An Online Course and Laboratory for Studying Automatic Control Systems

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Abstract—**This paper describes the online course and hands-on laboratory for studying automated control systems. The lab, which is based on a DC motor, is an open source suitable for modern mobile devices. The lab includes video broadcast of real-time activity control and does not require additional client software.**

Index Terms—**online course; hands-on laboratory; automatic control system; PID controller; LabVIEW, e-learning**

I. INTRODUCTION

Automatic control systems are widely used in industry and everyday life. For example, they are used for automatic control of temperature, pressure, and liquid levels in petroleum and other industries; speed in moving aircraft and spacecraft; and robotics, including operations dangerous to human health or life as well as for automatic control of modern home appliances (smart houses, heating and condition systems, etc.). For designing such systems, the real properties of a control object, including its inertia, imperfection and interaction with the medium, should be taken into account. Although significant differences exist among these processes, the design of automatic control systems (ACS) is based on the same principles and requires the use of special mathematical tools.

This is the subject of a course on the fundamentals of ACS theory. The course is a basic one in automation, measurement, electrical and computer engineering, mechanical, non-destructive control, aerospace and chemical engineering.

The activities of any online course can be easily provided by means of Moodle or similar platforms, but implementation of remote laboratories is sufficiently challenging. Educational institutions and commercial companies are developing a variety of hands-on and virtual laboratory trainers for education, scientific and industrial research to provide the necessary laboratory equipment [1-5]. In particular, the Canadian company Quanser, which is the world leader in the development of practical laboratory work, offers a number of different trainers for studying ACS aimed at interfacing with LabVIEW.

Similar laboratory trainers, which are based on special hardware, have significant advantages in comparison with virtual labs. The user investigates the behavior of a real control object rather than a mathematically simulated virtual object. Such a trainer helps to make research of the influences of physical characteristics of any control object at ACS. The application of a mathematical model of any control object in a virtual lab does not allow taking into account all of the properties of a real control object.

The study (including e-learning) of ACS by applying appropriate hardware is more efficient and the learning course is better compared with studies using virtual instruments.

At the same time Quanser labs and other hands-on laboratories can be used only within laboratory rooms of educational institutions or commercial companies. This leads to inefficient use of expensive equipment and the impossibility of sharing among different organizations.

Therefore, implementation of remote labs, based on hardware, is relevant. They can become an integral part of modern research and e-learning and provide universities and other institutions with the opportunity to jointly use expensive laboratory equipment.

II. PROBLEM FORMULATION

An important requirement for such online courses and hands-on labs is to provide access to them with modern mobile devices such as laptops and tablets. This requirement is connected with an increase in the mobility of students, engineers and researchers who are no longer tied to their work places. They need to conduct research using online labs not only at work or at home, but also when they have days off or are travelling.

It should also be noted that modern users need to carry out their research in an interactive mode with video broadcasts in real time for operation control of the hands-on lab and to avoid damaging it.

A separate important issue of hands-on or virtual labs is the installation of additional special software for operation. It complicates use of personal computers (PC) in places with public PCs or at work if installation of new software is limited.

Considering the high popularity of LabVIEW in hands-on and virtual labs [6], some features of existing technologies for creating remote LabVIEW-based labs such as NI LabVIEW Web UI Builder, LabVIEW Remote Panels, Data Dashboard and LabSocket should be defined. To use NI LabVIEW Web UI Builder, one should install the Silverlight application, which is not fully supported by popular mobile devices based on Android operation systems (OS). The application of LabVIEW's Remote Panels requires prior installation of a LabVIEW Run-Time Engine application, which also is not supported by popular Android OS. Data Dashboard allows ensuring an interface between a mobile device and LabVIEW, but requires installation of the Data Dashboard on the device. We should also point out prospective LabSocket technology that can be used to automatically create the web interface for LabVIEW, although commercial technology with a closed source does not allow editing the created web interface and does not fully support LabVIEW's graphical elements. These peculiarities limit the creation of remote laboratories based on LabVIEW for e-learning or for doing research using the popular mobile devices.

