Use of Remote Access Technologies and WebLabs as Teaching-Learning Strategy in Engineering

Uso de Tecnologias Acessíveis Remotamente como Estratégia de Ensino-Aprendizagem na Engenharia

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Resumo
Este artigo apresenta o uso de ferramentas tecnológicas e laboratórios remotos visando o ensino na área de controle de processos para cursos de engenharia. A proposta é demonstrar ferramentas que podem ser utilizadas para permitir o ensino mediado por tecnologias, com seus benefícios e limitações, considerando a necessidade de realizar atividades de caráter prático para complementar as aulas teóricas visando melhor assimilação dos conteúdos para uma efetiva aprendizagem. Além disso uma visão geral de projetos usando laboratórios remotos é apresentada, incluindo os seguintes WebLabs: "WebLab de Controle de Velocidade e Posição de Motor de Corrente Contínua", "Weblab de Controle de Movimentação de Robô Móvel", "WebLab de Controle de Temperatura em um Forno Didático" e por fim o "Weblab de Controle de Nível em um Tanque". Este último laboratório será detalhado mostrando os recursos didáticos disponíveis, suas funcionalidades, os experimentos que podem ser realizados e os primeiros passos para aqueles que desejam implementar um laboratório remoto na área de controle de processos.
Palavras-chave: Educação. Laboratórios remotos, Sistemas de controle. Controle de Processos. Identificação de sistemas.

Abstract
This work presents the use of technological tools and remote laboratories developed in order to teaching process control in engineering courses. The proposal is to demonstrate tools that can be used to allow teaching mediated by technologies, with their benefits and limitations, considering the need to carry out practical activities to complement the theoretical classes aiming at better assimilation of the contents for an effective learning. Furthermore, an overview of projects using remote laboratories developed are presented, such as: "WebLab for Speed and Position Control of DC Motor", "WebLab for Mobile Robot Motion Control", "WebLab for Temperature Control of a Didactic Oven" and finally a "Level Control System with Remote Web Access". This last remote laboratory will be detailed showing the didactic resources used, the available functionalities, the

experiments available and the first steps for those who want to implement a remote laboratory for process control.

Keywords: Education. Remote Laboratories. Control systems. Process Control. Systems Identification.

1. Introduction

In the programs of engineering courses, the area of Process Control and Instrumentation is of considerable interest, because it allows students to acquire important skills related to this segment, but also because it constitutes an important area of professional activity. Thus, it is essential that the programs of these courses present subjects related to "Process Control" and "System Modeling" contemplated in the respective pedagogical plans, providing adequate training in professional content in this area.

The contents covered in this area are often complex and difficult to assimilate if practical experiments are not used as complement in the teaching-learning process.

In recent years, many of the laboratory teaching activities could not be implemented due to the Corona Virus pandemic and consequently, in many cases, laboratory experiments were replaced by simulation tools.

Although the computational resources and functionalities available in current simulation software allow some differentials, laboratory activities are certainly lacking in the learning process, mainly because it allows contact with devices and equipment similar to those that will be found in the industry. Additionally, the physical phenomena and functioning of applications can be much better understood and analyzed by having laboratory resources where the student can interact.

During this period of social distancing, new teaching and learning alternatives based on the use of technologies became part of teachers' daily lives. Some features that have been employed as alternatives include: Virtual Environment Learning, videoconferencing applications, videos stored in the cloud (lives, lessons recorded using whiteboard, pod casts), software simulations, remote laboratories (WebLabs), active learning activities with virtual group classes, in addition to interactive resources such as quiz, games, among others. There are a multitude of educational opportunities and resources available. Often the main difficulty is to be able to define the alternative that best fits the topic to be addressed in the specific discipline or course.

Some of these new teaching strategies are here to stay and remain an excellent alternative to improve the learning process. However, factors such as motivation, physical interaction, advanced technological resources, continuous feedback and proximity to the teacher are implications that must be considered for improvement in a teaching and learning process that meets quality education (Marques, 2020).

