An Innovative Approach to Automatically Help Activities Corrections in Remote Laboratories in the Mechatronics Area Using Intelligent Digital Twins

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***Abstract* — This Innovative Practice research paper describes an intelligent digital twin platform designed to enhance the virtualization of practical activities in the field of mechatronics education. In recent years, the classic concept of digital twins has significantly evolved in academia and industry. In education, especially in engineering, digital twins have brought countless alternatives for building environments close to the reality of students' practical activities. To improve these activities in the mechatronics area, intelligent digital twins will add added resources and technologies that assist the virtualization process. Therefore, a platform was developed to access remote laboratories in the mechatronics area and help correct the experiments offered. This platform will enable teachers to insert practical activities into remote laboratories on the platform. This platform has three central areas: teaching plans, teachers, and students. In teaching plants, it is possible to create a register of plants that provides information on the characteristics necessary to connect with their equipment and the number of plant elements. In the teachers' area, it is essential to create an activity for students to conduct, and this activity must be conducted for the system to capture the data and images to form a correction model. The correction model uses these data to help intelligent digital twins digitize practical activities. In the student area, it is possible to check all available experiments and their virtualizations and automatically correct the practical experiment.**

Keywords— Mechatronic Laboratories, Remote Laboratories, Distant Learning Experiments, On-Line Students, Digital Twin.

I. Introduction

Experiential learning is an engaging and essential teaching tool for engineering students. However, the real-world educational resources of educational institutions are limited in quantity and number. Hence, students and teachers look for tools that help the teaching and learning process within engineering courses, especially in mechatronic engineering, as they work with high-value and difficult-to-access equipment [1-2]. Access to remote laboratories with physical equipment is one solution for schools and universities to conduct practices with students, as with this type of access, it is possible to share both virtual and physical environments [3].

A remote laboratory is a technology that consists of software and hardware to generate a real learning experience where experiments can be accessed remotely via the internet [4-6]. With remote laboratories, students can conduct experiments similarly to physical laboratories [7]. These laboratories can be tools used to provide students with experiments that will work with actual data and measurements in an updated context and that will motivate students to evolve in their professional careers. This tool is widely used worldwide, especially in Europe, with massive online open courses (MOOCs) [8-9]. A wide variety of resources are available within remote laboratories. Among these resources, it is vital to highlight the digital transformation of laboratories and the virtualization generated through the conception of the digital twin [10-14].

This digital representation can monitor, simulate, and analyze the physical system's performance in real time, as a large amount of data is generated to identify potential problems, optimize performance, and even predict failures before they occur [15-17]. The digital model can adjust and improve the physical system for the remote laboratory area, creating data for experiments and boosting the teaching and learning process.

For this proposal, the digital twin will be the basis for capturing data from a didactic experiment, where the data will be the input and output signals of a process since the mechatronics area has many experiments based on the following elements of industrial automation: sensors, controllers, actuators, and the process. Therefore, the purpose of this work will be to implement a system capable of automatically correcting experiments in the mechatronics area passed on by teachers within remote laboratories, and data from the experiments will be collected based on the fundamentals of digital twin technology. In this context, the digital twin will capture the signals sent from the sensors and the activation signals from the actuators through industrial communication protocols, in addition to all the time characteristics of the activations. This data information plus control signals automatically evaluates the student's activity.

Computer-assisted assessment has proven helpful in distance education (e-learning) school management platforms; however, it is time-consuming for teachers to implement the evaluation in an unfamiliar environment [18]. Considering this, educational technologies leave a digital trail; therefore, it is possible to transform the data generated during experimentation into information [19]. The automatic correction system developed in this paper will store and consider this information. Two elements will be created—the teacher's digital twin and the student's digital twin—and the experiments will be evaluated based on these data.

The article is organized as follows: section II presents the problem solved by the system. Section III presents related work on digital twins, learning assessment, and remote laboratories. Section IV presents the components developed and implemented in the system. Section IV describes the experimental procedures used to evaluate the laboratory selection method. The results are presented in section V, and the conclusions obtained from the work are offered in section VI.

