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Virtual and remote laboratory as a complementary support in control education

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Abstract
Virtual and remote laboratories are excellent tools to complement real on-site laboratories. This paper presents the development of a virtual and a remote laboratory to support and enhance the students' experience when dealing with a real pilot plant for control engineering education. Both labs, virtual and remote, are developed in Easy Java/JavaScript Simulations (EjsS) with similar interfaces and equivalent tasks as the real lab. The evaluation of the complementary labs through a student survey is presented at the end of the paper to validate the usefulness of this approach.

Keywords Control education, Virtual lab, Remote lab, EjsS

1 Introduction

In recent years, with the improvement of computing and networking capabilities, there have been many developments related to virtual and remote laboratories. The impact of the coronavirus pandemic (COVID-19) on education has reinforced the role of virtual and remote laboratories in education [1]. Control engineering education is an area that can be benefit from these two types of laboratories, taking into account the cost and size of the equipment.

Virtual laboratories allow interaction with software that simulates a real laboratory system. This has a number of advantages like: lower cost, no need to maintain physical components, simultaneous access by students. On the other hand, the real experience cannot be fully captured. In Guzmán and Joseph [8], a Web-based virtual simulation model of an anaerobic digester using a Javascript-based platform was developed to support courses in process control and process design. In Jara et al. [9], a new dynamic collaborative e-learning system was developed, based on Java applets with embedded virtual laboratories developed in Easy Java Simulations (EJS) and a real-time synchronised communication between these Java applets. In Deband Chattopadhyay [3], a virtual control systems laboratory is presented, developed using standard tools such as HTML, CSS and JavaScript. In Rossiter et al. [13], a virtual laboratory based on Matlab is presented to introduce the core concepts of PID autotuning. As a survey, Reeves and Crippen [12] show a systematic review of virtual laboratories in Undergraduate Science and Engineering Courses covering the period 2009–2019. Some other recent examples can be found in the literature, but, in general, virtual labs try to provide an intuitive environment where students can learn and experiment with systems that emulate the real world. Often, standard and open source technologies are used to develop these virtual labs, so that cost and maintenance are not a handicap for educational institutions. Although HTML, CSS, JavaScript and Java are used where Internet access is convenient, there are tools such as EJS [6], that greatly facilitate the development, maintenance and deployment of virtual laboratories. Furthermore, in control engineering education, Matlab [11], although not open source software, is practically a standard when dealing with control concepts.

Remote laboratories allow access to a pilot plant from a, in principle, long distance, usually via the Internet network. It can have multiple uses, such as sharing equipment between laboratories from different institutions, allowing students to access from home at any time, etc. Fabregas et al. [7] describe the creation of remote laboratories based on Simulink and EJS. Dormido et al. [5] presents a web-based control lab of a three-tank system where the client side was developed in EJS. In Lazar and Carari [10], the authors present a networked control system lab for remote process control and the architecture supporting it. In Ayvaz et al. [2] an industrial-scale remote access control laboratory system was developed to address the potential lack of practical laboratory experience in response to the Coronavirus Pandemic 2019 (COVID-2019). The same authors, in Yapakçı et al. [14], propose a methodology for developing industrial-scale remote access control laboratory applications using industrial automation and Industry 4.0 architectures. After reading these and other papers related to remote laboratories, it is clear that a remote laboratory involves several communication-related issues that need to be addressed.

Although the existence of virtual and remote laboratories is an advantage in terms of accessibility 24 h a day from any location with Internet access, another point of interest is to use them as a complement to the traditional on-site laboratories. In this sense, virtual and remote laboratories must be consistent with respect to the real world laboratory in terms of functionality, interface and ease of use. In this paper, a real pilot plant of the Department of Systems Engineering and Control of the University of Valladolid is taken as a case study, and both a virtual and a remote laboratory have been developed in order to increase the availability and complementary uses for the students. The paper is organised as follows. In sect. 2, a description of the pilot plant is presented as a case study. Section 3 lists all the functionalities available in the real plant that must be maintained in the virtual and remote laboratory as a prerequisite. Sections 4 and 5 describe the virtual and remote laboratories respectively, focusing on the relevant implementation decisions. An educational evaluation of the implemented laboratories is discussed in sect. 6. Finally, sect. 7 presents the main conclusions of the work.