2. Technological Tools Used to Teach "Control Systems"

With the impossibility of carrying out face-to-face classes, it became necessary to use technological resources to allow approaching the contents in control system area. In order to minimize the impact of not using laboratories, the following teaching-learning strategies were adopted in 2020 and 2021:

- classes in Virtual Learning Environment (VLE):

- videos with lessons recorded in the classroom, with solution of exercises on the blackboard;
- videos with classes recorded in the laboratory, demonstrating applications of controls;
- use of simulations using Matlab software, aiming to demonstrate the results of control systems projects; these simulations were most often used during online classes;
- interactive activity carried out in the first class of the course and using the Kahoot! application; the activity consisted of a quiz, with questions related to the basic concepts seen in the previous course, in order to assess the previous knowledge acquired by the students;
- virtual access to machines installed in the laboratories to carry out the implementation of control systems;
- access to remote laboratories (WebLabs) in order to implement control systems in real time.

2.1 Remote Labs (WebLabs)

With the advancement of technologies, most industrial control systems are performed using digital technologies, typically industrial controllers or computerized systems, where the controller is performed through computational control algorithms. This characteristic is propagated in the academic environment, so that the vast majority of didactic kits aimed at the area of "Process Control" use microcontrolled systems or data acquisition systems connected to computers. Teaching software is used to implement the control algorithm as well as to change the controller parameters in order to allow the designer to evaluate the dynamic behavior of the systems resulting from these changes.

An alternative for remote access to these equipment and control applications are WebLabs, which provide the possibility of developing practical experiments, remotely accessing equipment in real laboratories through the internet, allowing its control and data acquisition in real time.

Several remote laboratories have been used to teach "Process Control" for Engineering courses (Assis et al., 2020b) (Casini et al., 2003) (Cruz et al., 2005).

The main remote laboratories available for use at Instituto Mauá de Tecnologia (IMT) are: level control system in a tank (Assis et al., 2019), speed and position DC motor control (Assis et al., 2013) and temperature control system in a didactic oven (Assis et al., 2016).

The experiments that can be performed using these remote laboratories include: modeling and identification of systems through step-response tests, identification by the least squares method, tuning and implementation of PID controllers, among others.

Additionally, with the objective of demonstrating the movement control of a mobile robot and the implementation of algorithms in microcontrolled systems, the WebLab for mobile robot motion control was developed.

In the following sections these remote laboratories will be detailed showing the didactic resources used, the available functionalities, the experiments available and the first steps for those who want to implement a remote laboratory for process control (Agrawal and Srivastava, 2007) (Assis et al., 2020b).

3. Remote Labs (WebLabs)

The concept applied to WebLabs at IMT can be generalized by the block diagram in Figure 1, and presents the following elements:
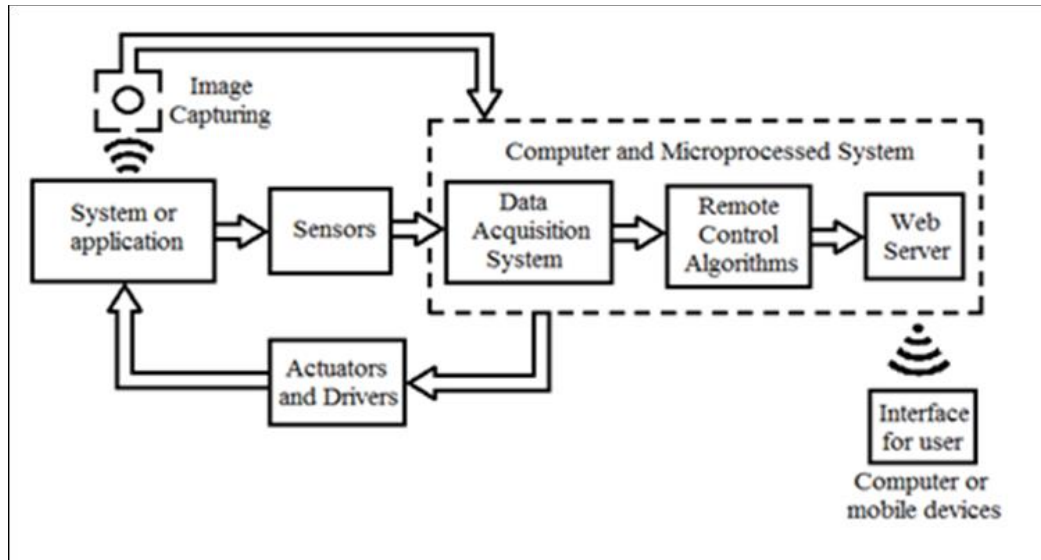
Figure 1 - Block diagram of Weblabs developed at IMT (Assis et al., 2020b)