II. Problem Description

Digital twins and remote laboratories are technological elements that are helping to evolve the teaching and learning process in mechatronics. To exemplify the problem of this proposal, we can think of the following situation: a student wants to check whether his activity is working correctly. That is, it will depend on the teacher's assessment of checking the functioning that was conducted in the didactic experiment by the student, but if the student is studying at 2 am, who will correct this activity? Who will help this student complete this activity?

To answer this question, the fundamental idea of using digital twin technology was considered, using a base tool that can capture teachers' and students' digital twins and compare the data to perform automatic correction. With this, the student will have their experiment automatically corrected at any time.

III. RELATED WORK

The related works of this research were divided into two groups: works related to the themes of digital twins and remote laboratories and works related to the themes of correction and automatic assessments in education.

With the themes of digital twins and remote laboratories, [20] described the use of digital twins to validate the control system of a robotic cell and compared the conventional study method against the study using digital twins developed in a remote laboratory. In [21], the results of an analysis of mechatronics teaching programs in Austria and Taiwan were presented, where, based on increased digitalization and the application of intelligent manufacturing, the courses evolved. In [22-25], remote laboratories were developed to monitor didactic processes aimed at learning.

With work related to the themes of correction and automatic assessments in education, [26-27] presented the implementation of remote laboratories that are part of massive open online course (MOOC) courses. These labs were implemented online and allow multiple simultaneous classes for students to run network applications through simulators and physical equipment. These tools also enable automatic assessment, making the teacher's work easier. In [28], text-mining techniques were applied using the Ratcliff/Obershelp algorithm to determine the similarity between two strings in open (subjective) answers, and in [29], an educational platform with remote laboratories that uses text-mining data based on learning analytics interventions, called laboratory experimentation data analysis (LEDA), was developed. This approach applied association rules and grouping techniques using learning data, including clicks, number of controlled components, and time spent during the activity.

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IV. Proposed System

The system to help with correction activities in remote laboratories in the mechatronics area will comprise the following elements that form its architecture (Figure 1): management, experiment, and didactic twin layers.

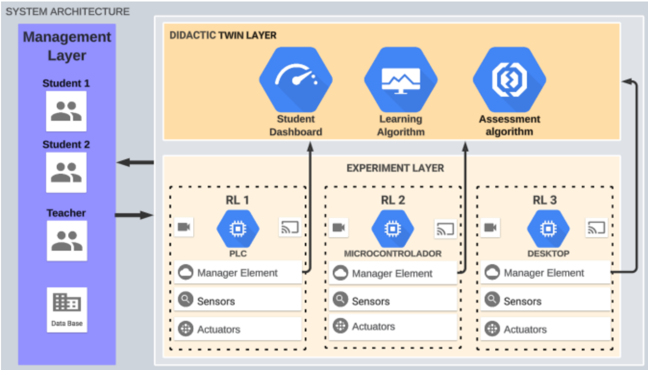


Fig. 1. Overview of the proposed system.

A. Management Layer

The management layer was developed to offer a registration area to store data from students, teachers, experiments, and remote laboratories (RLs). Fig. 2 presents the modeling of the database used to store the system's data.

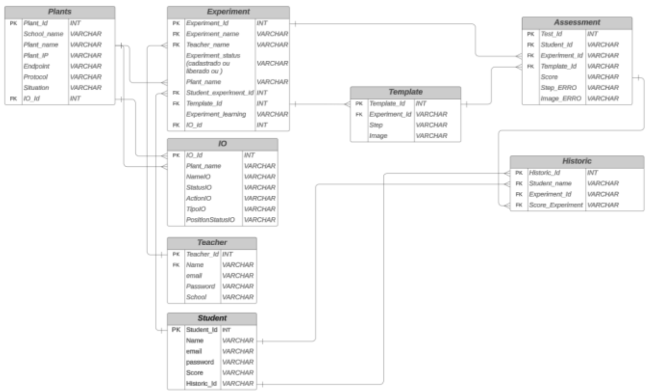


Fig. 2. System Database.

