Remote Lab Experiments in Mechanic: The Compound Pendulum

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Abstract—The world is not going to be the same. COVID-19 was the catalyst for the worlds Largest ever remote work experience, and clear trends show that we are at the beginning of a new world. The goal of the hands-on work is to help students understand theory, teach them the scientific process and manipulative techniques, and generate interest and motivation in science. To achieve these goals, students must first recall the mathematical model of the physical phenomenon to be studied, perform manipulations to measure the physical phenomenon, demonstrate the compatibility between the theoretical and measured results and conclude with an analysis. At the end of the session, students are evaluated on the scientific quality of their work and receive a grade. Our challenge is to make this methodology available on a digital platform to allow learning for all, regardless of time or place.

Keywords—compound pendulum, e-lab, remote lab, experiments

1 Introduction

The present work follows a previous publication on remote labs, in which we presented our approach to manufacturing and Developing Remote Labs in Physics for Practical Experiments in the University [1].

Our interest in this topic lies in the relevance of e-Labs in the academic curricula of scientific experimental work. Labs are an essential part of the learning process for students, but the current context of massification of higher education does not allow to plan them in a presentable and manageable way to a large number of students given the limited number of labs rooms and the high cost of equipment and scientific materials.

With the integration of Information and Communication Technologies (ICT) in the teaching practices at the university, it has become essential to use it to improve the accessibility of the students to the labs and enhance the practical aspect of their learning online. Moreover, several research works were led in this direction putting forward the various possibilities of experimental work by using simulations, virtualizations, online experiments and evaluating their impacts on the development of the skills of the learners [2].

Our research work goal is to allow students remote access to real laboratory equipment [3] and setup similar to those done in the classroom, using modern computer and network technologies to create the environment that will allow a remote user to perform the required hands-on physics experiments in a dedicated space that is the E-Lab [4] [5] [6].

Our main objective is to create an interactive environment that will allow students to access and control practical experiments in physics, especially students enrolled in the first year of Physics and Chemistry program at the University. The choice of this target audience is based on two main reasons. the first is that the first academic year needs attention in order to provide a welcoming and motivating teaching and learning environment, the second is that in recent years there has been an increase in rate of massification which forces teachers to make sacrifices at the level of practical work under the effect of logistical and temporal constraints.

The experiment chosen for this work is the manipulation of a compound pendulum we have designed and built a prototype of this manipulation in order to make it accessible to students via the Internet.

1.1 Compound pendulum experiment

We call a compound pendulum any solid mobile around an axis not passing through its center of gravity and placed in the field of gravity show as Figure 1.

The compound pendulum we are using consists of a homogeneous rod of length (d) and mass (m) to which is connected a disk of mass (M).

We neglect the radius of the disk in front of the length of the rod. This amounts to assimilate the disk to its center of mass.

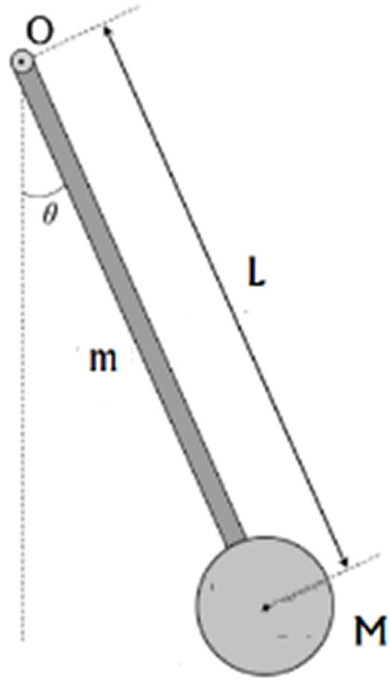

Fig. 1. The compound pendulum

I. The differential equation:

For small oscillations we can write with a good approximation
Sin$\theta \simeq \theta$, so the differential equation in this case is:

$$\ddot{\theta} + \frac{MgL}{J\Delta}\theta = 0 \quad (1)$$

II. Expression of the periodic time **T**:

The period of a free and undamped compound pendulum that oscillates with small amplitude has the expression:

$$\mathbf{T} = 2\pi\sqrt{\frac{\mathbf{J}_{\Delta}}{\mathbf{MgL}}}. \quad (2)$$

T: The period of the pendulum (s)
$\mathbf{J}_{\Delta}$: Moment of inertia of the system with respect to the axis (Δ) in (kg.m^2)
g: Gravity intensity in (m/s^2)

