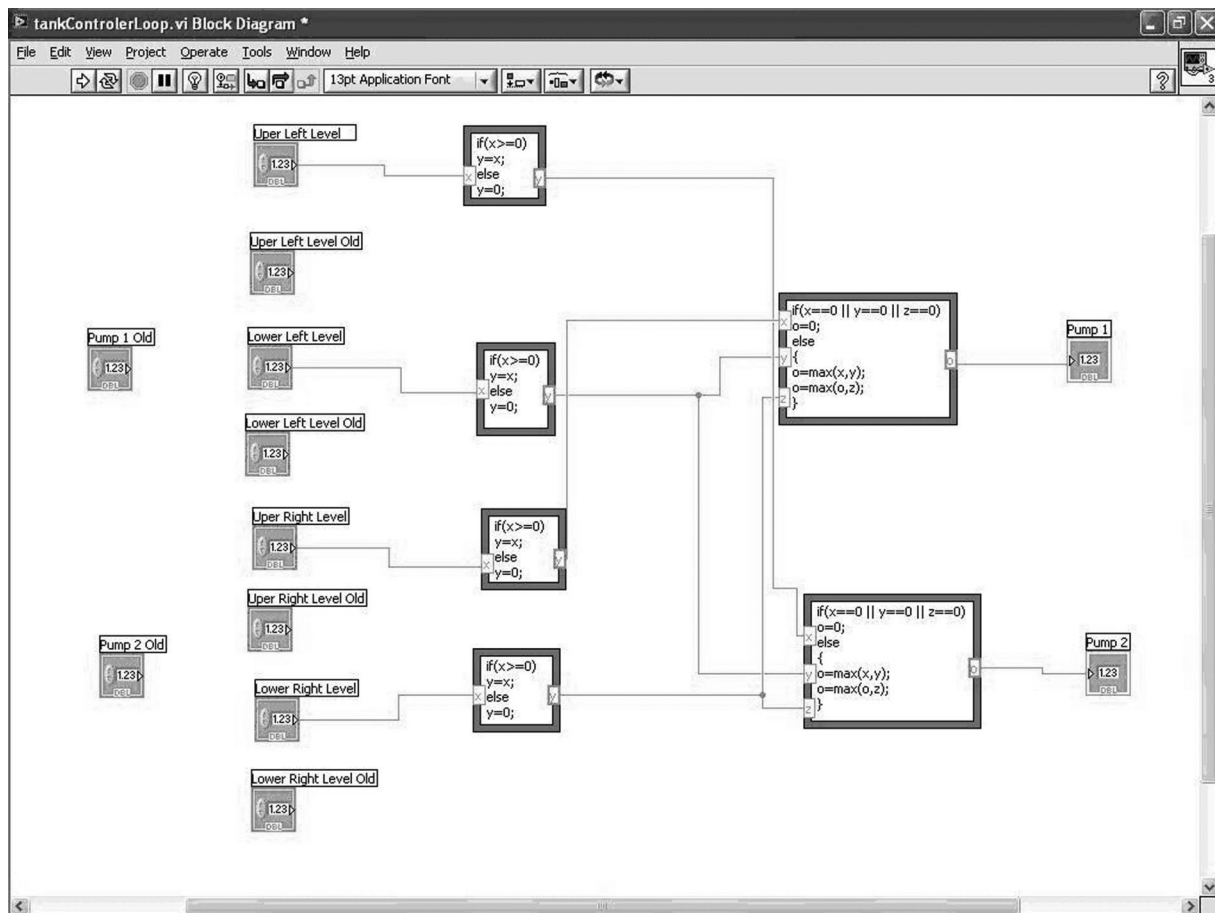
Figure 5 Simple controller with VI inputs and outputs (controller is ad hoc student attempt to make intelligent on−off controller for the correct filling of all tanks 4—the idea is to show the simplicity of the implementation of arbitrary controller).
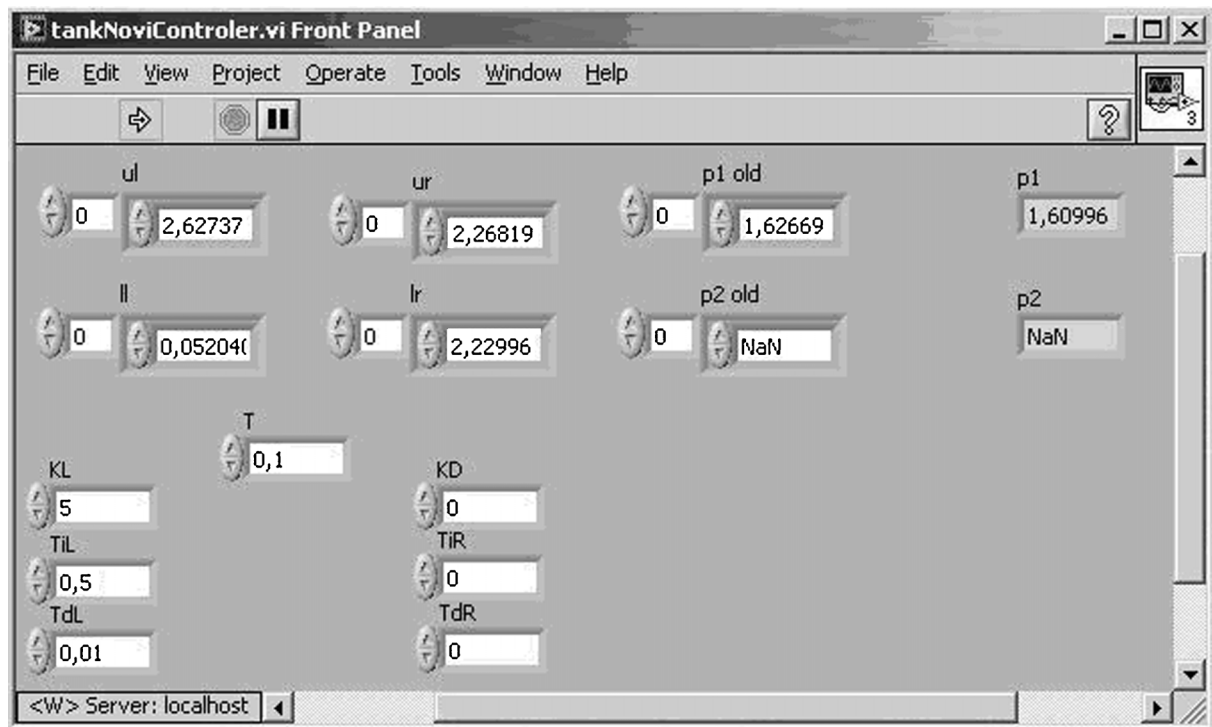