This layer will be a website (Fig. 3) that presents the laboratories, experiments, and student performance according to the execution of the experiments registered by teachers at educational institutions. For a laboratory to be registered, it must have the following requirements: a camera to monitor the experiment, a communication protocol, an endpoint for connection, and registered inputs and outputs to exchange data with the experiment.

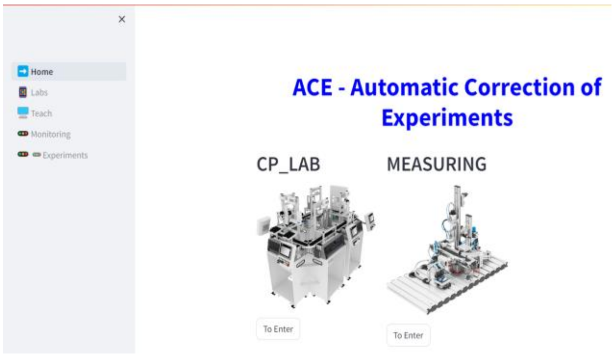


Fig. 3. System home screen.

B. *Experiment Layer*

The experiment layer will be composed of the following software: student program software and software called Management Element. The student's software will be uploaded to the area of each experiment, which can be in ladder form for PLCs or Python in the case of PCs and microcontroller platforms. The managing element will be responsible for monitoring experimental data through the communication protocol selected when registering information in the management layer and informing the remote laboratory's availability to perform the student's experiments. When the experiment begins, the managing element must monitor the operation of the experiment to monitor what is being conducted by the student or teacher. This monitoring occurs through communication protocols: Modbus or OPC-UA if the experimental controller is the PLC, the MQTT protocol if the controller is a microcontroller, and HTTP if the controller is a computer. The management element will acquire data from the different protocols and send these data via MySQL commands to the Management Element database.

C. *Didactic twin layer*

The didactic twin layer is an application responsible for learning the teacher's experiment to create the digital Twin, checking the data from the student's experiments to perform the correction, and scanning the student data to generate a track of the student's learning history. Therefore, the didactic twin layer can be divided into three modules:

- *Experiment learning module:*

This module is responsible for learning how the experiment works correctly and generating steps for student monitoring. Nevertheless, for this module to work, the teacher must conduct the didactic experiment according to the expected solution for the student's task. When the teacher executes the experiment, the learn didactic experiment button must be clicked so that the algorithm responsible for learning begins its execution. The algorithm developed in this module starts the execution of the digital twin of the teacher's experiment; with the experiment running, data are acquired from the management element, and then the step generation functionality starts. When the experiment runs, the inputs and outputs can change over time. When there are changes in the states of inputs or outputs, all states of the experiment must be stored. In this application, this event is called a Step. The first step is inserted into the software as a reference because, from there, it will start a loop to compare the previous step with the next step. If there is a difference, the current step is stored. This loop ends when the module's algorithm finds a repeated process. For example, in Table 1, Steps 0 and 4 are repeated, and then, from Step 4 onward, the algorithm checks whether the process is repeating itself throughout the time. If the process does not repeat itself over time, a second execution is necessary so that the algorithm notices a similarity between the executions. When the algorithm verifies that the process repeats itself or that there is a similarity between the executions, the step generation step of the digital twin of the teacher's experiment is completed and stored in the database. With each step stored, the time between the previous step and the new step is saved, and a photo is captured to complete the digital twin of the teacher's experiment.

Table I. System home screen.