1.2 Lab experiment lessons

The objective of the practical work is to help students understand the theory, teach them the scientific approach and manipulation techniques [7], and arouse interest and motivation for science. In order to achieve these objectives, it is first necessary to recall the mathematical model of the physical phenomenon to be studied, to perform manipulations in order to measure the physical phenomenon [8], to demonstrate the compatibility between the theoretical results and the measured results, and finally to conclude with analysis. At the end of the session, the student is counted on the scientific quality of his work and a mark is assigned.

Our challenge is to restore this methodology on a digital platform in order to allow learning for all, regardless of time or place.

2 Remote lab system design

2.1 Mechanical design

The objective of this part is to explain the mechanical composition of the experimental bench.

Mechanical requirements. The experimental bench for studying oscillation and gravitational field strength must to be motorized so that it allows the pendulum to be caught and released at different angles according to user input. The height at which the mass is suspended is kept fixed. Finally, the bench must be autonomous so it can detect its position at startup using end-stop sensors.

Mechanical parts design. Our approach was to start with the design of the prototype of the practical experiment, and then we developed our prototype such as we need to propose a real experiment to students.

All the pieces of the experiment were designed with SolidWorks Software as shown in Figure 2.

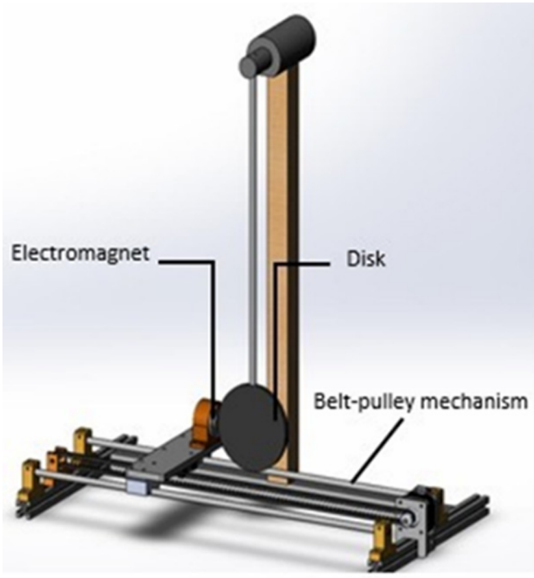

Fig. 2. 3D design of the assembly of our prototype

After the design, all the previous elements were made by the 3D printer, the laser cutting and the vinyl cutting in order to produce the following prototype [9] [10] [11], show as Figure 3.

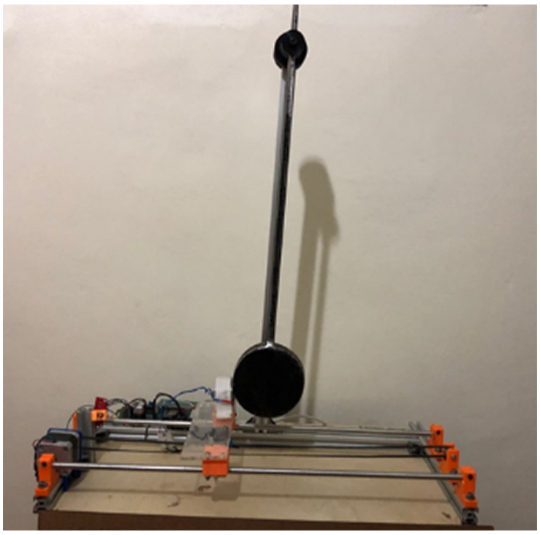

Fig. 3. Prototype developed for the practical experiment

2.2 Control system design

In this part, we will deal with the control system of the mechanical structure in order to realize the movements of the weighing pendulum. This part will describe the composition of the main electronic board as well as the sequence of the control program.