2 Pilot plant description

The pilot plant (Fig. 1), which will be the basis for the virtual and remote laboratory, consists of two open water tanks connected at the bottom by a short pipe. These tanks are placed on a tray that acts as a buffer, so that the water is recirculated to save water. There are several pieces of instrumentation associated with the system, such as: a pump, a level transmitter, a frequency variator, a data acquisition board, a personal computer, a

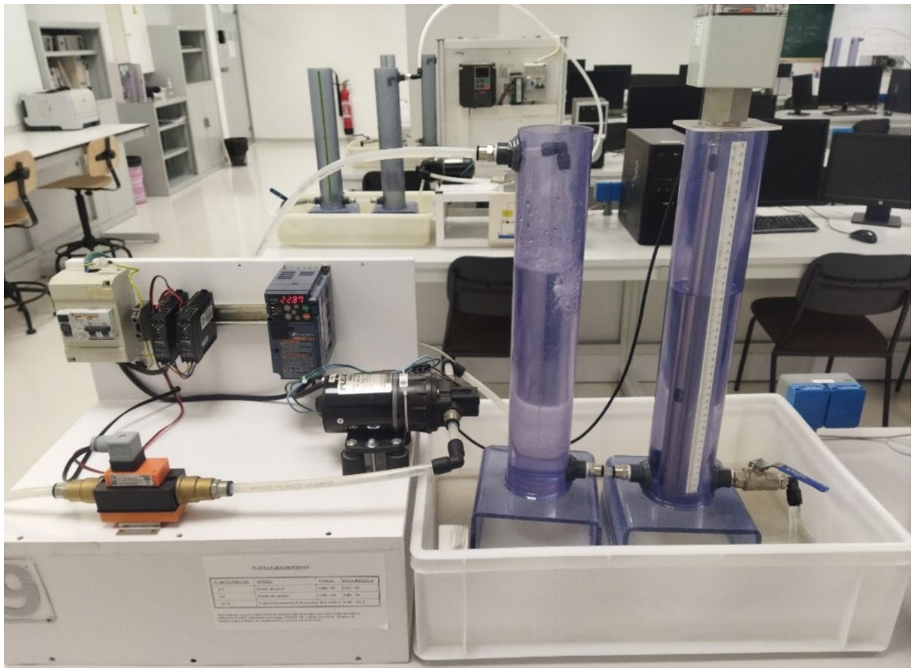

Fig. 1 Pilot plant photo in the control laboratory

Table 1 Main components of the pilot plant

Tanks	Two cilinders, height 50 cm, diameter 8 cm
Interconnection pipe	Length 15 cm, diameter 1 cm
Power supply unit	24 V
Pump	Maximum flow 18.2 l/min
Level transmitter	Capacitance sensor, 4-20 mA output
Frequency variator	Nominal power 0.4 kW
Data acquisition board	Analog inputs 14 bits resolution, analog outputs converter 12 bits

manual valve and a power supply unit. The operation of the system is quite simple. The pump, the power of which is controlled by the frequency variator, takes water from the tray and feeds it to the first tank. Water flows from the first to the second tank through the bottom pipe and, at the same time, water flows out from the second tank to the same tray. The level transmitter, located in the second tank, sends its signal to the data acquisition board and consequently to the PC. The PC can decide, on the basis on the level in the tank, which value to send to the frequency variator in order to achieve the control objectives (e.g., maintaining a constant level value in spite of external disturbances or changing the value of the desired level in the second tank). The main characteristics of each component of the system are described in the Table 1.

3 Functionality

The system configuration serves as a basis for the students to practice with PID controllers (testing, configuration, tuning and implementation). The main objective of the system is to maintain the water level in the second tank at a specified desired level (setpoint). As the water enters into the first tank but only the level of the second tank is measured, this introduced a slightly more complex dynamic with respect to having only one tank. The manual valve at the outlet of the second tank introduces a unmeasured disturbance affecting the level of water in the second tank. In this sense, the main variables to be taken into account in the system are:

- Pump power: Manipulated variable (through the frequency variator).
- Level of the second tank: Controlled variable (measured by the level transmitter).
- Manual opening of the valve at the outlet of the second tank: Disturbance

Students in the laboratory usually carry out the experiments using an in-house software called JavaRegula [15], in which they can follow all the steps for designing a controller (PID or others), such as:

1. Configuration of control loops
2. Calibration of transmitters and actuators
3. Configuration of the graphical interface
4. Manual operation
5. Logging of historical data as an export file
6. Tuning of PIDs and other advanced controllers
7. Control operation mode
8. Etc.