List I/O	Standard Step	Step 0	Step 1	Step 2	Step 3	Step 4
I0 – BT_STOP	1 (ON)	1 (ON)	1 (ON)	1 (ON)	1 (ON)	1 (ON)
I1 – BT_START	1 (ON)	0 (OFF)	1 (ON)	0 (OFF)	0 (OFF)	0 (OFF)
I2 – SENSOR_1	1 (ON)	0 (OFF)	0 (OFF)	1 (ON)	0 (OFF)	0 (OFF)
I3 – SENSOR_2	1 (ON)	0 (OFF)	0 (OFF)	0 (OFF)	1 (ON)	0 (OFF)
Q0 – BELT_0	1 (ON)	0 (OFF)	0 (OFF)	1 (ON)	0 (OFF)	0 (OFF)
Q1 – BELT_1	1 (ON)	0 (OFF)	0 (OFF)	0 (OFF)	1 (ON)	0 (OFF)
Step Timer	---	ST0	ST1	ST2	ST3	ST4

The flow of generating the digital twin of the teacher's experiment is shown in Fig. 4, where in this flow, it is verified that the experiment is only learned completely when the step, time, and image of each step belonging to the experiment are stored. Fig. 5 explains the digital Twin learning model of the teacher's experiment.

The data in Fig. 4 result from the execution of the learning module, which is standardized during the execution of the experiment. These data were obtained by repetition of steps or by association with the correct answer path. S is the step formed by grouping the state of each input and each output. It goes from input I1 to In and Q1 to Qn. When the step occurs and is different from the previous step Sn, an image is captured, named In (image), where n represents the step number and Tn is the time the step took to execute, where n is the number of steps occurring.

- *Student View Module:*

This module aims to graphically show the student's experience in conducting their experiment, which will be divided into three screens: monitoring, experiments, and student learning.

The monitoring screen shows all remote laboratories available to enter, and experiments to be conducted by students can be checked. This screen presents a list of remote laboratories with an index column with the name of the situation, where the laboratories may be in the following states: free with the Green Status, busy with the Yellow Status, and in maintenance with the Status Red. These states are updated every 250 ms by an application that runs in parallel and performs the select operation in the database to check the status of each laboratory. Fig. 6 shows an example of this screen with the laboratories registered in the system, as a screenshot of the system screen was captured.

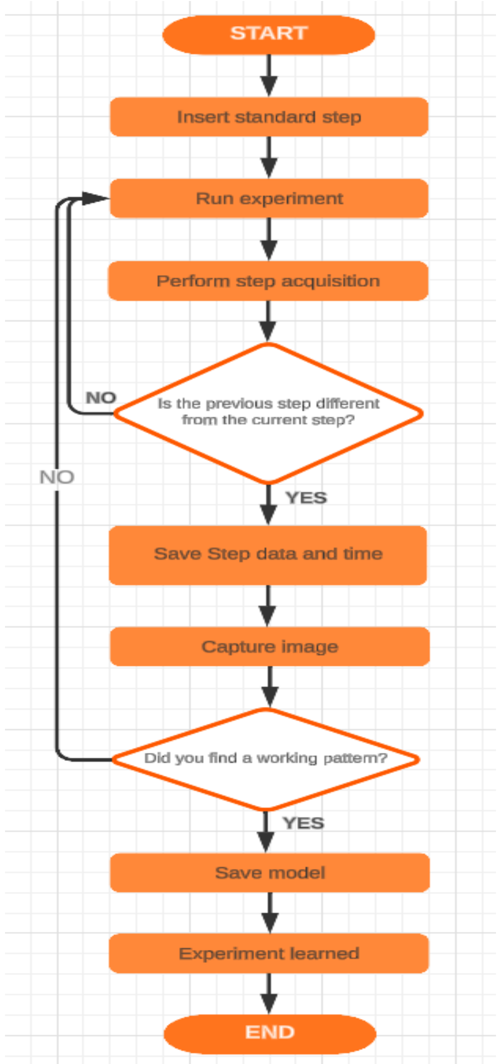


Fig. 4. Learning module flowchart.

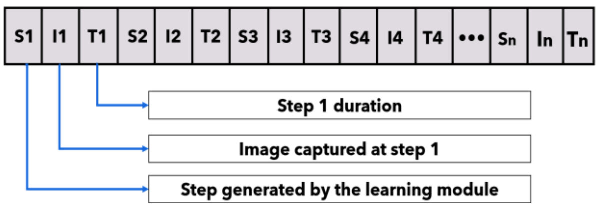


Fig. 5. Teacher experiment with digital twin learning model.