Functional requirements. The control card must be able to:

- Drive actuators such as the motor and the electromagnet
- To acquire data (sensors, images, measurements, etc.)
- To be connected to the internet
- Manage requests and communicate via a pre-established protocol
- To be supplied with a standard main power supply

Hardware structure. The control system consists of two entities: a master and a slave. The master is a multi-task application processor. It has higher performance than the slave processor: network management, web server, real-time video stream capture and wired serial communication. It is he who initiates the communication and sends the commands to be executed. The slave, on the other hand, simply guarantees the execution of the received commands (starting angles for compound pendulum), show as Figure 4.

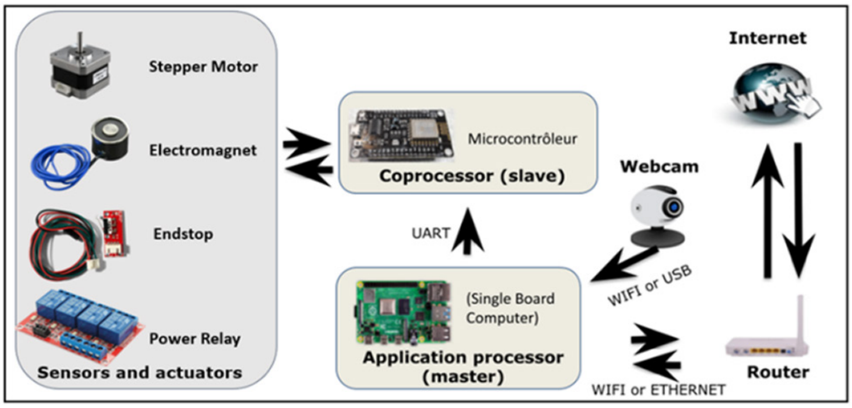

Fig. 4. Control system block diagram

- The Master controller:

In order to implement a web server, we opted for a single board computer called Raspberry Pi 4 [12], [13] because of its power, its reduced form factor and the different interfaces it exposes.

- The Slave controller:

It consists of an ESP8266 microcontroller from Espressif. Powerful and equipped with Wifi interface [14], it has been chosen to allow remote control via network during future improvements.

In order to power the hole system, we choose to work with 12vdc as an operating voltage. The following image (Figure 5) shows the power distribution:

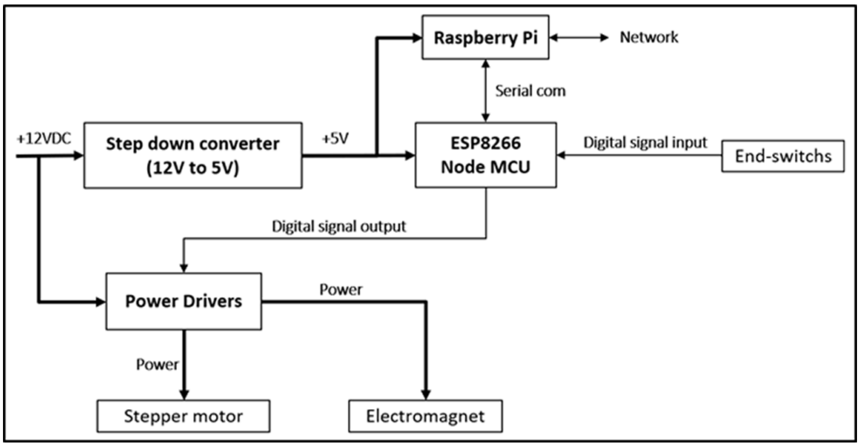

Fig. 5. Electrical schematic of the control system board

The board was designed with KiCad open-source software. We choosed to keep the system simple by just making a board that will host the modules (motor driver, voltage converter, microcontroller board…) Figure 6 shows the 3D view of the designed control system board:

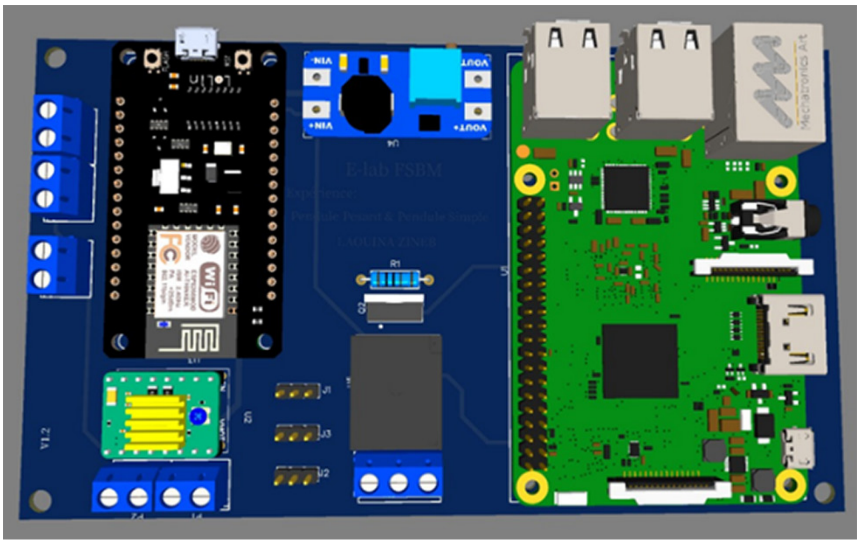

Fig. 6. 3D CAD of the Control system board

The next picture (Figure 7) shows the final result of the manufactured board:

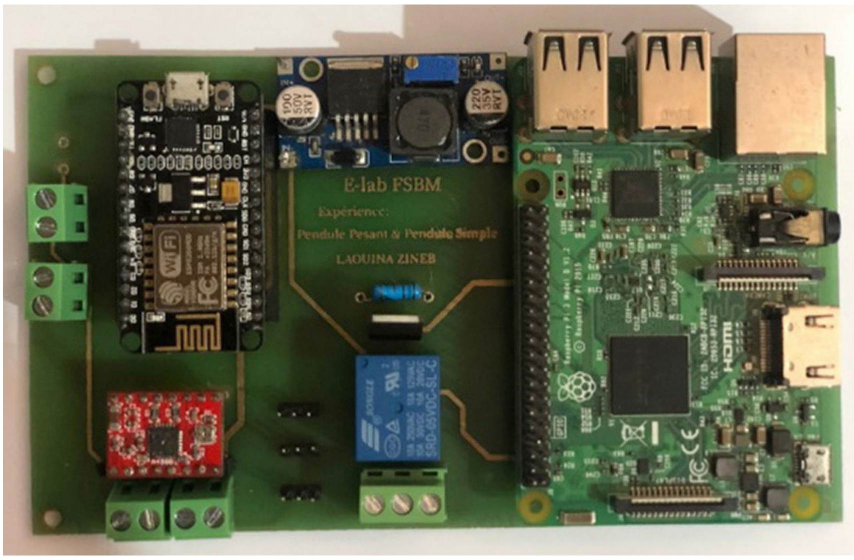

Fig. 7. Control system board manufactured

Firmware design.

Functional requirements. The control board must be able to perform the following functions for our handling:

– Active listening on serial port.
– Decoding orders received.
– Step motor position check.
– Control of the electromagnet

Main program. On power-up, the microcontroller scans the state of the end-stop sensors [15] to verify the presence of the electromagnet at its initial position. Subsequently, the microcontroller enters active waiting mode for "START" command triggered by a remote user. The start command contains the angle to be achieved by the motorized electromagnet.

Here is in Figure 8 the algorithm implemented in the microcontroller:

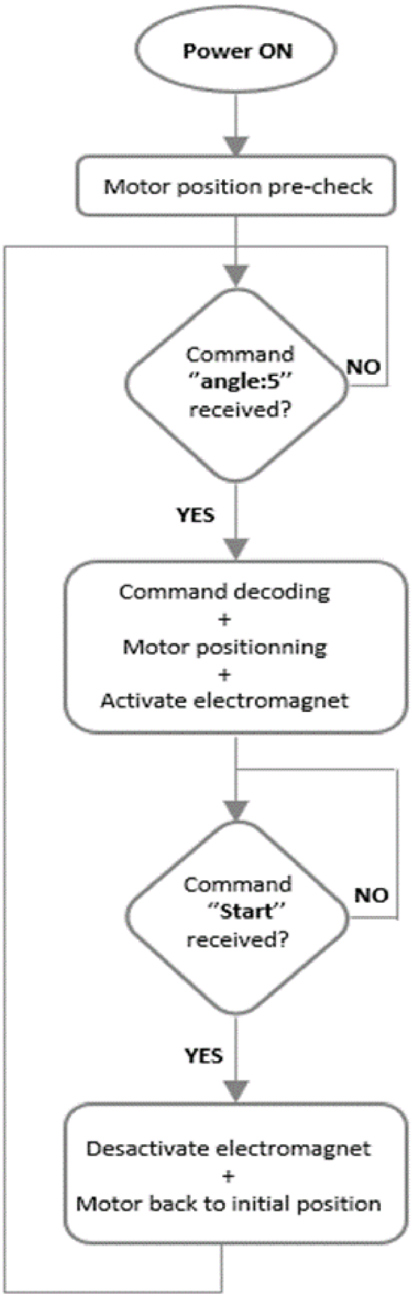

Fig. 8. Flowchart of the firmware

3 Web based d application

The web platform is the most important part since it exposes all the services necessary to guarantee an adequate user experience: From making appointments to carrying out laboratory work and assigning a rating. The objective of this part is to show the architecture adopted and the technologies used.

3.1 Application requirements

In this part we detail the needs of the project by identifying the actors who interact with the system as well as their use case stories.

Actors identification. Our solution is intended for students of the Faculty of Sciences of Ben M'sik enrolled in the first year in the physics and chemistry branch. It responds to the problems of the university's capacity limit and the difficulties of catching up on sessions following the absence of a student.

On the other hand, the solution gives access to the responsible teachers in order to follow the attendance of the students and to collect the marks obtained.

Functional requirements. In this part we proceed to the identification of all the functionalities of our system for each type of user by listing the functional requirements.

After the identification of the actors, the general use case diagram gives a global view of the functional behavior of our application.

The objectives of the system, in the form of a global use case diagram (UML), are shown in Figure 9.

