Web Lab Platform for Remote Management of Engineering Laboratories: Development and Implementation

[1]São Francisco University – Electrical Engineering, Campinas, Brazil,

Abstract*– This project is dedicated to advancing the design, development, and improvement of the WEBDIG computing platform, which is strategically aligned with the precepts of Education 4.0. Central to this effort is the flexibility of the platform, which will enable the management and execution of experiments remotely via the Internet, with a particular focus on educational applications. WEBDIG is differentiated by the integration of advanced digital technologies, including Internet of Things (IoT), Big Data, Cloud Computing, Simulation Systems, Advanced Robotics and Artificial Intelligence. This integration promises the synergistic fusion of physical and virtual elements, culminating in the creation of innovative 4.0 laboratories. Furthermore, the WEBDIG system will be integrated into the international remote laboratory platform SARL (Smart Adaptive Remote Laboratory), developed by Florida Atlantic University (FAU) in the United States. The SARL platform is known for providing accessible laboratories to students around the world, facilitating the creation of digital environments focused on education and promoting interaction between educators, students, and academic institutions. The collaboration between WEBDIG and SARL aims to enhance the provision of remote laboratories for engineering students, offering a practical and innovative educational experience that is in harmony with the principles of Education 4.0. This partnership between the two platforms will not only enrich the technical learning of engineering students but will also pave the way for more interactive and immersive educational approaches, reflecting the constant evolution of the 4.0 learning environment.

***Keywords*– Weblab, Online Laboratory, Smart Adaptive Remote Laboratory, WEBDIG.**

I. INTRODUCTION

In the era of Industry 4.0, technological advancements are profoundly transforming not only the industrial sector but also the way we interact with knowledge and education. In this context, accessibility and democratization of education have become essential pillars for sustainable socio economic development. One of the areas benefiting from these changes is science education, where the integration of emerging technologies is enabling remote and interactive access to real experiments.

For the engineering area, in particular, Education 4.0 is essential, as the presence of Industry 4.0 in this area is increasingly required. Therefore, it is crucial that the resume includes fundamental concepts such as IoT, artificial intelligence and digital data management, in order to prepare students for the challenges of the job market. It is in this context that WebLabs prove to be an excellent alternative for practical teaching and training of more qualified professionals for the demands of Industry 4.0.

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

Imagine an innovative digital platform that transcends the physical barriers of traditional laboratories, allowing students, researchers, and enthusiasts to access and participate in real experiments in real-time, regardless of their geographic location. This is the revolutionary proposal of the platform to be discussed in this report, which represents a milestone in the convergence between Industry 4.0 and education accessibility.

In this context, this article will explore how this platform aligns with the principles of Industry 4.0, emphasizing the integration of cyber-physical systems, the Internet of Things (IoT), cloud computing, and artificial intelligence to optimize processes and create new opportunities. Additionally, it will show how this initiative is democratizing access to scientific knowledge, providing an enriching and inclusive educational experience for a diverse range of users.

Throughout this report, it will be shown the potential impacts of this innovative platform on the educational landscape, highlighting its implications for teaching, research, and technological development. The project developed by São Francisco University consisted of installing sensors and actuators in a distillation column present in the university's chemistry laboratory, allowing its remote control and integration into the SARL (Smart Adaptive Remote Laboratories), developed by Florida Atlantic University (FAU).

II. DISTILLATION COLUMN: EXPLORING THE CONCEPT

A distillation column is a crucial equipment used in liquid mixture separation processes, especially in chemical and petrochemical industries. Its main function is to separate components of a mixture based on their differences in volatility, leveraging the different boiling points of each substance.

Operation:

Heating: The process begins with heating the liquid mixture in a vessel, usually called a boiler or drum. The applied heat causes the mixture to reach its boiling point, converting it into vapor.

Vaporization: The resulting vapor is directed to the base of the distillation column, where vaporization occurs. This step is crucial for separating the components of the mixture, as substances with lower boiling points vaporize first, while those with higher boiling points remain liquid.

Liquid rising in the column: The ascending vapor encounters the descending liquid mixture in the column, known as a distillation tray. In this process, there is a heat and mass exchange between the ascending vapor and the descending liquid.

Fractionation: As the vapor ascends the column, component separation occurs based on their differences in volatility. Components with lower boiling points tend to concentrate at the top of the column, while those with higher boiling points remain at the base.