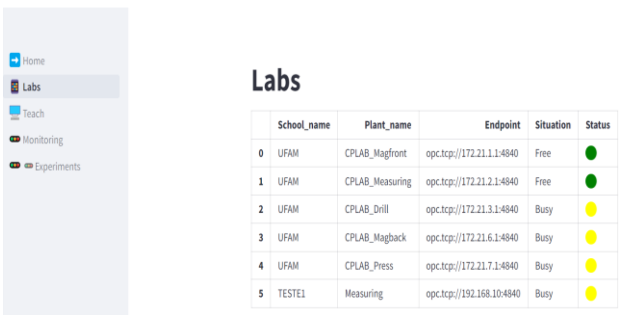


Fig. 6. List of available laboratories.

By filtering each laboratory, it is possible to check the status of each experiment. In each remote laboratory, you can also observe the inputs and outputs in the experiment and update when changes occur in the states of each registered input or output. Fig. 7 shows the status of the inputs and outputs of the selected remote laboratory; for each input or output, it is possible to check the Status through the column called StatusIO, where the status of this column can be False, which means that an input or output is disabled and will be colored red or True, which means that an input or output is activated and will be colored Green. For this screen, a scan is also performed to check changes in the inputs and outputs of each experiment conducted by the student or teacher.

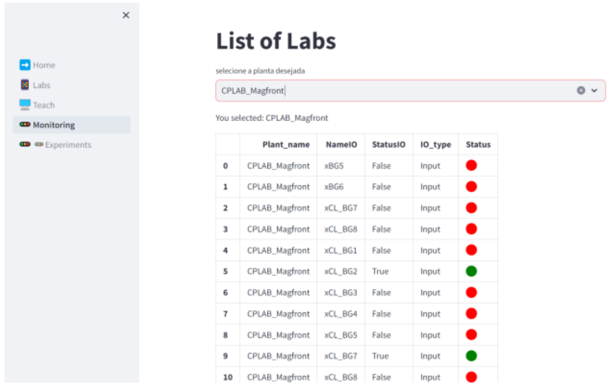


Fig. 7. List of inputs and outputs of the experiment.

On the experiment screen, it is possible to filter each registered experiment and view the experiment that is already connected with the remote laboratory of that experiment. On this screen, it is possible to check the experiment camera and the information necessary for the student to start their experiment without the teacher's intervention. Fig. 8 shows an example of an application with data already included to perform the proposed experiment.

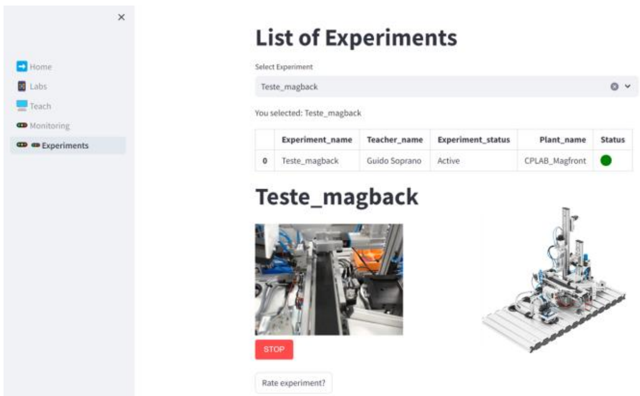


Fig. 8. Screens from one of the remote experiments.

- *Experiment correction module:*

The experiment correction module is responsible for the following functionalities:

A) Monitor Experiment: When starting their experiment, the student or teacher can switch between screen options generated by the visualization module to monitor the operation of their experiment. The student learning area is responsible for allowing the experiment to be monitored by viewing the steps and tables generated by experimenting. This visualization process is controlled by the correction module, which compares the digital Twin of the teacher's experiment, called the learning template of the experiment carried out by the learning module, and compares it with the functioning of the current experiment (student's digital Twin), checking whether there are differences in flow and time. Fig. 9 compares the Teacher experiment (teachers' digital twins) and the current experiment, Student Experiment-S (students' digital twins). Each step is compared (TS (Teacher Step) == SS (Student Step)), then each image is compared (TI (Teacher Image) == SI (Student Image)), and the times are compared (TT (Teacher Timer) == ST (Student Timer)).