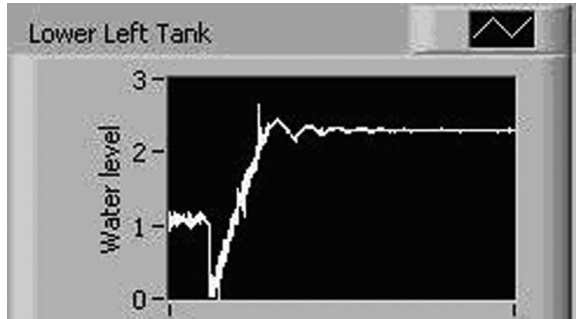**Figure 6** Front panel for implemented PID controller.

Figure 7 Water level/time diagram of PID controller.

When students interact with the laboratory plants they have the opportunity to verify what happens when they modify and manipulate the experiment. Several studies have shown that laboratory practices have achieved positive influence on learning skills, on well-prepared professionals, especially in scientific and technological fields. Some authors [11] illustrate that students retain 25% of what they hear, 45% of what they hear and see, and 70% if they use the ''learning-by-doing'' methodology. The construction of fully furnished scientific laboratories is very expensive because specialized and sophisticated equipment is needed. This cost is sometimes prohibited for many institutions. The few existing laboratory equipment has to be shared among researchers and students enrolled in different programs with adjusted schedule and different knowledge levels. Instructional staff spends much time of every lab session describing the equipment lab, demonstrating the correct operation of laboratory equipment before doing the actual experiment, and review the experiment procedures.

For engineers of different profiles is very important to understand how system of coupled water tanks works, how to apply measurement techniques and appropriate hardware components, and how to control the problem through the writing of control software. 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. Then, the problems of chemical treatment or fluid mixing in the tanks are also very frequent. In all these cases, the level of fluid in the tanks must be controlled, as well as the flow between the tanks. Often tanks are coupled so their levels are in mutual interaction, and that must be mutually controlled. Control of levels and flow into tanks is one of the central issues of process/chemical engineering systems.

