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A Web Platform for Learning Control System Based on IoT Application

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A Web Platform for Learning Control Systems Based On IoT Application

***Abstract*—This work presents the development of an IoT application aimed for teaching process control, which allows remote access by web. It is a level control system with a friendly, responsive and interactive interface that allows the implementation of SISO type control systems (Single Input and Single Output) and can be accessed and controlled directly through mobile devices. The interface includes dashboards and graphics, real-time monitoring of the equipment image and adjustment of reference values for the control, which is computationally implemented through discrete PID (Proportional, Integral and Derivative) controllers. The work approaches the accomplishment of the following experiments: determination of the characteristic equation that relates the level with the measurement in the sensor, mathematical modelling of the continuous and discrete system and the implementation of several tuning techniques of PID controllers. The practical results obtained are validated by simulation and practical experiments demonstrating the efficiency of the implemented control system and the functionality of the solution.**

Keywords— Remote laboratory, PID control, education, engineering education

I. INTRODUCTION

Remote laboratories represent a very important evolution in the concept of digital teaching because it can provide to students and researchers the possibility of carrying out experiments, collect data, and analyze results through a web interface. Therefore, the students can access the laboratory from any computer or mobile devices with an internet connection, enabling them to conduct experiments even if they don’t have access to a physical laboratory.

WebLab's have been implemented in several institutions since the 90's, presenting solutions for remote operation generally using commercially available software or dedicated networks [1]-[6]. At the Instituto Mauá de Tecnologia, several remote laboratories were produced, some of them aimed at process control applications [7]-[11] while others show industrial applications in the oil sector [12], robotics application [13] and other systems related to IoT applications and biomedical engineering. All these applications use high-cost commercial software and require the user to install a plugin that consumes considerable memory space in a time-consuming procedure. In addition, the interface has some limitations such as difficulty in controlling user access as well as obtaining registration to identify their profile.

In this sense, this project consists of creating of a WebLab for teaching control in Engineering courses, but which presents as a differential the possibility of application of several strategies of SISO (Single Input and Single Output) control systems. Therefore, it is intended to develop a solution that allows the monitoring and control of different systems, but allows the application of didactic techniques and strategies for modeling and controlling the system. Additionally, the proposal is to create a responsive, didactic and attractive interface to encourage students to use the tool in different types of remotely controlled systems.

II. REMOTE LAB DEVELOPMENT

The concept applied to WebLabs can be generalized by the block diagram at Fig. 1, and presents the following elements:

- the system or equipment which is controlled remotely;
- monitoring system by sensors, that acquire process variables in real time; may include electronic signal conditioning circuits and transducers;
- data acquisition system that captures signals at appropriate sampling frequency and makes the data available to WebLab system; these variables can be viewed (graphically or numerically) on user interface;
- actuators and drivers, necessary when the designer wants, not only monitoring the system data, but control devices through actuators; drivers are electronic circuits required to convert control signals to appropriate levels depending on the application;
- control algorithm, which can be a conventional controller typically used in control applications (for example, a PID control) and/or algorithms that allows 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 making system information available (signals from sensors, equipment images, etc.) at interface accessible by the user remotely;
- user interface, which consists of the user-defined way to access the remote experiment by internet (computer terminal, mobile devices, among others).

III. LEVEL CONTROL SYSTEM WEBLAB

The level control system is a didactic application and its hardware consists of 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. The level control system proposed in [7] and [11] includes signal-conditioning board, Arduino Uno board, electronic driver for driving the pump using PWM (Pulse Width Modulation) signal and finally a computer with a LabVIEW^{TM} interface and webserver that allows the remote access by Internet. It results in a high-cost commercial solution with a non-responsive interface that cannot be accessed by some operating system and mobile devices.