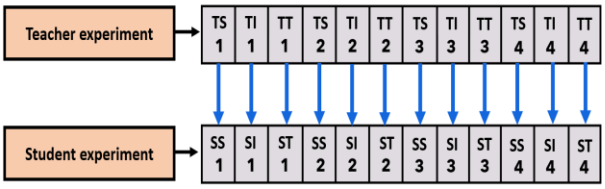


Fig. 9. Comparison of experiments.

Suppose there are differences in time or steps. In that case, a signal is stored in the database, and the visualization module that follows the process changes the color of the circle, which is green, to red. If there is a difference in flow, the circle becomes red. Fig. 10 shows the student's monitoring area while experimenting.

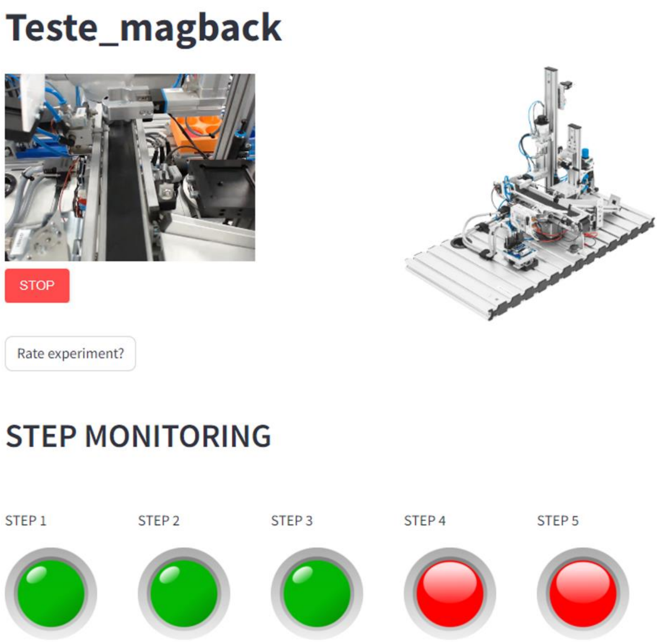


Fig. 10. Experimental monitoring area.

In this correction process, the digital twin data from the teacher's and the student's experiments are initially saved in .txt files and later uploaded to the database. This procedure occurs due to the speed of the input signals and outputs when they are being executed in experiments. These files serve as a backup in case there is latency in communicating with the database, and they are saved on the local machine of the remote laboratory to collect all data from the experiments. At the time of correction, it works with three files: one being the correction template (teacher's digital twin from that experiment), the current correction file (student's experiment), and a response file. The number 1 (one) will be stored in the response file for equal steps and times, and for each difference, 0 (zero) will be stored. These files will be uploaded to the bank in table form. Image capture is performed in parallel to capture an image in each step. The correction of the experiment becomes complete when the didactic twin is formed. This twin stores the characteristics of the student's digital twin, the student's experiment execution images, and the student's monitoring characteristics, and this didactic twin can be transformed into an extensive report of learning for the student, which will be particularly useful for the decision-making of the subject teacher or educational institution.

V. EXPERIMENTAL PROCEDURES

The scenario created to evaluate this system followed the following steps:

- **1st Step:** A didactic plant from the Industry 4.0 Laboratory at the Federal University of Amazonas called CP-LAB was used; this plant has six modules that form a didactic cell phone production process. Only the cell phone's back cover insertion process was used to assess this tool. In Fig. 11, the CPLAB_Magfront scenario is presented. This experiment used a conveyor belt to carry the transport pallet, parts storage, a mechanism to conduct production, and sensors for the start and end of the process conveyor. The back cover is inserted into the parts store to begin the cell phone assembly.