III. PROBLEM SOLUTION

To meet these needs, both the online course and laboratory for the ACS study were developed within the frameworks of Tempus project 530 278 - TEMPUS-12012-1-DE-TEMPUS-JPHES "iCo-op: Industrial Cooperation and Creative Engineering Education based on Remote Engineering and Virtual Instrumentation"[7].

The purpose of this course is to acquire basic knowledge of modeling, analysis, simulation and design of the ACS of real objects. Prerequisites for the course are knowledge of fundamental high school mathematics and electrical engineering.

The course includes 11 lectures, 3 remote laboratory projects via the Internet with video broadcast for operation control of the lab in real time and 1 practical work "Calculation of the proportional-integral-derivative controller for control object with specified dynamic parameters." The volume of the course is 20 study hours and its duration is 2 months.

The course covers the following topics:

- Classification of ACS types.
- Time characteristics of linear ACS.
- Typical dynamic units of linear ACS.
- Frequency characteristics of linear ACS.
- Structural scheme of linear ACS.
- Stability of ACS.
- Stability criteria of ACS.
- The quality of ACS.
- Methods to improve the quality of ACS.
- Laws regulation in the ACS.
- Calculation of regulators.

The structure the online course and lab for the ACS study is shown in Fig. 1.

Through a laptop or a tablet connected to the Internet, users have access to the online course in Moodle platform 3. The online course consists of lectures, video and text guides for labs and the practical work, and an examination after every topic. Moodle 3 is installed on web-server Apache 2, which is on the OS GNU Linux, CentOS. The web-server provides Moodle activity and graphical web interface for the hands-on laboratory.

The lab is based on the National Instruments ELVIS II+ platform of with a mounted trainer Quanser DC Motor Board (Fig. 2). Equipment 5 is connected to PC 4 with installed standalone LabVIEW software «SAC». The developed software «SAC» controls the Quanser DC Motor Board, acquires and processes data reflecting the work of the DC motor (motor shaft position and its velocity, the current that passes through the motor, and voltage that enters the motor, and so on) via the web interface. PC 4 also has an installed LV control service for on/off functions and for checking the status of the software "SAC" and video broadcast software via a web interface.

Software "SAC" and LV service control receive the control parameters; then the "SAC" transmits measured data to the main web-server 2. It displays the data measured and processed by «SAC» (up to 500 values per second depending on the hardware performance) and experiment video broadcast in real time. It should be emphasized that GNU Linux OS, CentOS with web-server 6 are installed as a virtual machine in the Virtual Box environment.

Video broadcasting is implemented using an HD webcam and open source video streamer FFmpeg, which provides video compression and stream from PC 4 to the main server 2. The main server has an installed media server FFmpeg [8], which provides web-streaming (see Fig 3, left side).

It should also be noted that LV control service can manage the software at PC 4 via the Internet. It allows using different labs on the same PC depending on a user's needs. The main server 2 only has access to the LV control service to prevent an unauthorized running of other applications on the PC.

Software «SAC», LV control service and video broadcast software are installed on PC 4, connected to the National Instruments ELVIS II + and Quanser DC Motor Board. The virtual machine with server 2 is installed on a separate PC, which functions as a server.