In this work the system was improved as illustrated at block diagram in Fig. 2, which include the following changes:

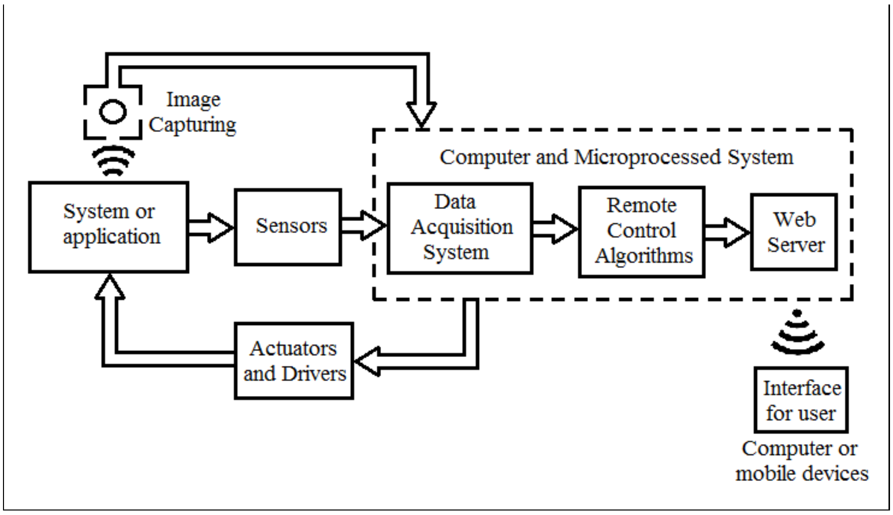


Fig. 1. Block diagram of WebLabs depeloped at IMT [7]

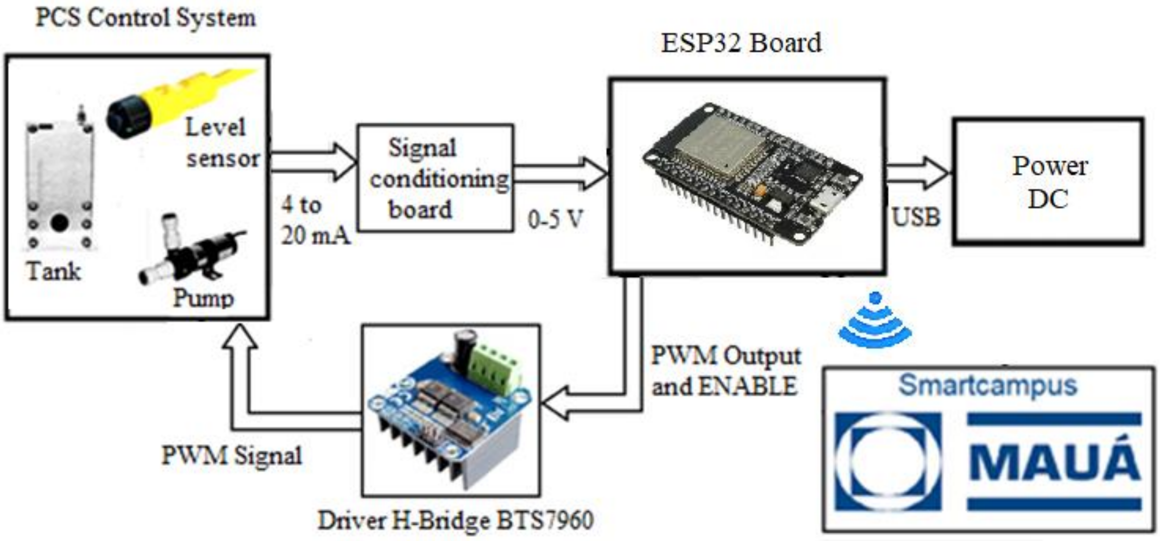


Fig. 2. Block diagram of level control system.

a) Replacement of the Arduino Uno board with an ESP32 board, which, in addition to having better characteristics in terms of processing and storage capacity, features wireless communication via Wi-Fi and Bluetooth. Thus, there is an improvement in the connectivity characteristics of the application;

b) replacement of the LabVIEW software by an application using several open-source tools that allow the creation of the back-end and front-end applications; the new approach includes the integration with the Smart Campus platform, which will be described later.