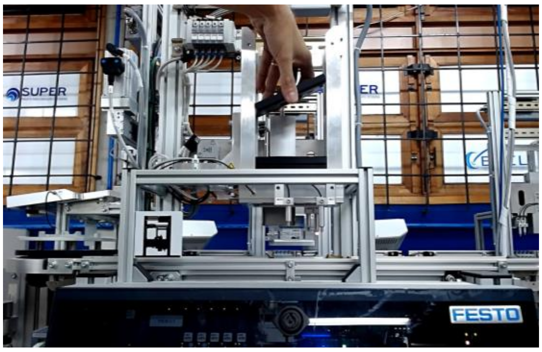


Fig. 11. Teaching plant for the test experiment.

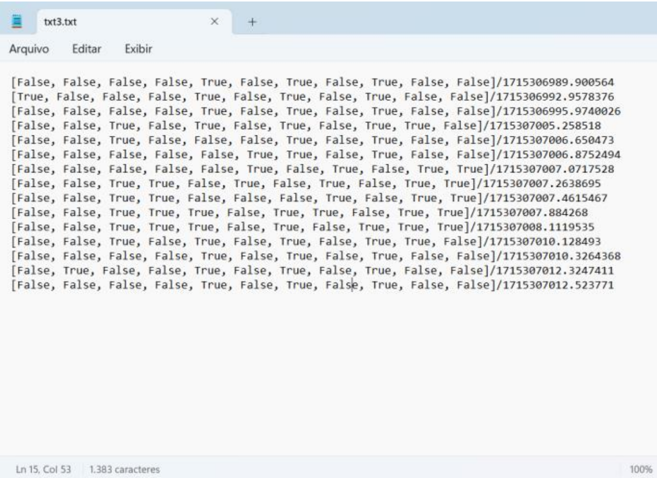
- **2nd Step:** The CPLAB_Magfront plant was registered, the inputs and outputs of the didactic plant were recorded, and then the Teste_magfront experiment was performed. This experiment aims to insert the rear part of the cell phone into the transport vehicle; among the registered information, it is necessary to pay special attention to the endpoint of the laboratory and the inputs and outputs for the proper functioning of the activity conducted by the teacher. After registration, the proposed experiment must be executed, and the learning experiment button must be clicked.

- **3rd Step:** At this moment, the application of the manager element starts monitoring the experiment to capture the steps, which checks the state changes of each registered input and output to save the execution steps. With each saved step, the time from the previous step to the next step is collected, in addition to activating the image capture application. This learning formed the digital twin of the teacher's experiment, and the information was stored in a .txt file and the database as a template for the teacher's experiment for Teste_magfront.

- **4th Step:** At this moment, the application of the manager element starts monitoring the experiment to capture the steps, which checks the state changes of each registered input and output to save the execution steps. With each saved step, the time from the previous step to the next step is collected, in addition to activating the image capture application. This learning formed the digital twin of the teacher's experiment, and the information was stored in a .txt file and the database as a template for the teacher's experiment for Teste_magfront.

VI. RESULTS

The results of the tests carried out will be presented to verify whether the system can learn the system steps at the time of the teacher's execution, forming the digital twin of the teacher's experiment and whether the correction carried out by the system occurs in comparison with the experiment carried out by the student. The scenario in Fig. 10 initially verifies the teacher's learning from the experiment. At this point, it was evaluated numerous times, and everyone showed the same behavior. Fig. 12 shows the .txt file stored after the teacher learned the experiment.


txt3.txt

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Ln 15, Col 53 1.383 caracteres 100%

Fig. 12. File for filling out steps and times.

Ten training procedures for the teacher's experiment were conducted, and the same result was obtained when executing the teacher's programming. The times were collected at each step, and in the .txt file, they were saved at the end of each step; these teams were saved as the type timestamp. The images of this experiment were captured at each step by a thread of the application dedicated to image capture. Fig. 12 presents the photos collected during the teacher's execution.