Figure 1. The structure of the online course and laboratory for ACS study

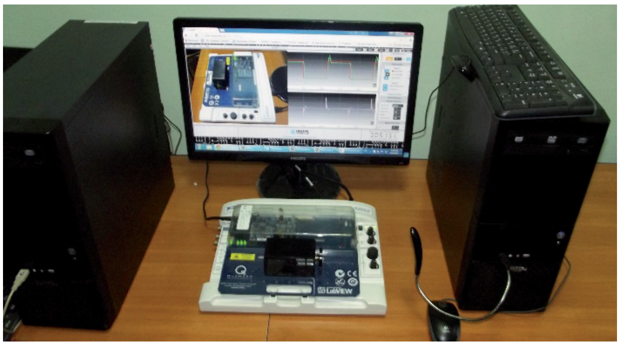

Figure 2. The equipment of the hands-on laboratory for ACS study in real time

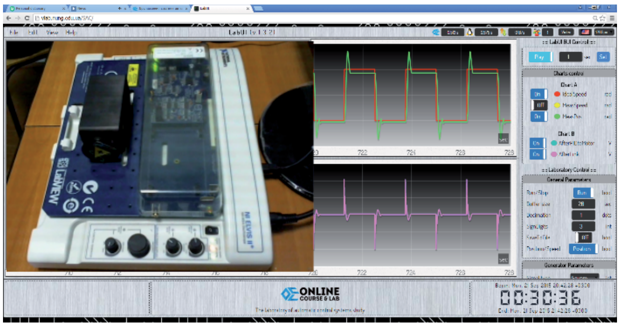

Figure 3. Web - interface of the hands-on laboratory with video broadcast in real time

Virtualization of server 2 and the autonomy of software «SAC», the LV service control, and video stream software allow one to configure the hands-on lab even on the basis of one PC with sufficient hardware resources. Therefore, the offered online course and laboratory for ACS study can be easily implemented with minimal network configuration in any educational institution if equipment 5 is available. A similar laboratory can also be developed for National Instruments, Quanser hardware, or other manufacturers.

The graphical web interface (Fig. 4) supports different screen widths (from 768 until 1366 pixels). This ensures correct representation of the lab for such popular mobile devices as laptops or tablets. The web interface (LabUI) uses the following modern open source technologies: HTML5, PHP, CSS, JavaScript, Ajax, jQuery[9], jQuery UI, Flot [10] and others.

The lab supports a multiplayer mode. This allows conducting online group research or laboratory workshops. In such cases, an educator or researcher operates the laboratory and other participants observe the research results in real time. A student can also operate the laboratory and a teacher can evaluate the correctness of research results made by a student or a group of students.

The lab constantly interacts with expensive hardware, which is why it is important to ensure the safety of the lab equipment in case of wrong user actions. Examples of incorrect operations are as follows: closing the laboratory webpage before the equipment is stopped; incorrect setting for equipment parameters, and so on. To protect the online lab against such erroneous actions, there is a special script for user control, i.e. server 2 continually monitors the number of active users connected to the lab. When a user visits the lab webpage, web-server 2 detects the emergence of a new user and sends an appropriate command to the LV control service. The service starts the software "SAC" with the default parameters. If the user closes the webpage, the server checks other active users, and during their absence it completely unloads both the "SAC" (it also automatically stops hardware) and the video stream software from the memory of PC 4. The procedure allows one to perform the restart of the lab in cases of incorrect user actions by simply closing and reopening the lab's webpage.

The laboratory has a status bar that displays real-time information about the presence of lab equipment failures, data transfer time from "SAC" to the server, data update time from the server, amount of data transferred by the server, number of active users, video stream mode, language and screen width of the web interface (left to right, Fig. 5). This status bar allows an administrator or any user to monitor correct lab activity.

During implementation of the lab, except for licensed LabVIEW, including LV blocks for Quanser used for interaction with Quanser DC Motor Board, exclusively open source technologies are used.

It should be noted that this lab allows users to gain necessary practical skills of ACS theory application. For example, users can study and compare both real and established positions of a DC Motor shaft (upper green and red lines on Fig.3, respectively) and observe real signals from an ACS regulator toward the DC Motor (bottom cyan line Fig. 3). This can help users find the best parameters of the ACS regulator to eliminate the difference.