• the system or equipment which will be remotely controlled;

• sensor monitoring system, which measure process variables in real time; may include electronic signal conditioning circuits and transducers;

• data acquisition system that captures signals at the appropriate sampling frequency and makes the data available to the WebLab system; these variables can be viewed (graphically or numerically) in the user interface;

• actuators and drivers, necessary when the designer wants not only to monitor the variables, but also to control them; drivers are electronic circuits used to convert control signals to appropriate levels depending on the application;

• control algorithm, which can be a conventional controller normally adopted in control applications (for example, a PID control) and/or algorithms that allow processing information and defining actions according to the values of the measured variables;

• image capture system, which collects images in real time;

• web server, responsible for providing system information (sensor signals, equipment images, etc.) in the remotely accessible interface by the user;

• user interface, is the way in which the user accesses the remote experiment over the internet, which can be one through a computer terminal, mobile device, HMI (Human-Machine Interface), among others.

The main limitation in the use of remote labs by students is the need to use the LabVIEW™ software, which requires users to install a plugin so that the complete interface can be viewed.

Another limitation is the need to leave the equipment in continuous operation, during the day and night, usually for a large number of days. This brings flexibility to the use of the application by the user, but on the other hand makes the solution unsustainable. This limitation can be minimized if the equipment is put into operation only on demand, that is, when someone is interested in remotely controlling the equipment or when the teacher proposes an activity or project using WebLab. Thus, unnecessary energy consumption is avoided, making solutions more sustainable and avoiding the need to keep a technician continuously monitoring the system's operation to put it back into operation in case of technical problems (for example: power outage or drop in internet signal).

Another interesting alternative is accessing the laboratory remotely using virtual machine concepts, for example, during an online class (Assis et al., 2020b).

Using WebLab it is possible for several people to access the same experiment simultaneously, although only one of them can interact. Anyway, when there is another student controlling the equipment, it is possible to visualize the results. In addition, the student can request access to the experiment. WebLabs have a system that manages access control, limiting each student a maximum time of use and releasing the equipment to other students, as long as they have requested access.

4. Speed and Position DC Motor Control WebLab

The first remote laboratory from IMT was created in 2010 and allows the communication of a central computer with a speed and position control system. The system consists of a didactic kit CtBoard, designed for engineers from IMT in order to develop control applications, together with the ELVIS^{TM} kit (Educational Laboratory Virtual Instrumentation Suite) from National Instruments.