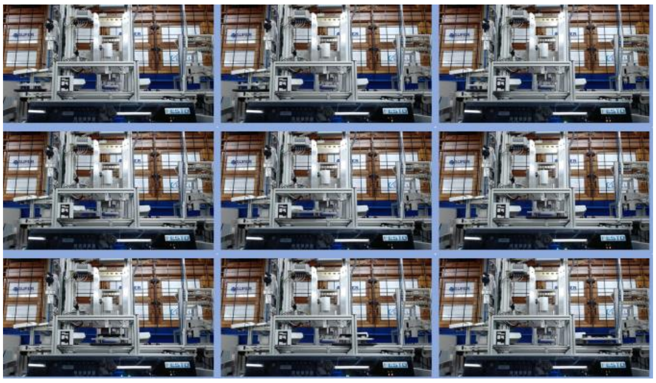

Fig. 13. Images captured from the camera of the teacher's experiment.

A programming error was developed in the student's software to assess the system and show the correlation between the teacher's and student's experiments. The error was not inserting the cell phone cover, and the transport vehicle would pass without the cell phone cover. Fig. 14. The teacher's steps are compared with the student's steps, and the steps that differ from the teacher's steps are highlighted.

STEPS	IN1	IN2	IN3	IN4	IN5	IN6	IN7	IN8	IN9	IN10	IN11
STEP1 - Teacher	False	False	False	False	True	False	True	False	True	False	False
STEP1 - Student	False	False	False	False	True	False	True	False	True	False	False
STEP2 - Teacher	True	False	False	False	True	False	True	False	True	False	False
STEP2 - Student	False	False	False	False	True	False	True	False	True	False	False
STEP3 - Teacher	False	False	False	False	True	False	True	False	True	False	False
STEP3 - Student	False	False	False	False	True	False	True	False	True	False	False
STEP4 - Teacher	False	False	True	False	True	False	True	False	True	True	False
STEP4 - Student	False	False	True	False	True	False	True	False	True	True	False
STEP5 - Teacher	False	False	True	False	False	False	True	False	True	False	False
STEP5 - Student	False	False	True	False	False	False	True	False	True	False	False
STEP6 - Teacher	False	False	True	False	False	True	True	False	True	False	False
STEP6 - Student	False	False	True	False	False	True	True	False	True	False	False
STEP7 - Teacher	False	False	True	False	False	True	False	False	True	False	False
STEP7 - Student	False	True	False	False	True	False	True	False	True	False	False

Fig. 14. Table comparing the steps between the experiments.

In the seventh step of the comparison, the difference was verified, and the student was notified of the error, which showed the photo of the wrong step. Fig. 15 shows the student as a way of indicating that the rear part of the cell phone was not left; therefore, there was a difference between the steps.

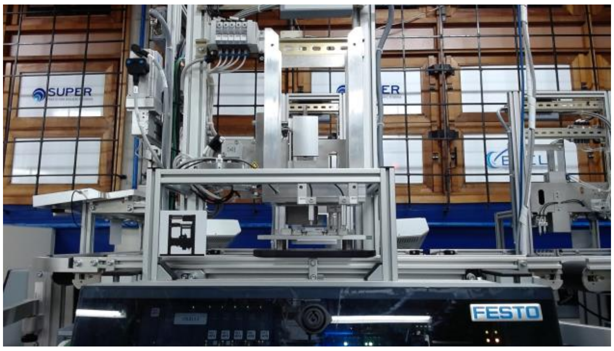

Fig. 15. Student feedback at the time of their programming error.

VII. CONCLUSIONS

The system proposed in this article managed to achieve its objective, as a test experiment was developed to verify whether the architecture of this system can help in the automatic correction of experiments in remote access laboratories. The didactic twin is a proposal that aims to evaluate the result of an experience and the entire journey that the student developed to reach the definitive answer. Therefore, the intelligent digital twin is the tool that helps us correct the experiments passed by teachers. The functioning of the architecture with three layers facilitates understanding, helps organize experiments, and contributes to the evaluation process in remote laboratories. Both the digital twin of the teacher's experiment and the functioning of the student's experiment are ways of providing feedback to the student.

The significant contribution of this article was the development of a system capable of helping to correct experiments. When there is a validated template, learning can always occur when the student uses this learning to correct the experiments without needing the teachers to release their fix.

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