The back-end application consists of the communication system between the interface and the hardware, as well as the implementation of the code on the hardware itself.

The interface operating logic was developed using ESP32 functions programmed in C/C++ that includes trigger to enable a waiting time and guarantee the sending of information, switches, which are basically conditional functions that define the direction of the message flow, and setters that allow adjusting messages to values defined by the programmer by MQTT blocks, where the MQTT protocol allows to receive messages from ESP32 informing the current values of analogue level and control effort as well sending of messages to the ESP32, as for example, the control effort.

The front-end is responsible for the UX/UI (User Experience and User Interface). At this application the front-end was developed by using the Node-RED softwared, which is an interesting tool originally developed by IBM to connect hardware devices, APIs and online services as part of the Internet of Things. Figure 3 illustrates how the Node-RED flow works at this application.

The diagram in Figure 4 shows the project's operating stages and the flow of information, starting with the reception and processing of data sent to the microcontroller. At the beginning, the microcontroller receives the analog signal from the plant, encapsulates and sends JSON (JavaScript Object

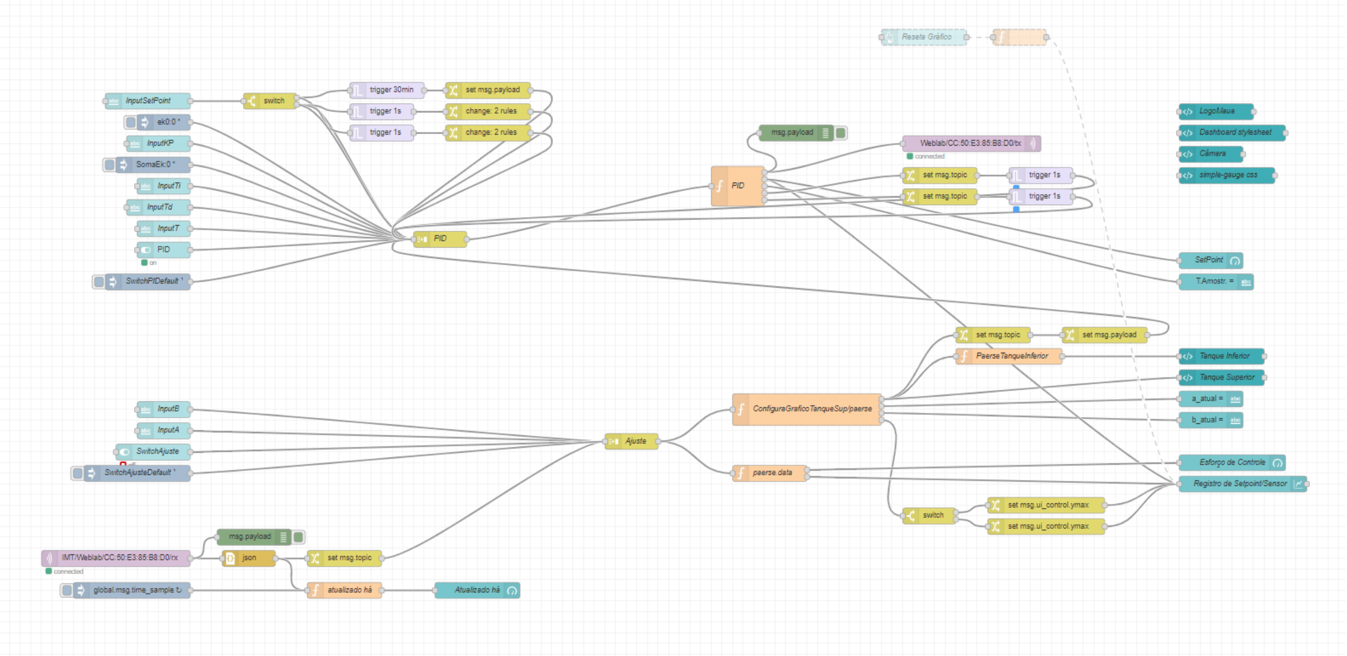


Fig. 3. Flow of operation of WebLab with front-end and back-end developed in Node-RED.