Laboratory setup presented in Figure 3 allows wide specter of experiments with various levels of complexity.

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 general objectives of this laboratory experiment are to ensure that students:

(1) Get familiar with the system of feedback control—general ideas from the theory of systems, components, and systems terminology.

(2) Gain experience in calibration of sensors, performance and implementation of laboratory experiment, and preparation of appropriate software.

(3) Test acquired knowledge in the field of modeling and process identification.

(4) Analyze static and dynamic features of processes and systems with feedback to make quality assessments and evaluate the main parameters of the control system.

(5) Demonstrate performance and limits of the system with open feedback (manual control) when there is a need for change in the set of values or fix the effects of disturbance.

(6) Demonstrate unstable work with the system with feedback, as the result of influence of clear time delays in the system.

(7) Demonstrate influence of changes of P (proportional) and the dynamic and static characteristics of the system.

(8) Demonstrate influence of the introduction of integral regulation (transformation of P regulators in PI) in terms of elimination errors of stations state system of control system with feedback.

(9) Gain experience in the synthesis and the setting up of various control algorithms (the usual methods: PI + feedforward control, PID algorithms, the method of setting pole, MPC algorithms, feedback by the state, etc.).

(10) Gain experience in the implementation of algorithms to manage through the writing of the appropriate software to work the system in real time.

(11) Gain experience in the application process of computers (PLC, HMI, etc.) and accompanied software for the implementation of specific control strategies.

Considering the fact that experiment could be controlled via computer network, some other possible educational tasks in the field of design, development, and implementation of systems for supervision, control, and data acquisition are also possible (development of software, database development, supervision functions, acquisition, storage, presentation and visualization of data etc.).

The methodology of problem-solving approach (problem-based learning) based on experimental apparatus in a wide range of fundamental interdisciplinary theoretical content includes:

A. Concepts of modeling and system analysis:
   • System modeling.
   • Identification of the system.
   • Linearization of the model.
   • Conversion of the model (presentation of the model in complex, frequent and time domain, etc.).
   • The study of stability and performance of other systems based on the model.
B. Algorithm management in a broader sense (with their associated functions):
   • Control of open and closed feedback.
   • PID control procedures and adjustments of PID regulators.
   • P control with the associated compensators.
   • Synthesis of controllers in the frequency domain.
   • Feedback by the state, controller synthesis based on the model in space conditions and concept of optimal control (LQR controller, etc.).

- Implementation of observer or estimators of condition (Kalman's filter, etc.).
- Synthesis of controller by method of setting pole.
- Predictive control (MPC algorithms).
- Fuzzy control, etc.

C. Restriction factors in the real functioning of the system:
- The presence of measurement noise.
- Influence of disorders on functioning of the system.
- Effects of no-modeled dynamics (or ambiguity of the system).
- Effects of saturation of actuators (wind-up).

Using this remotely control laboratory experiments, students could cover number of contents above. Using manual mode students could test experimental setup working condition, set the initial water levels, and perform the identification of the system's parameters or demonstration of the system operation. Students could implement and test adequate control algorithm (using template for development of different controller); compare different control algorithms or different methods of adjustment of the same control algorithm (P, PI, PID, fuzzy); and suggest a specification of the rational technical demands according to the functionality of the systems. They also could perform analysis of comparable simulation and experimental results and make conclusion in which criteria the experimental simulation confirm the theoretical consideration (taking into account different factors of functioning of real system: measurement noise, disturbance such evaporation, heating, etc.).

Example of Project Task

As a part of different courses this project task has been given to the students of Faculty of Mechanical Engineering. Control strategy should be achieved by controlling/monitoring the level of liquids in the lower tanks, irrespective of changes in the position of valves that allow filling all four tanks. There are many possibilities for creating different control algorithms, which later can be tested experimentally by changing the parameters of the system and the introduction of disorder. Synthesis of control algorithm is always based on preexistent information on the model of controlled process and the available signals. Identification of the model is a special mission, as well as skills acquisition and signal processing.

Application of ICT technologies for the implementation of control and associated functions (monitoring, diagnostics, visualization, etc.) presents especially field for the exercise. The task requirements are possible for other configuration laboratory models.

Project Task. The plant is a tank filled with fluid (water). Output parameter is the level of fluid in the tank. The level of fluid is influenced by input flow and output flow. It is free to select control variable and disturbance. The task is to present solution for regulation of the level of the flow in the tank, simulation of results on computer, and verification of suggested solution.