The application with remote access was performed using software developed in LabVIEW^{TM}, including webserver that can be configured to limit each user's access time, as well as manage access requests. Through WebLab interface (Figure 2) it is possible to perform tests in open loop modifying the control input (Set Point) to produce changes in the speed or angular positioning of the motor. It is also possible tuning PID controller inserted in the feedback loop. Tuning can be performed in real time by the user, using the interface accessible on the internet, where it is possible to view the dynamic behavior of the system from modifications of the controller parameters.
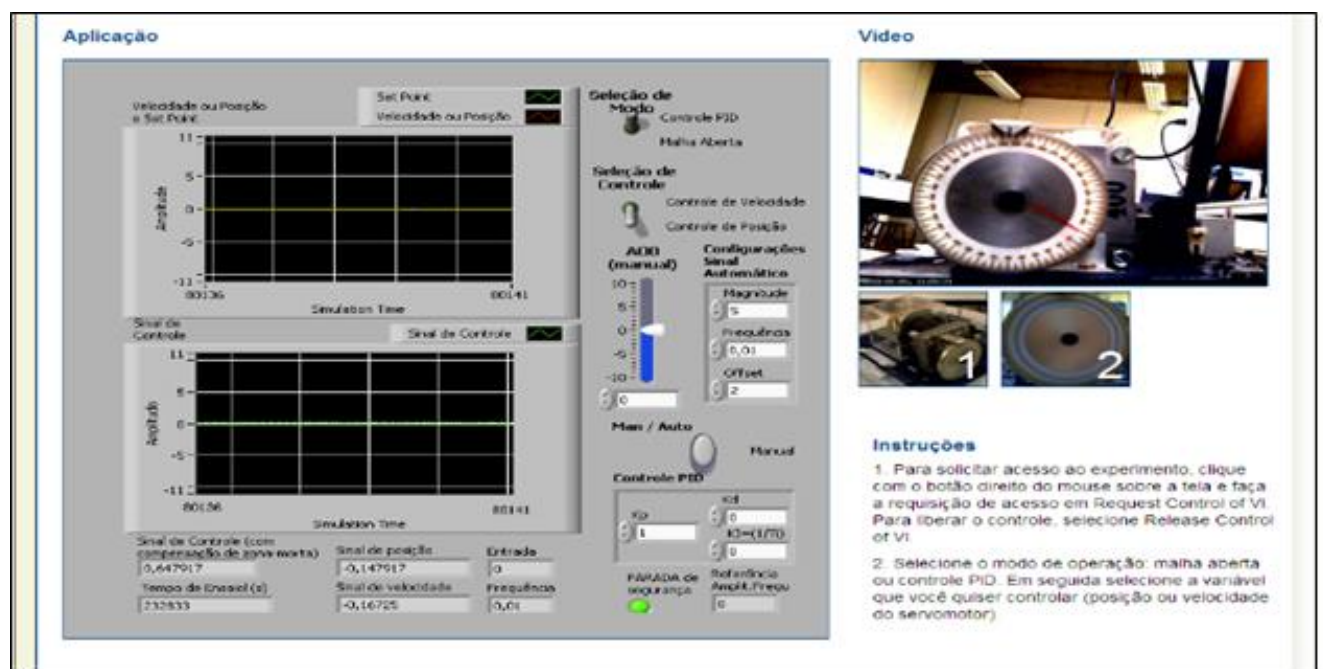

Figure 2 – WebLab for Speed and Position Control of DC Motor (Assis et al., 2020b)

An example using the DC motor speed and position control system is presented at the link: https://web.microsoftstream.com/video/9051e379-3cd9-4f9b-a4f2-150f5da13218.

This is a class held during the Covid-19 pandemic using the speed control system WebLab. A video showing an equivalent equipment to carry out the motor speed control is presented in the link: https://web.microsoftstream.com/video/751e9960-6a74-4de5-b564-e4dc7bbf7edd?list=studio

5. WebLab for Mobile Robot Motion Control

This project proposes the development of a remote access laboratory consisting of a small mobile robot (Figure 3(a)), which can be controlled remotely by Internet. The proposal presents an interesting tool for teaching concepts related to robotics, communication using ZigBee™ technology, process control, microcontrolled systems, servo drive, among others.

The project was presented during the "Hands On Mauá" (Assis et al., 2014), an event open to the public that intends to receive high school students. The event included lectures and visits to facilities and laboratories, but the focus was to hold workshops in several areas of knowledge related to the courses that the institution offers. Thus, it was an opportunity to combine theory and practice by demonstrating specific applications in playful, creative and interactive activities in order to help the students choosing the career.