A screenshot of the JavaRegula software performing a PID control of the real system is shown in Fig. 2, where the control action (pump power) is drawn at the top, and the tank level and its setpoint are drawn at the bottom. A contextual menu offers the option to change the parameters of the controller and the control operation mode.

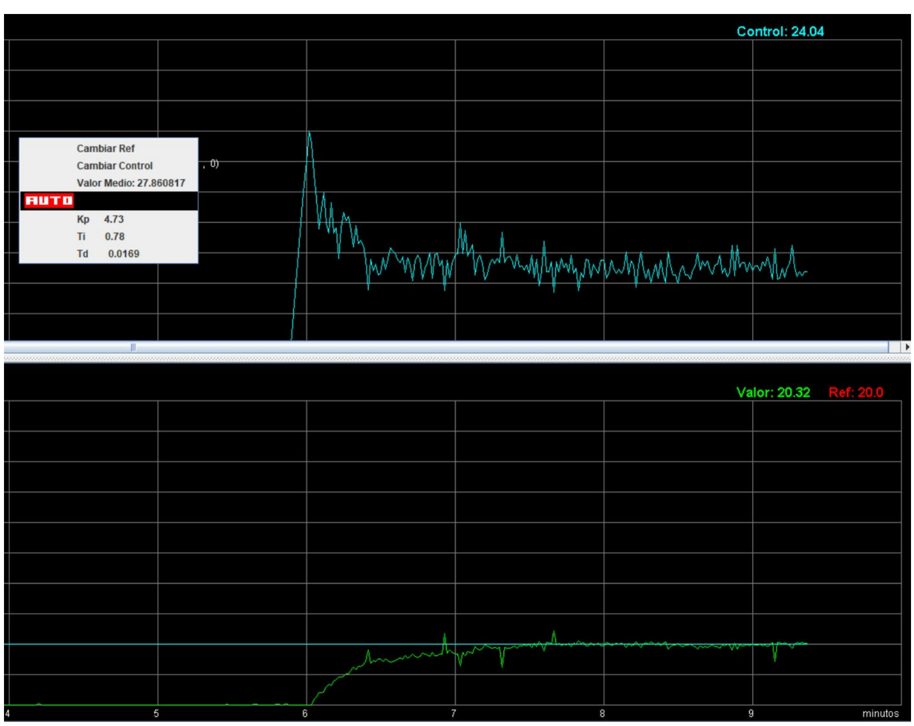

Fig. 2 Real laboratory screenshot with the JavaRegula software

4 Virtual laboratory

The idea of the virtual laboratory is to be as similar as possible to the control system on site (JavaRegula), so that students can reinforce some of the tasks to be performed on the real plant, such as:

- Familiarise themselves with the operation of the plant.
- Carry out experiments in the virtual laboratory if it is not possible to access the real laboratory.

In this sense, the virtual laboratory could be considered as a complement to the real laboratory, where students can play with the system at any time, from any place, without any restrictions. In fact, if the student does not have access the real laboratory, all the tasks related to the exercise could also be done in the virtual laboratory:

- Open-loop experiments (manual) to collect dynamic data
- Fitting a simple first order model plus dead time to the data
- Obtain the optimal PID parameters using one of the available PID tuning methods
- Implement the obtained PID parameters in the virtual lab
- Validate the response to changes in the setpoint or the influence of the disturbance
- Fine-tune the PID parameters

4.1 EjsS

EjsS [6] is a software tool for the rapid creation of applications in Java/JavaScript. At the end of the development process, one ends up with a final product composed of XHTML, HTML, CSS, JavaScript and images that can be published on any web server, but the important point of EjsS is that it is not necessary to be a programmer to create the graphical interface or the underlying code. EjsS has been designed to allow science teachers to create science simulations without worrying about the technical aspects. Simulations built with EjsS can be visualised in any web browser and are platform independent. It is not the purpose of this paper to delve into all the features and possibilities of EjsS. The reader interested in developing his own simulations in EjsS can access its official website https://www.um.es/fem/EjsWiki/ where the installer, manuals and exam ples can be found.