Figure 4. Web - interface of the online course and hands-on laboratory for different mobile devices

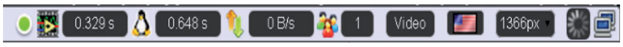

Figure 5. Real-time status bar of the hands-on laboratory

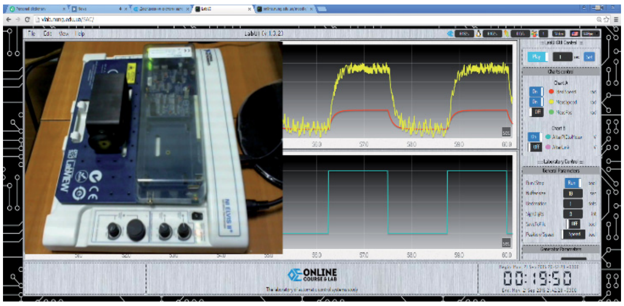

Figure 6. Web - interface of the online laboratory for ACS research in real time

Users can also assess both real and simulated speeds of the DC Motor shaft (upper yellow and red lines on Fig.6, respectively). The simulated speed is received from the ACS controller, which is developed by the user. Users can design any ACS controller (proportional-integral, proportional-derivative, and proportional-integral-derivative) and can research the activity of the DC Motor being controlled by a user's ACS.

Having calculated the ACS controller parameters, users can identify the real established speed (Fig. 7) or position of the control object.

The hands-on lab for this ACS study allowed performing the following lab works:

- studying time and frequency characteristics of ACS typical links;
- studying any ACS controller (proportional-integral (PI), proportional-differential (PD) or proportional-integral-differential (PID)) depending on amplitude, frequency, shift, waveform of an input signal;
- modeling controllers (PI, PD or PID) with simultaneous observation of simulated and real speed signals or positions of the DC motor;
- studying the dependence of regulators with feedback on the sampling frequency of the measured signal;
- studying untypical regulator links made by the user as a set of characteristic equations, including the 2nd order equations;
- studying regulators with and without feedback;

- determining the dynamic characteristics of controllers based on their acceleration curves;
- studying ACS regulators depending on output signal disturbance;
- determining the influence of the DC motor windup and anti-windup on the controllers in ACS;
- determining the quality characteristics of linear ACS, etc.

Thereby the lab is an integral part of the online course and can promote gaining sufficient practical skills and knowledge.

IV. CONCLUSIONS

We believe the developed online course and hands-on lab meets modern requirements for conducting online research and e-learning. It should be noted, that the system offers the following advantages:

- has integrated theoretical and practical parts to efficiently gain knowledge and practical skills in ACS study;
- does not need any additional client software;
- supports modern mobile devices such as laptops and tablets;
- works via modern web browsers such as Chrome, Opera, Safari;
- provides a lab interactive mode with simultaneous display of research results;
- provides video broadcasts of the lab activity;
- is based on open source technologies;
- supports lab multiplayer modes for group online learning or research;
- provides a wide range of ACS research based on a DC motor;
- can be quickly deployed in any institution and adapted to the other equipment.

If a student successfully passes all examinations and performs lab work, then he will receive an international certificate, shown in Fig. 8. The certificate confirms the user's basic theoretical knowledge and practical skills in modeling, analysis, simulation and design of ACS.

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Figure 7. Real and simulated speeds of the DC Motor shaft after controller parameters calculation

CERTIFICATE

Vasyl Pishchak
personal identification number: ______

It is hereby certified that he/she attended the training program

Theory of automatic control systems

held from .... to .... in ....

The attendee has successfully passed the examination.

The programme of the course consisted of lectures, laboratory and practical exercises and covered the following main topics:

- ✓ Classification of automatic control systems (ACS) types.
- ✓ Time characteristics of linear ACS.
- ✓ Typical dynamic units of linear ACS.
- ✓ Frequency characteristics of linear ACS.
- ✓ Structural scheme of linear ACS.
- ✓ Stability of ACS.
- ✓ Stability criteria of ACS.
- ✓ The quality of ACS.
- ✓ Methods to improve the quality of ACS.
- ✓ Laws regulation in the ACS.
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Karsten **Henke**
The project coordinator

Fedir **Kozak**
First vice-rector of IFNTUOG

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Figure 8. International certificate about completion of the online course of ACS study

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