The application developed in LabVIEW™ allows movement control in all directions based on image captured and presented at WebLab interface. Students were challenged to control the vehicle in order to get it out of the maze as quickly as possible (Figure 3(b) and Figure 3(c)).
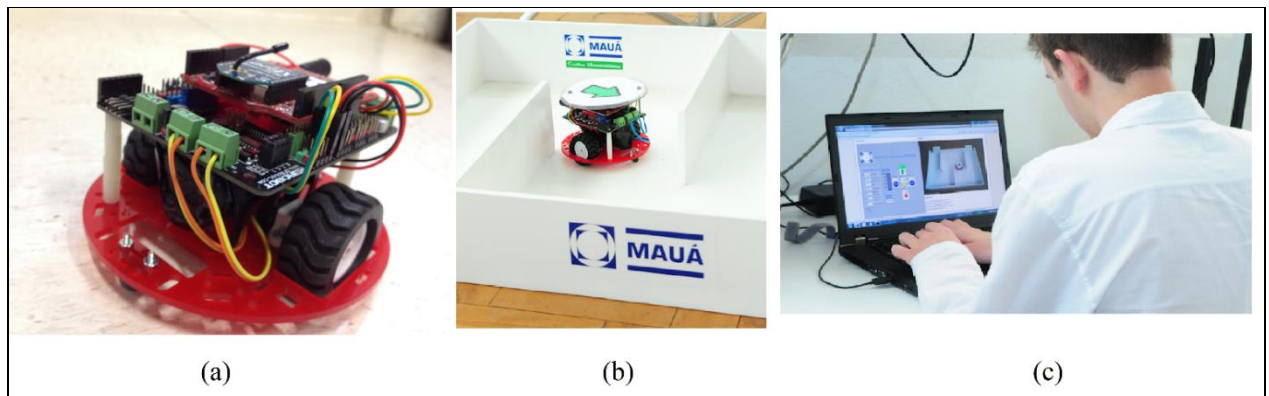

Figure 3 – WebLab for Control a Mobile Robot. (a) The Robot. (b) Robot in the Maze. (c) Student Controlling the Robot Through Internet. (Assis et al., 2020b)

6. WebLab for Temperature Control

This project consists the use of a teaching tool in order to perform the temperature control in a didactic oven (Assis et al., 2016).

The process control system (Figure 4) is a didactic heating system, built with wood, including a lamp, where the heating is controlled by adjusting the applied voltage. A thermocouple was used as temperature sensor and provides a voltage proportional to temperature measured. An electrical panel, including electronics signal conditioning circuits, provide the conversion of voltage levels of

sensor, while a solid-state relay produces adequate power in the lamp based on control signal generated by a data acquisition system. The control voltage applied to a cooler produces cooling.

The temperature control system was implemented using ELVIS™ toolkit and LabVIEW™.

The WebLab allows the PID temperature control and the system identification by Weighted Least Square Method with the differential that it could be accessed remotely, whenever the students wants, and thus producing better evaluating of results.

Figure 4 – Temperature Control System

6. Level Control System WebLab

The level control system is a didactic application (Figure 5) and its hardware consists a fluid control plant, which includes level, flow and temperature sensors, and a pump that allows the transfer of fluid from the lower to the upper tank. Electronic devices were introduced in order to allow the control to be performed computationally through an interface developed in the LabVIEW^{TM} software (Assis et al., 2019).