4.2 Functionalities of the two-tank virtual laboratory

The aim of the interface of this virtual laboratory is to resemble the main functionalities encountered on the JavaRegula interface when experimenting with the real plant. In this sense, as an aid for the student, a graphical sinoptic has been included on the left (see Fig. 3), so that it resembles the real physical system. Four indicators have been added: the level in the second tank (in cm), the power of the pump (in %), the flow rate (in l/min) and the opening of the manual valve (in %). As in the JavaRegula interface, two graphs show the evolution of the main variables of interest: the level of the second tank and its reference in automatic mode, and the feeding flow. These graphs are updated every 0.5 s, although this frequency can be changed if desired. In the Options section there are some controls that allow the user to play/pause/reset the simulation, speed up the simulation, register the data to be saved to disk and a pair of controls for the graph properties. At the bottom of the interface, two controls allow the user to manipulate the pump and the manual valve when in manual mode or the PID parameters when in automatic mode,

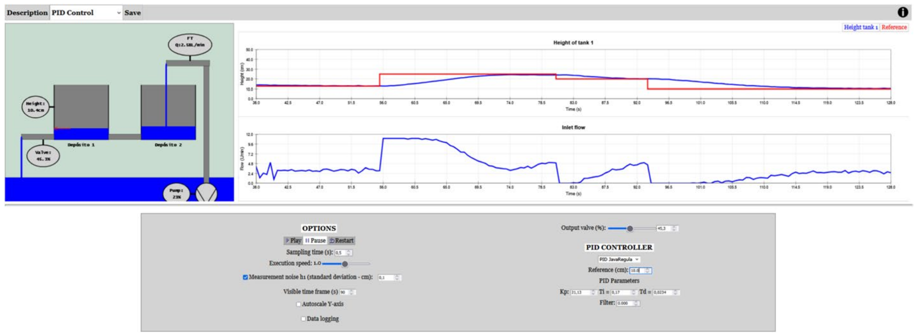

Fig. 3 Virtual laboratory screenshot

which can be selected from the top menu. In automatic mode, two PID formulations have been implemented: an ideal PID and the exact same formulation as in JavaRegula, so that direct comparisons can be made between the virtual and the real system.

Access to the virtual lab is publicly available at https://www2.eii.uva.es/jmzama/material/labo2tanques/virtual_en.xhtml

5 Remote laboratory

The virtual lab is an excellent tool for the students to familiarise themselves with the pilot plant, but as a simulation it cannot capture every aspect of reality. When students are exposed to a real system, they can learn how to deal with certain issues, especially instrumentation issues, which will prepare them to be better engineers. In the case of our case study, a remote laboratory can be a good complement to the real pilot plant for students who need to carry out experiments on the pilot plant when the laboratory is closed, just to complete unfinished work on site, or for students who are unable to attend laboratory lectures for any reason, such as illness, disability or forced to be away from the University for any other reason.

In this case, and for this very first version of the remote lab, no security measures have been considered for access to the remote lab. It is assumed, at least in our case, that its use will be limited to occasional times, so whenever a student needs to access the pilot plant via the remote lab, the servers would be started for the required time slot, so that the student can connect and perform the experiments. If, for some reason, another student tries to connect to the remote lab at the same time, that second student (and subsequent ones) would only be allowed to visualise the operation of the plant, but not to operate on it.

The design of the remote lab interface has been based on the virtual lab interface, so students do not have to learn another interface. Of course, there will be some differences. For example, the synoptic of the plant has been replaced by a video stream coming from a webcam focused on the tank whose height is being controlled. There is a configuration button to enter the URLs of the webcam and data server (allowing a common interface for any other pilot plant). The list of options has also been considerably reduced, as there is no need to simulate noise and the speed of execution cannot be changed (it is always real time). The rest of the interface is quite similar, as can be seen in figure 4.