Collection: The separated components are collected at different points in the column, depending on their relative volatilities. This allows for obtaining purified or fractionated products from the initial mixture.

In summary, a distillation column is an essential tool for separating complex liquid mixtures into their individual components, leveraging differences in volatility between substances. This process is fundamental in various industries for obtaining high-purity chemical and petrochemical products.

III. DISTILLATION COLUMN AUTOMATION

The WEBDIG platform operates by utilizing user commands, which are transmitted to a Raspberry Pi via the MQTT protocol. This setup necessitates the automation of various components within the distillation column to ensure precise and reliable interaction for online users. It is crucial that the automation not only delivers accurate results from the column but also ensures equipment safety. Therefore, the automation implementation must prioritize precision, reliability, and safety to meet the demands of online user interaction with the distillation column.

The distillation column used was a didactical batch column model XP1520.3 from Labtrix (Fig. 1).

Fig. 1 Labtrix XP1520.3 distillation column

A. Control Panel Switches

On the control panel (Fig. 2) you can notice the existence of two on/off switches, responsible for controlling the reflux peristaltic pump and the vacuum pump. These two points that are activated manually during the experiment must be controlled remotely, and for this purpose a relay module will be used.

With the FL-3FF-S-Z 4-Channel Relay Module (Fig. 3), it is possible to control lamps, motors, household appliances and other devices using just one control pin. This is due to the complete isolation between the circuit to be powered and the microcontroller circuit. The module operates with a voltage of 5V and has the capacity to drive loads of up to 250VAC or 30VDC, with support for a maximum current of 10A. It has an LED power indicator, two power pins, one control pin and an output terminal with screws, making it easier to connect equipment.

Fig. 2 Distillation Column Control Panel

Therefore, two channels of this module are used to connect in parallel to the panel's on/off switches, and the control signals will be connected to the digital ports (I/O) of the Raspberry Pi, which have an output voltage level of 5V, being enough to activate the module. This way, using the Raspberry Pi it will be possible to receive an external signal via the internet and MQTT protocol, and control the activation of the reflux peristaltic pump and the vacuum pump remotely. This setup allows for remote switching of the control panel, enhancing user convenience and safety.

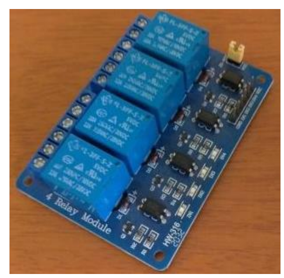

Fig. 3 FL-3FF-S-Z Relays

B. Temperature Sensors

The column has several distillation stages, and six sensors measuring the temperature at different points in the experiment, including the heating blanket. These temperature data are essential parameters both for the student to correctly analyse the experiment, and eventually include them in a practical class report, and to verify the correct functioning of the system. Currently, these sensors are read, and the values are shown on the bench control panel, however, for this experiment to be carried out remotely, these sensors were replaced with similar ones (model DY-HFT 150C), using the existing fixation on the column structure.

Fig. 4 Temperature sensor of one of the column stages

Then, these sensors will not be connected to the control panel, but directly to the Raspberry Pi, making it possible to communicate with an external HMI via the internet. These readings will be transmitted to the online platform, providing real-time data monitoring and analysis.

From this data, it is possible to create a graph with the temperature curve over the time of the experiment, similar to the example shown below:

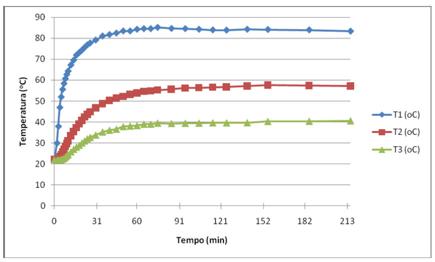

Fig. 5 Temperature curve graph

C. *Distilled Ethanol Output Valve*

The KS42STH40-1204A stepper motor is responsible for controlling the manual valve of the burette in charge of releasing the distilled ethanol. This valve must be activated at the end of the experiment to release the distilled ethanol from the burette into a graduated cylinder, where the student can analyse the product and determine the ethanol concentration.

This stepper motor was selected, which has a torque of 4.2 KGF.CM, because precision control of this valve is crucial to prevent leaks, ensuring the integrity of the distillation process, and this model satisfies these requirements as well as the torque demand.