Figure 5 – Process Control System – PCS – Festo

The application's block diagram is illustrated in Figure 6 and includes level control plant, signal-conditioning board, Arduino Uno board, electronic driver for driving the pump using PWM (Pulse Width Modulation) signal and finally a computer. Note that the application allows the access the interface remotely by accessing a web page; so, the user can use smartphones or tablets, for example.
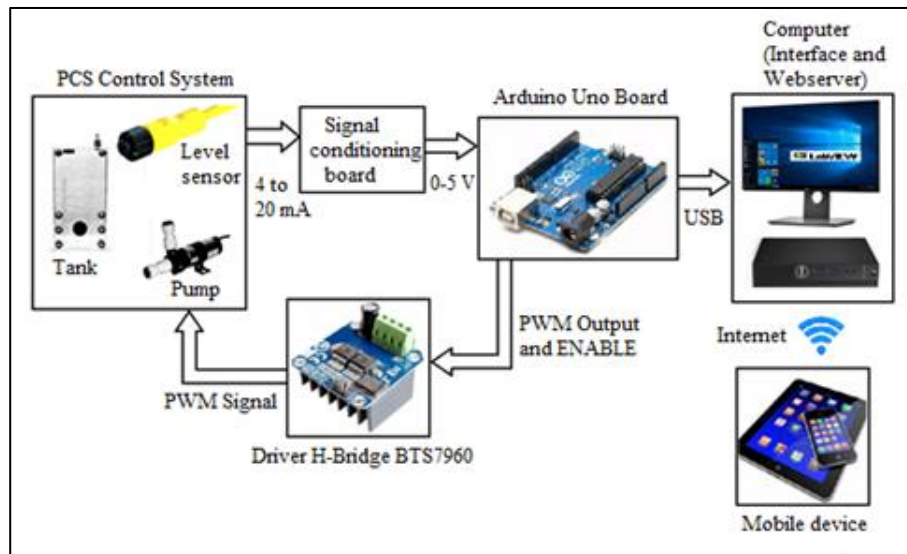

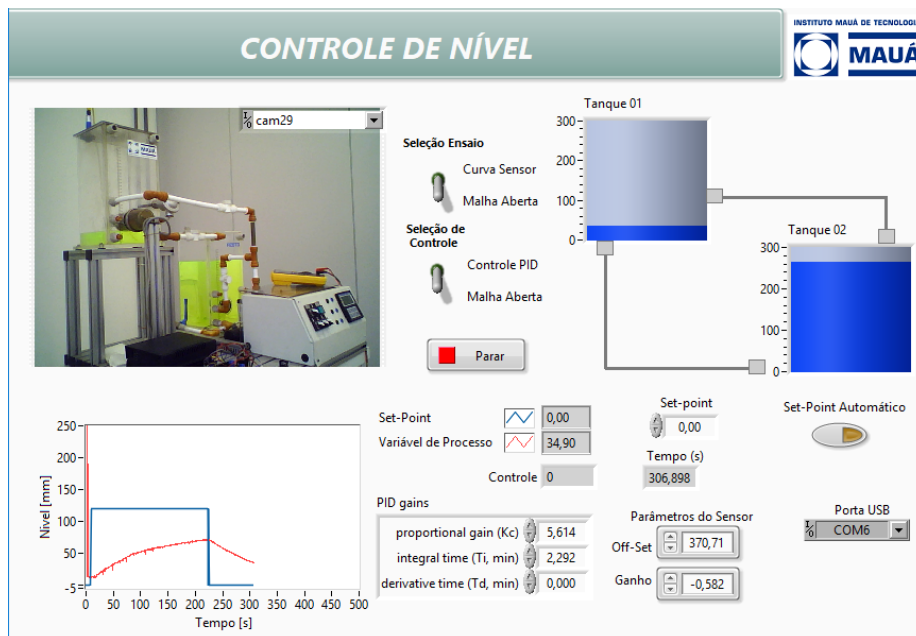Figure 6 – Block Diagram of Level Control System

Figure 7 – Level Control WebLab Interface

An example using the level control system in class is presented at the link:
https://web.microsoftstream.com/video/a585c5ea-abb0-4ca0-8ebd-1dfe5a0102b9

7. Results - Level Control System WebLab

In order to demonstrate the functionality of remote laboratories in the process control area, some experiments that can be performed using the level control WebLab will be presented.

Accessing the level control WebLab interface, shown in Figure 7, the user can perform the following experiments remotely:

- test to obtain the level x voltage relationship for level sensor by using the Least Squares Method (Aguirre, 2004);
- identification of transfer function through step response test;
- PID controller tuning for the closed loop level control system.