The RIP protocol [4] was used as the mechanism for exchanging data between the interface and the plant, since it is well integrated in EjsS and easy to implement on the server side. A Python version of the server has been developed that communicates

Fig. 4 Remote laboratory screenshot

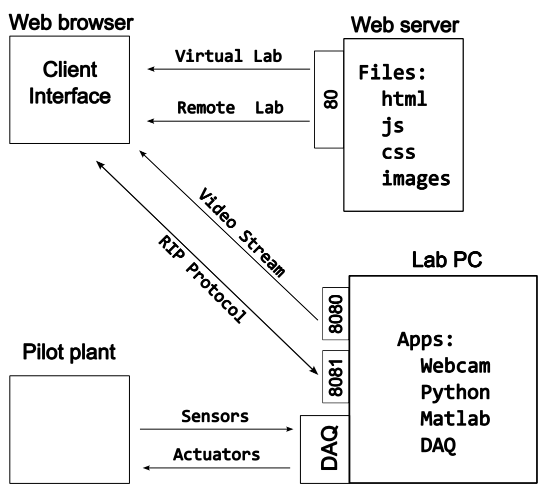

Fig. 5 Components of the remote laboratory

directly with Matlab. Matlab is responsible for running the PID algorithm and to communicating with the Data Acquisition Board (DAQ) to receive data from the plant (level transmitter) and send controller actions to the plant (pump power).

All the files needed for the user interface can be obtained from an external web server, independent of the RIP server running on the PC connected to the pilot plant. The scheme of the different modules and their communication is shown in figure 5. As can be seen in the figure, the virtual laboratory, described in the previous section, has been included in the same web server.

6 Educational evaluation

In order to evaluate the usefulness of the virtual laboratory as a complementary support to the real laboratory, an anonymous survey was carried out among the students of the subject "Process Control" included in the last semester of the Degree in Industrial Electronics and Automatic Engineering at the University of Valladolid. Although the remote laboratory was tested, no survey was carried out because it was only installed in one of the laboratory workstations (due to firewall restrictions) and this was kept as an emergency alternative that was not needed so far.

The survey included two statements to assess the usefulness of the virtual lab:

1. I have found it useful to test with the virtual lab to understand how the system works.
2. I think that the virtual laboratory could replace the real system in emergency situations where access to the physical laboratory is not possible.

Students were asked to indicate to what extent they agreed with the above statements. Possible answers were: Very much, Quite a lot, Somewhat, A little, Not at all.

According to the students' answers (18 out of 24 students responded), 33.33% of them agreed very much and 66.67% of them agreed quite a lot with the first statement. Regarding the second statement, 22.22% of them agreed very much, 55.56% agreed quite a lot and 22.22% agreed somewhat.

The results of the survey show that the students find the virtual lab a good tool for a better understanding of the pilot plant operation and that they think that it could be a good alternative if the real plant were not accessible.

7 Conclusions and further research

In this paper, a virtual and a remote laboratory have been developed for an existing pilot plant. The focus has been set on usability and maintaining the same functionality of the real laboratory, so that it can be used not only as a replacement but also as a complement.

The tool used for its development was EjsS, which allows easy design of the laboratories and their construction without the need for programming skills. It also allows the laboratories to be exported using standard web technologies so that they can be published on any web server.

A survey presented to the students shows their satisfaction with the virtual laboratory in terms of a better understanding of the pilot plant and its usefulness in case of unavailability of the real plant.

There are two main limitations to this study. Firstly, as this was the first academic year in which the virtual lab was tested among students, the sample size was small, the scope was local and the number of proposed activities was low. To widen the scope of the analysis, we will continue testing it in subsequent years and extend the range of activities proposed to students. Furthermore, the virtual lab is planned to be published on the UNILabs (University Network of Interactive Laboratories) platform (https://unilabs.dia.uned.es/) to increase its accessibility to a large number of students. With respect to the remote lab, a similar study to that of the virtual lab needs to be conducted to assess its utility, and an improved access policy must be implemented, incorporating scheduling tools and user authentication. These issues will be addressed in a future version of the remote lab.

Access scalability should not pose any issues in the case of the virtual lab, as it is hosted on a central web server to which a large number of users can connect simultaneously. In any case, the limitation will depend on the configuration of the web server. The remote lab could have more issues, as the PC hosting communications is a standard lab PC. Therefore, a more in-depth study must be taken into consideration when implementing user accessibility controls in future software versions.

Author contributions
All authors (J.M.Z., J.C.R. and G.A.) contributed to the study's conception and design. The first draft of the manuscript was written by J.M.Z., and all authors commented on versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Statement regarding research involving human participants and/or animals
Not applicable.

Ethics approval and consent to participate
All procedures performed in the study were approved by the University of Valladolid in accordance with its own guidelines and regulations. Informed written consent was obtained from all individual participants included in the study.