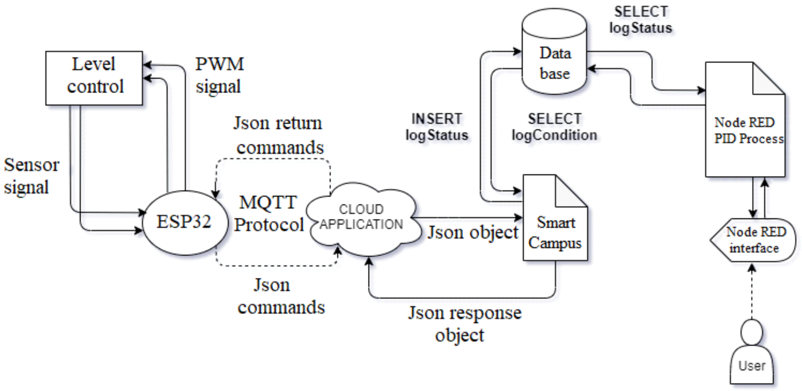


Fig. 4. Operation scheme in microcontroller logic and its interaction with the user-accessible interface

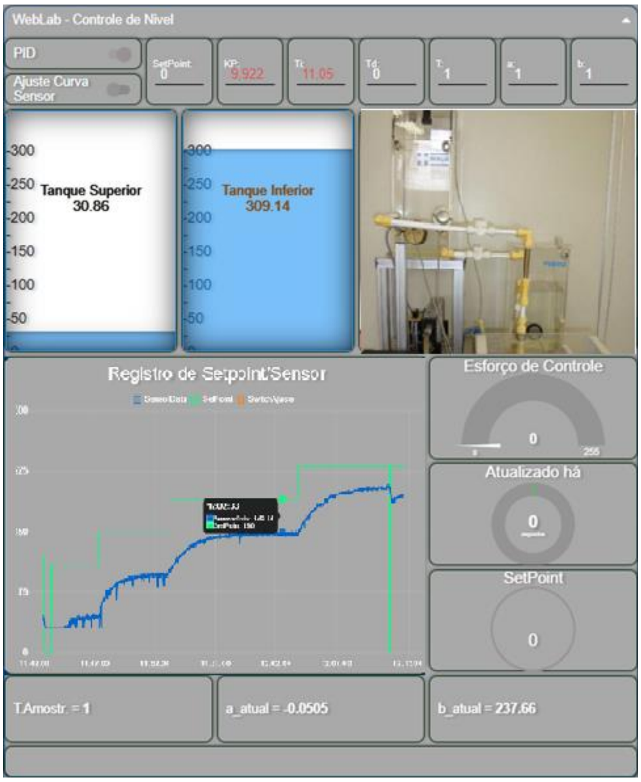
Notation) comands to the Smart Campus platform through MQTT protocol. The data is received on the Smart Campus platform, which receives and stores the data of interest in the database. Once the values are inserted, the logStatus request is made to calculate the response of the PID control. After the control is calculated, an update is made to the logCondition in order to save the control value in data base that can be accessed by Smart Campus platform. In addition, this value is also sent to the user's dashboard. After the new PID control value is saved, the first file makes a request to the database for the new control value, so that it can return via MQTT to the microcontroller and from there to the plant.

The interface developed for WebLab user access is presented in Figure 5, through which it is possible to develop several experiments such as: adjustment of parameters for sensor calibration, modeling of the level control system through response testing to step, tuning and performance evaluation of PID controllers, etc.