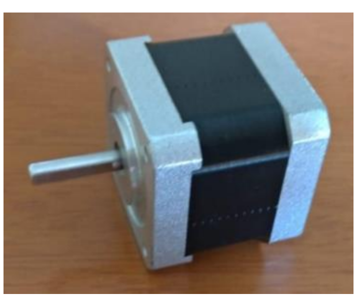

Fig. 6 KS42STH40-1204A Stepper Motor

This actuator was controlled using the L298N dual H bridge, connected between the motor and the Raspberry Pi. This component has two outputs, thus allowing the connection and separate control of two DC motors, however, in our case, these two outputs were used to connect the two stepper motor coils. Therefore, from the signals sent by the Raspberry Pi's digital ports, which reach the H bridge inputs, it is possible to control the activation of the two motor coils independently.

To couple this motor to the burette valve, it was necessary to design a support, which will be fixed to the distillation column bench, to allow the motor to be at the same height and aligned with the valve. The support was designed with the help of Autodesk Inventor software, and a height adjustment was provided for the part where the engine is fixed.

In addition to this support, it was necessary to create a part for coupling between the stepper motor shaft and the valve. This is similar to an existing one, as shown in the image below, and it is necessary to lengthen it, as the motor shaft is approximately 10 centimeters away from the valve.

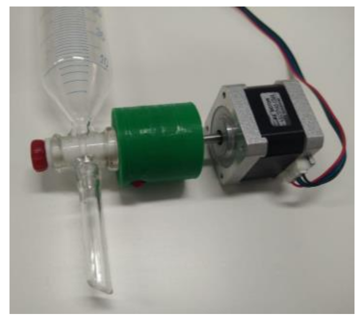

Fig. 7 Stepper motor coupled to the burette valve

D. *Reflux Control*

The distillation column has a peristaltic pump responsible for reflux control. The speed of this pump is adjusted by a potentiometer that is manually moved. To drive this potentiometer, the 28BYJ-48 stepper motor is used, whose torque is lower compared to the motor mentioned previously, but for this application, a less powerful motor is sufficient.

Fig. 8 Peristaltic pump

In a similar way to the previous one, to control this stepper motor it was also necessary to connect an intermediate driver between the motor and the Raspberry Pi. The component used was the ULN2003, which has four signal inputs coming from the board, four outputs that control the two motor coils, an input for power supply in the range between 5V and 12V, and a terminal for connecting GND. The connection in this case was simpler, as the engine comes with a plug that fits perfectly with the ULN2003. In this way, it is possible to remotely control the 28BYJ-48 engine using commands sent to the Raspberry Pi. This automation enables precise adjustment of the pump speed, ensuring accurate fluid flow rates during the experiment.

Fig. 8 28BYJ-48 Stepper motor

E. *Reinitialization pump*

Another peristaltic pump was installed in the column, to enable the experiment to be restarted remotely, as this process is currently done manually. This pump acts on the beaker present at the end of the experiment, to return the distilled ethanol to the flask with water from the column, so that the distillation can be started again. The actuator used is the AK380/92.4ML24S9100C DC motor, and because the pump only needs two states (on or off), a relay can be used to control this motor.

Fig. 9 Peristaltic recycling pump

F. *Heating System*

The heating system is responsible for raising the temperature in the column flask containing the ethanol and water solution. This blanket is activated at the beginning of the experiment, and it is at this moment that the distillation process begins. Previously, this heating system was connected directly to a socket that has specific protection that is part of the bench's safety design, so it is not possible to make changes at this point, eliminating one of the automation alternatives for this system. However, another option has emerged and has been developed, which involves connecting a smart socket between the system and the existing socket, so that it will be possible to send signals to turn the smart socket on or off via Wi-Fi communication. This way, the heating of the balloon can be controlled remotely, without changing the existing security system.

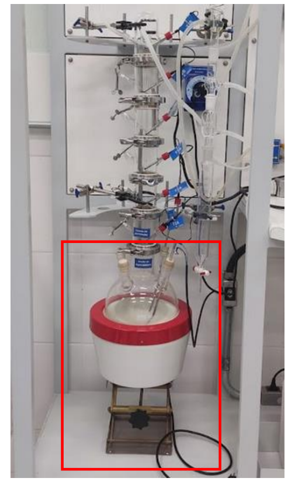

Fig. 10 Heating system of the column

IV. INTEGRATION AND CONTROL

All processes will be controlled by the Raspberry Pi, which will communicate with the online platform using the MQTT protocol. This integration allows for seamless operation and data transmission, enabling users to remotely monitor and adjust experimental parameters in real-time.