1. *The structure of the system*: Define all components of system, describe it, and present mathematical model of the system. Students should present:
   - Functional schema and description of work.
   - Detailed and realistic (nonlinear) mathematical model of the plant in a broader sense.
   - Static characteristic of the plant.
   - Linearization of mathematical model of the plant near working point (defined with $x\%$ of maximal height of fluid level in the tank; different for each student).
   - Structural block diagram of the system in continual and digital version.
   - Check of stability of linearized model (using MatLab and Simulink, present linear and nonlinear model (continual and discrete).

The same, step signal is set on all models and level of the fluid has been monitored. Validity of linearized model (its correspondence to nonlinear model in different points of static characteristics) is monitored. Using MatLab, students should give alternatives and characteristics of the plant model (presentations of poles and zeros, frequency characteristics of the plant).

2. *Identification of the plant*: Nonlinear Simulink model is the basis for further simulation and for experiment and parameter identification. Identification of the plant gives opportunity to examine effects of influence of model, input, sampling time, identification method on the quality if a model is developed (ARX, for instance). Procedure of identification of model using MATLAB and verification should be described.
3. *Synthesis control algorithm*: Selection of structure and adjustment of parameters of PID control algorithm. In this step, continual and digital PID algorithm should be defined.
4. *The analysis of the system*: Analyze dynamic features of the system with feedback using programming packages Matlab and its tools *ltview* and *sisotool* (to give the parameters and analyze the dynamic response in selected working point, the frequency characteristics of the system, poles and zero pole, etc.).
5. *The results of the simulation*: Simulation of function of control system with real aspects of the system (real plant is not linear). Test the validity of the control algorithm, digital and continual and present the following diagrams: (a) the response (disturbance $= 0$), (b) the response by the disorder (the reference level is a constant). *Eventually*: (c) Improve simulation through animation, (d) examine sensitivity of the system to change the parameters OU (draw the appropriate indexes performance and analyze their change), (e) on presented plant implement fuzzy control and compare it with PID control, (f) implement some of the advanced control algorithm by choice.
6. *Conclusion.*
7. *Reading (and annex)*: Behavior and efficiency of controllers could be traced directly by the visual apparatus, then through the level indicators in the tank shown in Figure 4 and over diagrams that write change of the liquid level in tanks during the period. In addition, during the experiment all measurements of liquids level in tanks and control voltages are saved in six files, four files for the levels of each of the four tanks, and two files for the control signals of each pump. The contents of these files with the numerical values can be used for precise analysis of behavior controllers after the execution of the experiment. Reference values (desired) of level of liquids in the reservoirs and time are also recorded.

EVALUATION OF USAGE AND EDUCATIONAL RESULTS

There are two main issues that should be answered:

(1) Evaluation of web laboratory in educational process.
(2) Evaluation of usability of web laboratory (number of access and preferred GUI—graphic user interfaces) for students.

Implementation and introduction of web laboratories in educational practice in Faculty of Mechanical Engineering, University of Kragujevac, started in the first semester 2007. Experiments supported by web laboratory are part of different courses (automatic control, CIM, etc.). For the reason of this survey, students were separated in two groups (groups with the same number and quality of students). One group was labeled as "Traditional" (they did not have web lab support) other group was labeled as "Web Lab" (they had access to web lab). Survey covered three semesters: 2007/I (the first semester in 2007), 2007/II (the second semester in 2007), and 2008/I (the first semester in 2008). The number of students included experiment is presented in Table 1.

As it was stated in Educational Goals Section, the important educational goals were recognized. The most important educational goals are listed in the table. On the final exam students are evaluated according to fulfillment of educational goals (for the purpose of this survey). Each of the stated outcome was evaluated according to the answers to the specific group of questions (there were 11 groups of questions in order to evaluate fulfillment of educational goals). Students received just one grade but for the purpose of survey there were 11 sub-grades. Results show that students who had access to web laboratory (they could perform laboratory exercises on their own, repeat them, and analyze the results) have better scores and better fulfillment of educational goals compared with other group (Table 2).

In addition the students from "web lab" group had better final grades compared with other group (it is important to emphasize that both groups were equal in the beginning) (Fig. 8). Another issue that was raised was usability of web laboratory. According to counter of access to exercise, the experiment (coupled water tanks) was started 455 per month. Figure 9 presents the number of experiments per day for a period of 1 month.