The system can be accessed by any user in the interface integrated to the IMT's Smart Campus. This platform is an IMT (Instituto Mauá de Tecnologia) initiative aimed at transforming its São Caetano do Sul Campus, in the ABC region of São Paulo. The platform include several Internet of Things applications developed that could be published, monitored and controlled. Access and real-time monitoring of the system can be done through the link http://smartcampus.maua.br/dash, where several variables monitored by means of sensors in the works developed are available for real-time monitoring.

The level control system can be accessed by: https://weblab.maua.br/#!/9?socketid=VFqf36mr7wn0jT5gAACg.

By accessing the level control WebLab interface, shown in Fig. 5, 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; identification of transfer function through step response test; PID controller tuning for the closed loop level control system.



SetPoint: 0

KP: 9.922

Ti: 11.05

Td: 0

T: 1

a: 1

b: 1

Tanque Superior 30.86

Tanque Inferior 309.14

Esforço de Controle 0

Atualizado há 0

SetPoint 0

T.Amostr. = 1

a_atual = -0.0505

b_atual = 237.66

Fig. 5. WebLab for speed and position control of DC motor.

A. Level x Voltage Relationship.

This experiment allows deducing the relationship between the tank level (in millimeters) as a function of the voltage measured in the sensor. Thus, 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:

$$h(t) = as(t) + b \qquad (1)$$

where: *h(t)* is the level of the sensor measured in millimeters; *s(t)* is the 12 bits value measured by microcontroller, *a* and *b* are the parameters of the linear equation that relates the level measurement, 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.

B. Model identification by step response.

This experiment allows for deduction of the level control system model, which can be represented by the following first order transfer function:

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

where τ and K_S are respectively the time constant and static gain of system; *H(s)* is the level measured by the sensor and $V_{Control}(s)$ is the control voltage applied to the pump.

The model can be determined by measuring, after submitting the system to a step response test [11], as shown in the graph of the WebLab interface in Fig. 5.

C. PID Level Control.

The 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. *E(s)* is the error produced by the difference between the desired level (*Set Point(s)*) and the value measured at sensor *H(s).*

$$G_C(s) = \frac{V_{Control}(s)}{E(s)} = K_P\left(1 + \frac{1}{T_I s} + T_d s\right) \qquad (3)$$

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

PID control was implemented using a control algorithm to implement in Node-RED the following discrete PID control:

$$u(k) = \Bigg(K_P e(k) + \frac{T}{T_I}\left(e(k) + \textstyle\sum_{i=1}^{\infty} e(k-i)\right) + \\ + T_d\left(\frac{e(k)-e(k-1)}{T}\right)\Bigg) \qquad (4)$$

where T is the sampling time.

IV. EXPERIMENTAL RESULTS

Measurements were performed to evaluate the behavior of the level sensor with the variation of the tank level. The sensor presents 4 to 20 mA depending on the level of the tank. However, the signal conditioning circuit results in voltages from 0 to 3.3 V, suitable for monitoring at the input of the ESP32 board. The device has an AD converter with 12-bit resolution, which means that measurements are programmed to range from 0 to 4095.

Tests were carried out measuring the tank level and the corresponding value produced in the measurement. The result is presented in the graph of Fig. 6. The experiment can be carried out in the interface of Fig. 5, with the graphical measurements obtained by ESP32 board, while the level measurements in mm can be monitored in the captured image in real time. If necessary, it is possible to perform a zoom on the image to facilitate measurements.

It can be seen that the graph decreases practically linearly, except for values between 0 and 44mm and between 250 and 300mm. Therefore, measurements were limited to a level range between 45 mm and 250 mm.