7.1 Relationship Tank Level x Voltage at Sensor

The experiment that allows deducing the relationship between the tank level (in millimeters) as a function of the voltage measured in the sensor is performed by directly varying the voltage at the pump. The user can measure the values in volts produced in the sensor and observe the level measured in mm directly in the tank. In this case, the user can use the image captured in real time to develop this activity remotely. Using two measurement points the user can deduce the equation of the line given by the following equation:

$$h(t) = as(t) + b \tag{1}$$

where: $h(t)$ is the level of the sensor measured in millimeters; $s(t)$ is the value of the voltage measured at the level sensor, a and b are the parameters of the linear equation that relates the level to the measured voltage, being respectively the slope of the line and the value of the level when the voltage measured at the sensor is zero.

After deducting the values, the student can adjust parameters a and b on the interface. This adjustment is important so that the variable measured at the interface coincides with the values of the effective levels of the tank. Therefore, after this adjustment, the user can check if the calculated variable $h(t)$ coincides with the value presented directly in the real time captured image by WebLab.

7.2 Experimental Identification by Step Response

The identification experiment allows deduce the level control system model, which can be represented by the following first order transfer function:

$$V_H(s) = \left(\frac{K_S}{\tau s + 1} \right) V_{Control}(s) = \left(\frac{K_S / \tau}{s + 1/\tau} \right) V_{Control}(s) \tag{2}$$

where τ and K_S are respectively the time constant and static gain of system.

The model can be determined by measuring, after submitting the system to a step response test (Assis et al., 2019), as shown in the graph of the WebLab interface in Figure 7. An example is shown in Figure 8.

7.3 Level Control Using PID Controller

The experiment using PID level control implementation can be carried out through the feedback control strategy, using PID controllers as presented in equation (3), where the K_P, T_I and T_d parameters have to be adjusted by the designer to produce an adequate performance, typically eliminating stationary error from the system and ensuring relatively quick response and without oscillation.

$$G_C(s) = \frac{U(s)}{E(s)} = K_P\left(1 + \frac{1}{T_I s} + T_d s\right) \tag{3}$$

In the tuning of the PID controller, several methodologies can be adopted, which the students learned in the theoretical classes, such as: Ziegler-Nichols method, pole cancellation method, direct synthesis method, among others.

Figure 9 illustrates an example of a result obtained from a project based on the pole cancellation method. Comparing the responses obtained in the waveforms of Figure 8 and Figure 9 is observed that the system presents a much faster response and eliminating stationary error.
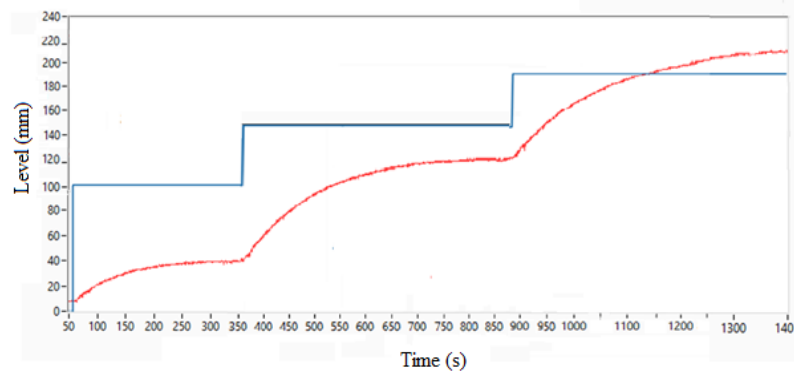