According to previous questionnaire and surveys that web laboratory and remote control experiments could improve quality of education and contribute to better fulfillment of educational goals, students like to perform online experiments (68 students made 455 accesses to remote experiments).

CONCLUSION

WebLab system was designed and implemented to enable remote access to instruments and experiments for academic education in the domain of sciences and engineering. It is a modular and distributed system that can be easily expanded by adding new hardware and software resources for new experiments. In addition to benefits of remote access and 24 h/7 day availability, students can use it at their own learning pace. Sharing of specific and expensive equipment among various institutions is made much

Table 1 Number of Students Included in the Survey

Year/semester number	No. of students	
	Control group	WL
2007/I	28	28
2007/II	26	26
2008/I	34	34

Table 2 Results of Survey: Fulfillment of Educational Goals (5−10 Grade Scale)

| Educational goals	Number of students—88	
	Traditional	Using WebLab
(1) Get familiar with the system of feedback control—general ideas from the theory of systems, components, and systems terminology	8	9
(2) Gain experience in calibration of sensors, performance and implementation of laboratory experiment, and preparation of appropriate software	6	10
(3) Test acquired knowledge in the field of modeling and process identification	7	9
(4) Analyze static and dynamic features of processes and systems with feedback to make quality assessments and evaluate the main parameters of the control system	8	9
(5) Demonstrate performance and limits of the system with open feedback (manual control) when there is a need for change in the set of values or fix the effects of disturbance	7	8
(6) Demonstrate unstable work with the system with feedback, as the result of influence of clear time delays in the system	6	8
(7) Demonstrate influence of changes of P (proportional) and the dynamic and static characteristics of the system	7	8
(8) Demonstrate influence of the introduction of integral regulation (transformation of P regulators in PI) in terms of elimination errors of stations state system of control system with feedback	7	8
(9) Gain experience in the synthesis and the setting up of various control algorithms (the usual methods: PI + feedforward control, PID algorithms, the method of setting pole, MPC algorithms, feedback by the state, etc.)	6	8
(10) Gain experience in the implementation of algorithms to manage through the writing of the appropriate software to work the system in real time	7	8
(11) Gain experience in the application process of computers (PLC, HMI, etc.) and accompanied software for the implementation of specific control strategies	7	10
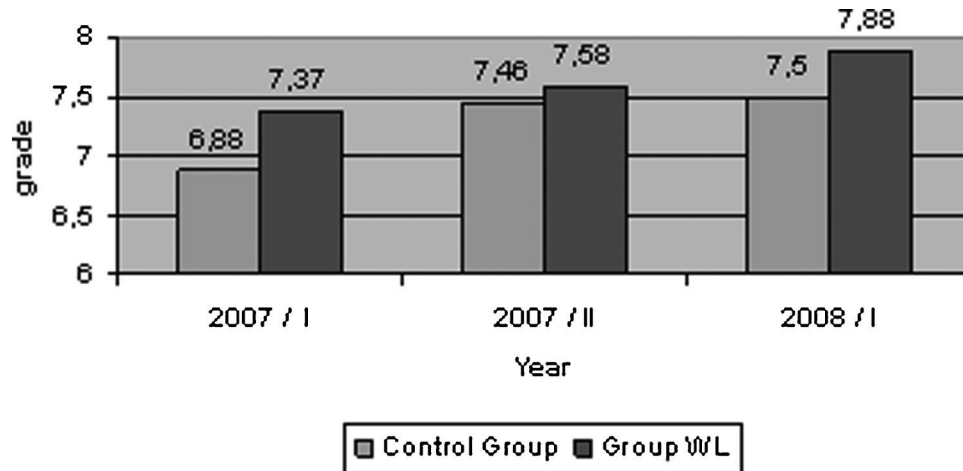
Figure 8   Average grades of students in different groups.

easier, as it can be used from any place with secure and controlled access.

There is little availability of real physical systems or laboratories to perform the experiments in control courses [23]. WebLab University of Kragujevac has laboratory experiment in control courses that could be remotely controlled (Gantry Crane—implementation based on C# and Coupled tanks—implementation based on LabVIEW). WebLab system at University of Kragujevac is a combination of two different implementation approaches that are transparent to the user of the WebLab. Implementation based on programming languages and Microsoft platform is quite satisfactory but takes much longer time for development compared to development with LabVIEW system that enables rapid development and excellent visual design using number of ready-to-use controls and indicators not present elsewhere. LabVIEW is in general better and much more

effective alternative to programming when developing measurement and control applications, except for some specific tasks that could require customized software. Some other solutions have been developed using the platform Matlab/Simulink [23,24]. The scalability and the ease in designing a user interface provided with LabVIEW, as well as its multi-platform implementation, make this package well suited to develop didactic tools. Moreover, the possibility to compile stand-alone virtual instruments, which can be distributed freely to the students, is a big advantage. Students are provided with stand-alone VIs, which enable them to experiment locally or remotely the behaviors of the controllers they have studied in class, such as the PID controller.