From the results shown in Fig. 6, and applying least squares method it was possible to obtain the parameters of equation (1) resulting:

$$h(t) = -0{,}0505\, s(t) + 237{,}66 \tag{5}$$

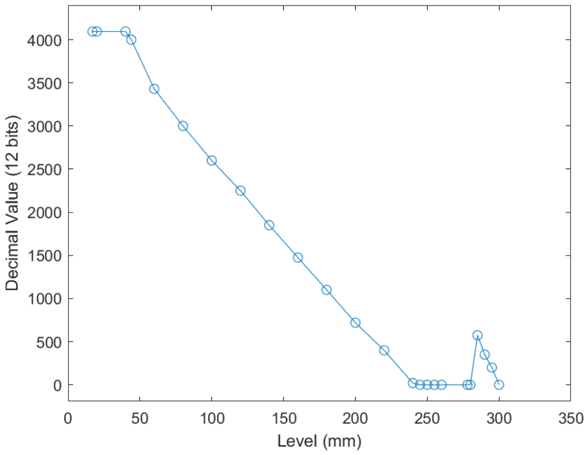


Fig. 6. AD Converter Measurements x Tank Level.

In order to get the experimental model of the system, the interface in Fig. 5 was used by conducting a step response test. Fig. 7 illustrates the result obtained for variations in the system input (*Set Point*) by monitoring the sensor signal (*H(s)*). At the interface the sensor signal is present as Sensor Data. The test was performed varying the Set Point from 110 to 150, then to 190 and finally to 230, and these changes were made in time intervals after signal stabilization as presented at Fig. 7. These intervals were also measured. From the measurements and using systems identification techniques, three models for the transfer function were deduced. The average of the results was calculated by obtaining the model of equation 6.

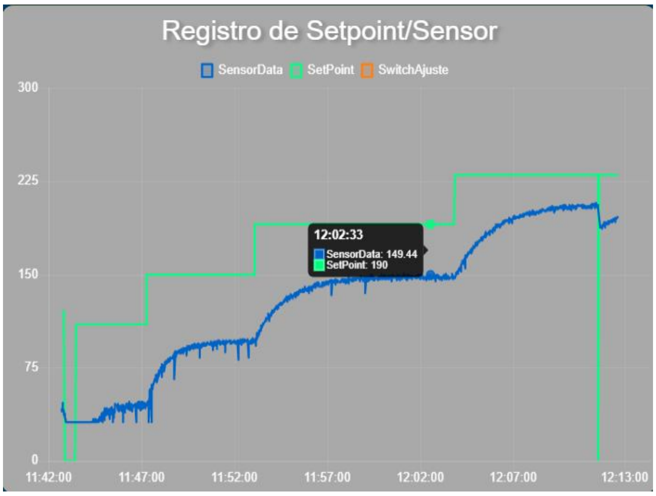


Fig. 7. Step response test varying the Set Point

$$H(s) = \left(\frac{1{,}325}{62+1}\right) V_{Control}(s)) \tag{6}$$

A PI control was designed and implemented with the aim of achieving: elimination of the stationary error (for this reason the $T_d = 0$ s), response with a damping ratio close to 0.8 (which results in minimal oscillation) and a response about 8 times higher faster than in the original system (resulting in the design in an undamped natural frequency ωn 8 times higher). The tuned PI controller is:

$$G_C(s) = \frac{V_{Control}(s)}{E(s)} = 9\left(1 + \frac{1}{11{,}5s}\right) \tag{7}$$

The sampling time considered is T = 1 s.

The practical result obtained is presented at Fig. 8. It is observed that the system presents a much faster response and without oscillation, although it presents stationary error when the system approaches the non-linear region.

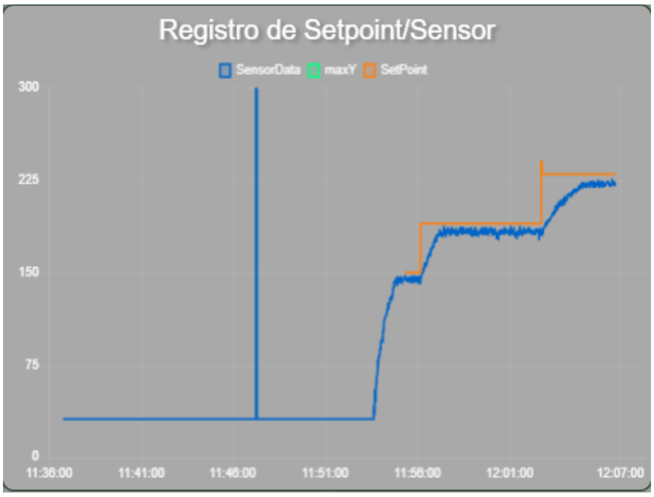


Fig. 8. System response with PI control.