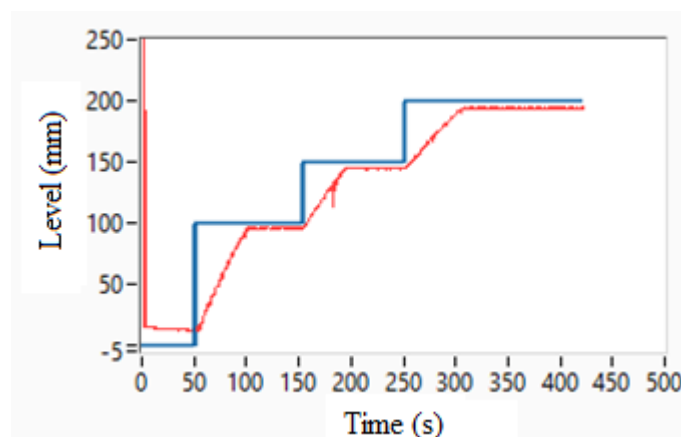Figure 8 – System Model Identification Test

Figure 9 – System Response with PID Control Timed by the Pole Cancellation Method

8. Conclusions

WebLabs were used as teaching tool in subject related to "Control Systems" in Electronic Engineering course and in the postgraduate course in "Industrial Process Control Engineering", as well in complementary activities.

In the case of "WebLab for Mobile Robot Motion Control", it was used in an event to attract students to the undergraduate course in Electronic Engineering or Control and Automation Engineering, having attracted the attention and interest of several young people.

In all cases, the differential is the possibility to use the didactic resources remotely, whenever the students want, and thus producing better evaluating of results.

All the WebLabs developed have interfaces that are easy to use and the algorithms are efficient. However, a major disadvantage is the need of installing a LabVIEW™ tool, requiring a procedure, which may consume time depending on the computer and, consequently, is discouraging, especially for those who do not have a lot of time to dedicate trying to access the experiment.

Although the software presents these drawbacks, the option for using this software is merely due to the ease of development of control algorithms, using graphical and intuitive programming, easy for students to understand, in addition to the ease of creating interfaces with attractive and intuitive design.

Another advantage of using the LabVIEW™ tool is the availability of the access management panel where we obtain information about users connected to WebLab. Through this tool, it is possible to obtain a list of the users who accessed the experiment (user's computer name and IP), date and time of the start and end of the connection, the status of the connection and the data transfer rate in bytes per second. It is also possible to control the access time, so that when there is more than one user trying to access the experiment (as is the case if there are many students interested to use the tool), a queue system is generated, in which the user who first accesses the network can maintain control for a while limited, from which your access will be blocked, and the experiment will be released to other users who are in the queue.

However, other programming tools are being evaluated and will certainly be presented in future works.

All the WebLabs mentioned in this paper work properly. However, they are put into operation just on demand, that is, when someone is interested in remotely controlling the equipment or when the teacher proposes an activity or project using WebLab. Thus, unnecessary energy consumption is avoided, making solutions more sustainable from this point of view. When desired, WebLab is enabled and put into operation for days or even weeks, all day and night, to meet demand.

Some remote laboratories focused on teaching electronics explore the possibility of design the hardware, changing the components and devices used. However, the remote laboratories presented at this work do not have this flexibility, since the objectives is just to allow the students to apply concepts related to system identification techniques, tuning of PID controllers, systems performance analysis based on changes imposed on inputs of control system, or simply perform the remote control. Thus, certainly the remote laboratories do not intend to replace the laboratory's practical classes, where the student can effectively work on the hardware of the equipment, carry out the design of the control and automation systems and effectively explore details of the programming of devices.

In relation to the level control system, the implementation can be carried out through the feedback control strategy, using PID controllers where its parameters have to be adjusted by the

designer to produce an adequate performance, typically eliminating stationary error from the system and ensuring relatively quick response and without oscillation.

To assess students' performance after using the tool, they must submit a report showing:

- the mathematical deduction of the system model based on test performed using WebLab;

- simulation using other software in order to compare the system performance with that obtained in the practical system accessed remotely;

- detailing of the method adopted when tuning the PID controller;

- comparison of the performance of the PID controller designed by simulation and that implemented in WebLab.

The results obtained were very promising, showing the feasibility of using the remote laboratory as a teaching and learning assessment tool.

Finally, after the good results, it is expected that this work will boost other research projects and experiments related to remote industrial process control, for example, using adaptive control.

Acknowledgements

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