Consent for publication
Informed written consent was obtained from all individual participants included in the study to publish the anonymized data.

Informed consent
This study was performed in line with the principles of the Declaration of Helsinki. Informed written consent was obtained from all individual participants included in the study to participate in the study and to publish the anonymized data.

Competing interests
The authors declare no competing interests.

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References

1. Abumalloh RA, Asadi S, Nilashi M, Minaei-Bidgoli B, Nayer FK, Samad S, et al. The impact of coronavirus pandemic (covid-19) on education: the role of virtual and remote laboratories in education. Technol Soc. 2021;67:101728. https://doi.org/10.1016/j.techsoc.2021.101728.
2. Ayvaz B, Yapakçı B, Gültekin HE, Yumuk E, Ergenç AF. Application of industrial remote access control laboratory. 4th IFAC Workshop on Internet Based Control Education - IBCE 2024. IFAC-PapersOnLine. 2024;58(26):130–5. https://doi.org/10.1016/j.ifacol.2024.10.283.
3. Deb AK, Chattopadhyay P. A virtual laboratory for control system engineering. 4th IFAC Workshop on Internet Based Control Education - IBCE 2024. IFAC-PapersOnLine. 2024;58(26):64–9. https://doi.org/10.1016/j.ifacol.2024.10.272.
4. de la Torre L. Specification of the remote interoperability protocol for online laboratories. 2019. Accessed date: June 2024. https://github.com/UNEDLabs/rip-spec
5. Dormido R, Vargas H, Duro N, Sánchez J, Dormido-Canto S, Farias G, et al. Development of a web-based control laboratory for automation technicians: the three-tank system. IEEE Trans Educ. 2008;51(1):35–44. https://doi.org/10.1109/TE.2007.893356.
6. Esquembre F. Easy java simulations: a software tool to create scientific simulations in java. Comput Phys Commun. 2004;156(2):199–204. https://doi.org/10.1016/S0010-4655(03)00440-5.
7. Fabregas E, Farias G, Dormido-Canto S, Dormido S, Esquembre F. Developing a remote laboratory for engineering education. Comput Educ. 2011;57(2):1686–97. https://doi.org/10.1016/j.compedu.2011.02.015.
8. Guzmán JL, Joseph B. Web-based virtual lab for learning design, operation, control, and optimization of an anaerobic digestion process. J Sci Educ Technol. 2021;30(3):319–30. https://doi.org/10.1007/s10956-020-09860-6.
9. Jara CA, Candelas FA, Torres F, Dormido S, Esquembre F, Reinoso O. Real-time collaboration of virtual laboratories through the internet. Comput Educ. 2009;52(1):126–40. https://doi.org/10.1016/j.compedu.2008.07.007.
10. Lazar C, Carari S. A remote-control engineering laboratory. IEEE Trans Ind Electron. 2008;55(6):2368–75. https://doi.org/10.1109/TIE.2008.920650.
11. MathWorks. Matlab version: 9.13.0 (r2022b). Natick, Massachusetts. United States: The MathWorks Inc.; 2022. Accessed date: June 2024. https://www.mathworks.com
12. Reeves SM, Crippen KJ. Virtual laboratories in undergraduate science and engineering courses: a systematic review, 2009–2019. J Sci Educ Technol. 2021;30(1):16–30. https://doi.org/10.1007/s10956-020-09866-0.
13. Rossiter J, Visioli A, Dormido S, Bars R. A matlab virtual laboratory to support learning of auto-tuning pid approaches. 4th IFAC Conference on Advances in Proportional-Integral-Derivate Control PID 2024. IFAC-PapersOnLine. 2024;58(7):73–8. https://doi.org/10.1016/j.ifacol.2024.08.013.

14. Yapakçı B, Ayvaz B, Gültekin HE, Yumuk E, Ergenç AF. Methodology and development of industrial-scale remote access control laboratory. 4th IFAC Workshop on Internet Based Control Education - IBCE 2024. IFAC-PapersOnLine. 2024;58(26):43–8. https://doi.org/10.1016/j.ifacol.2024.10.268.
15. Zamarreño J. Remote control system for laboratories: Javaregula. In: Second IFAC workshop internet based control education (ibce'04), Grenoble, Francia. 2004.