The most important characteristic of the LabVIEW software support for experiment with Coupled water tanks is the design of the universal controller template for implementation of any kind
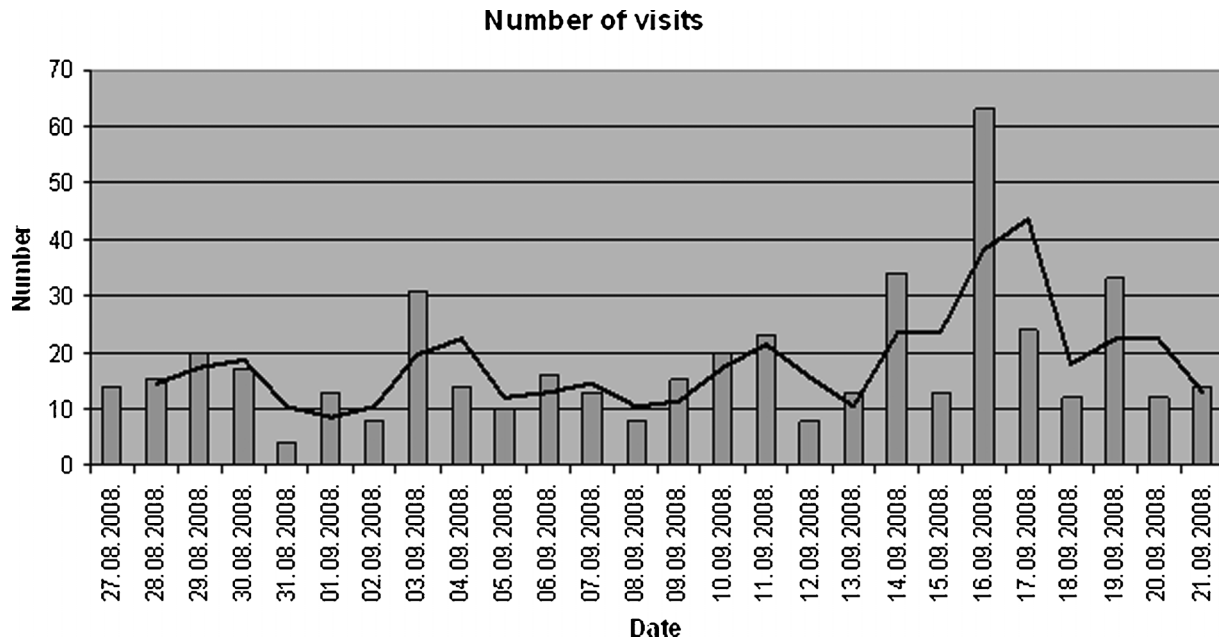

Figure 9   Number of experiments per day (totally 455 per month).

of controller while the designer is free from all implementation details concerning the experimental setup. All implementation details are handled by the main experiment VI which uses controller based on template as sub VI. Users can design their own controllers using controller template, and remotely control real laboratory equipment. This feature enables easy changing and comparing different controllers, variation of different parameters, validation of studied control algorithms, and changing module controllers without restart software environment.

Once the experiment is developed in LabVIEW, with simple setup it is available on the web for remote users.

Web laboratory has been used in educational process in University of Kragujevac for years. During the year 2007 and 2008, different experiments controlled over Internet were used in education, especially control engineering education. The survey on different groups of students, during that time, shows that students who had access to web laboratory (and possibility to perform laboratory exercises on their own with full support of web lab) have better educational outcomes in the field of control engineering. The main 11 educational goals were recognized and success of different students' groups was measured according to these goals. Fulfillment of educational goals and average grades of students show that usage of web laboratories produce better results and contribute to better control engineering education. The main reasons for these advantages are the facts that web laboratories change character of courses, make laboratory exercises easier (giving unlimited opportunity for students to repeat experiments using different parameters), and give open access (from anyplace, anytime).

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