By implementing these planned automations, the distillation column will offer enhanced control, precision, and accessibility, making it an invaluable tool for laboratory experimentation in various scientific and educational settings.

As the user interacts with the various buttons on the online platform, those interactions will be sent to the Raspberry as numerical inputs, triggering functions responsible for controlling the actuators related to the button pressed on the online platform.

The data read on the sensors will have a similar working principle, but instead of sending simple numbers to the online platform, the data will be sent as a JSON document, which will be decoded by the website and shown on the interface as a number, indicating the temperature reading collected by each sensor.

IV. MQTT PROTOCOL

The MQTT (Message Queuing Telemetry Transport) protocol is widely recognized for its efficiency, lightweight nature, and reliability, making it an ideal choice for integration with devices like the Raspberry Pi. Its lightweight, message-based communication architecture allows for efficient data exchange, even in networks with limited resources. Additionally, MQTT offers different levels of quality of service (QoS), ensuring reliable message delivery, which is essential for data integrity in automation systems. The flexibility of MQTT also stands out, as it enables bidirectional communication between devices, allowing the Raspberry Pi to effectively send commands and receive data in real-time. Therefore, considering its efficiency, reliability, and flexibility, MQTT emerges as an excellent option for integration with the Raspberry Pi in automation and device control projects.

V. Conclusions

In conclusion, the integration of emerging technologies into education, particularly in the field of science and engineering, is vital for preparing students for the demands of Industry 4.0. The innovative platform discussed in this article represents a significant advancement in this regard, aligning with the principles of Industry 4.0 and democratizing access to scientific knowledge.

By transcending the physical barriers of traditional laboratories, this platform enables remote and interactive participation in real experiments, fostering a more inclusive and enriching educational experience. The utilization of cyber-physical systems, IoT, cloud computing, and artificial intelligence optimizes processes and creates new opportunities for teaching, research, and technological development.

The project developed by São Francisco University, in collaboration with Florida Atlantic University, exemplifies the potential impact of such initiatives on the educational landscape. Through the installation of sensors and actuators in a distillation column, remote control and integration into Smart Adaptive Remote Laboratories were achieved, paving the way for enhanced practical teaching and training of professionals in the era of Industry 4.0.

Acknowledgment

The authors would like to acknowledge the mentor professors Vicente Idalberto Becerra Sablón, Filipe Coelho, Daniel Loureiro and Felipe Cavalaro. Also, they would like to acknowledge both São Francisco University, CNPq and Florida Atlantic University for all the support, as well as LACCEI for the opportunity to present this work.

References

BALOIAN, N., CASTRO, A., & ZURITA, G. A WebLab platform to support remote experimentation in engineering education. Computers & Education, 56(2), 584-601. 2011.

GILLET, D., SALZMANN, C., & MARMONTEL, N. WebLab: a versatile e-learning platform for practical experimentation on control systems. IEEE Transactions on Education, 52(2), 211-219. 2009.

GARCÍA-ZUBÍA, J., ORDUÑA, P., LÓPEZ-DE-IPIÑA, D., ALZUA-SORZABAL, A., & HERNÁNDEZ-JAYO, U. WebLab-Deusto: Development and evaluation of a remote laboratory for control engineering education. Computers & Education, 58(1), 228-238. 2012.

GARCÍA-ZUBÍA, J., LÓPEZ-DE-IPIÑA, D., & ORDUNA, P. The WebLab-Deusto remote laboratory management system. IEEE Transactions on Industrial Electronics, 54(2), 993- 1002. 2007.

LEE, H. K., & KANG, B. J. A Web-based virtual laboratory system for power electronics experiments. IEEE Transactions on Industrial Electronics, 56(12), 4731-4739. 2009

J. A. Sanchez-Viloria, L. F. Zapata-Rivera, C. Aranzazu-Suescun, A. E. Molina-Pena and M. M. Larrondo-Petrie, "Online Laboratory Communication Using MQTT IoT Standard," 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), Madrid, Spain, 2021, pp. 550-555