The modeling and control results were validated using simulation, obtaining the results shown in Fig. 9.

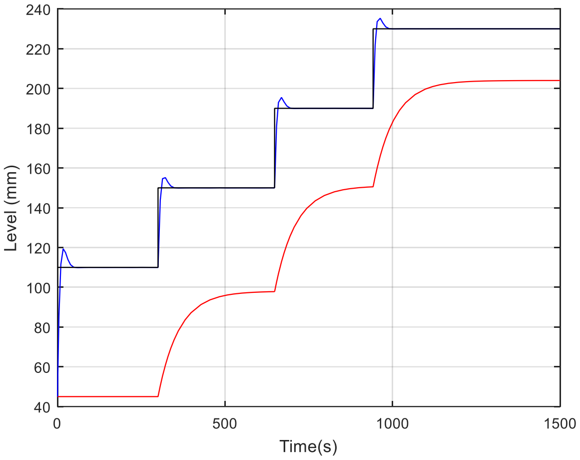


Fig. 9. System simulation - Control validation

Consider that the scale in the graphs of Fig. 9 shows level (mm) x time (s). The graph shows the Set Point signal in black, the open-loop step response in red, and the response with the tuned PI control in blue. In Fig. 7 and Fig. 8 the variables are the same but the time scale is in the pattern hour:minute:second.

These simulation results were obtained according to the block diagram in Figure 10.

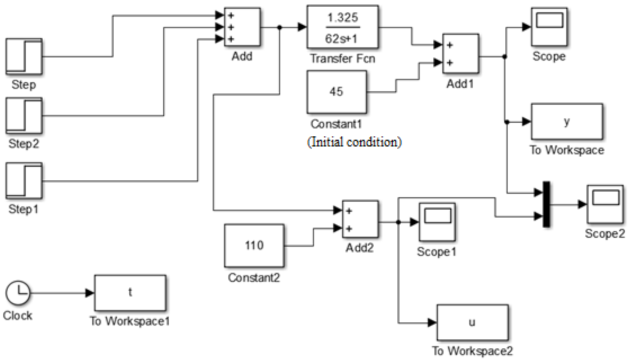


Fig. 10. Block Diagram in Simulation

V. CONCLUSIONS AND FINAL REMARKS

WebLabs were used as teaching tool in subject related to "Control Systems" in the latest grade of Electronic Engineering course and in the postgraduate course in "Industrial Process Control Engineering", as well in complementary activities. The remote laboratory, after the creation of the new interface, proved to be an interactive, immersive and responsive didactic tool of easy access, having been used in several didactic experiments and tests, including by graduate students. As reported by the students, the main differential is really the ease of use and the possibility of remote access at any time and from any place just depending of the internet access. In addition, the understanding of the methodology adopted in carrying out the project and the several aspects and concepts involved, it also provided learning in the area of Internet of Things.

The system includes a real-time image of the workbench and the possibility of adjusting the parameters of the PID controller, whose algorithm was implemented in Node-RED. Graphs show user-adjusted Set Point and sensor measurements in real time. The results obtained are consistent and demonstrate the ease of using the interface, with the possibility of implementing several PID controller tuning methods as well as the performance of experiments for system modeling.

The development of the back-end and front-end using Node-RED will allow the implementation of future WebLab's in different areas with maximum use of the interface and with integration to the Smart Campus institutional platform, becoming a stimulus for the development of other projects and for using the tool in didactic applications.

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