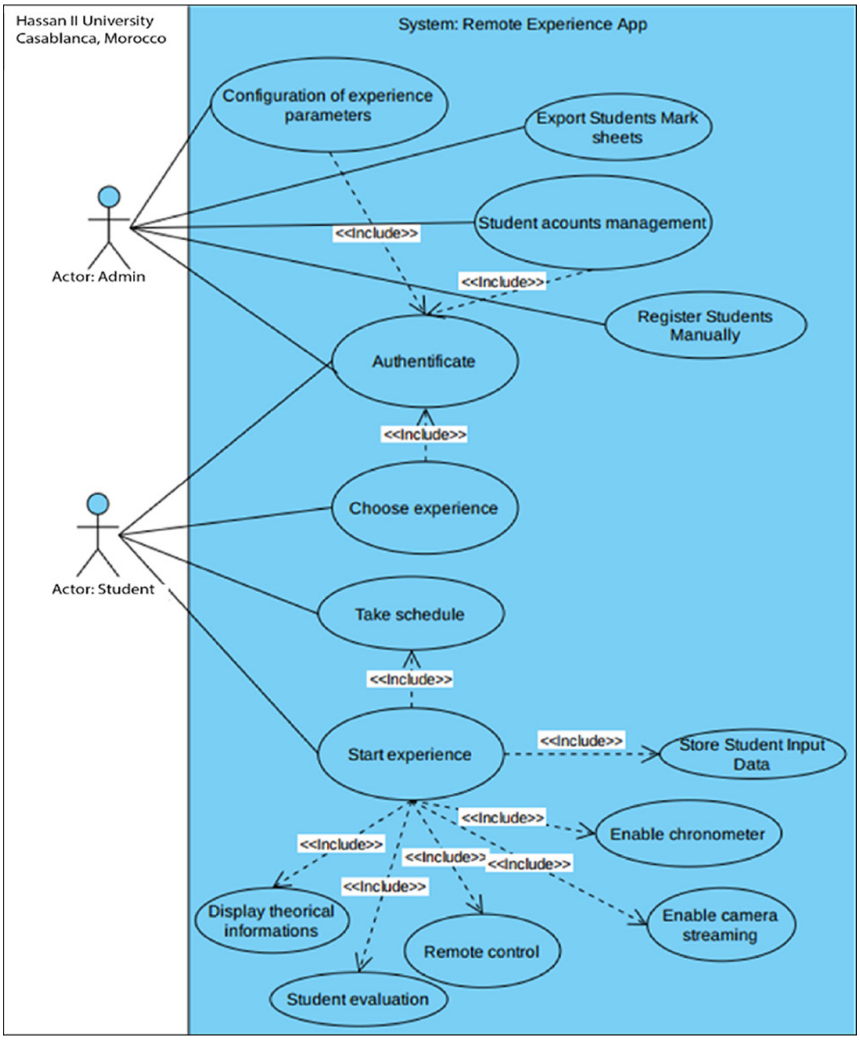

Fig. 9. The global use case diagram

Student use-cases.

a. Authentication:

In order for students to have access to the platform, they must have their unique username and password. Two scenarios may arise, either the student registers on his own on the platform, in which case the authentication is not automatic and requires confirmation from the administrator. Either the student is already in possession of identifiers assigned by his institution.

b. Choice of Experience:

The student has the opportunity to browse the menu of the proposed experiences and read their illustrated documentations. Each documentation explains the theory, the sequence and the expected objectives.

c. Appointment Booking:

In order to gain access to an experience, the student is required to make an appointment. To this end, each experience has a booking field where the student chooses the date and time desired. The platform ensures availability and reserves the experience immediately.

d. Conduct of the experiment:

Upon arrival of the appointment time, the platform gives access to the experience for a period of 30 minutes during which the student can repeat the manipulation as many times as he wishes.

On his screen, the student visualizes the experimental bench through an installed camera in the premises of the establishment. To guide him, a job code is at his disposal to carry out the experiment. The results obtained by the student should be inserted into their appropriate fields and submitted for the platform to store in its database.

The administrator use-cases.

a. Importing the student list:

Each academic year, the administrator feeds the platform with a file containing the list of students and their future identifiers. The platform uses this list when a authentication is detected.

b. Export results:

The administrator has access to the records related to each student: duration of the session, results obtained and calculated values. This record can be exported to a spreadsheet for attribution and submission of points.

3.2 Application architecture

The software architecture contains two main components, show as Figure 10.

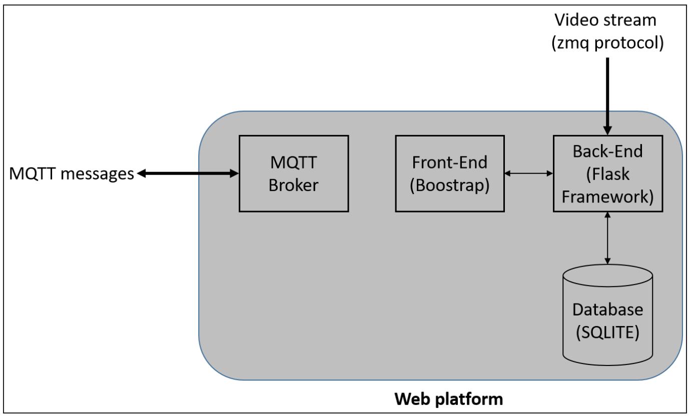

Fig. 10. Synoptic the remote experiment platform

i. Server:

– The platform that serves the education experiments web application, it contains the following elements:

a. The back-end side of this project was reloped using FLASK library which is a Micro web framework written in Python. It is classified as a microframework because it does not require tools or libraries.
b. The front end was developed using BOOTSTRAP which is a free and open-source CSS framework directed at responsive, mobile-first front-end web development. It contains CSS- and (optionally) JavaScript-based design templates for typography, forms, buttons.
c. SQLITE database in order store the Users credentials, Experience Information and Date/Time of Appointments (experience).

– The MQTT broker to communicate with the RaspberryPI [16] [17].

ii. Client:

Which is hosted in the Raspberry-pi and serves the following:

a. Streaming the video capture via ZMQ protocol for real time stream [18].
b. Communication with MCU(microcontroller) via UART that plays the role of Actuator.

3.3 User experience

The web application was hosted under www.e-labfsbm.com domain name. Here is the scenario of usage:

– User gets his credentials to access the platform, show as Figure 11.

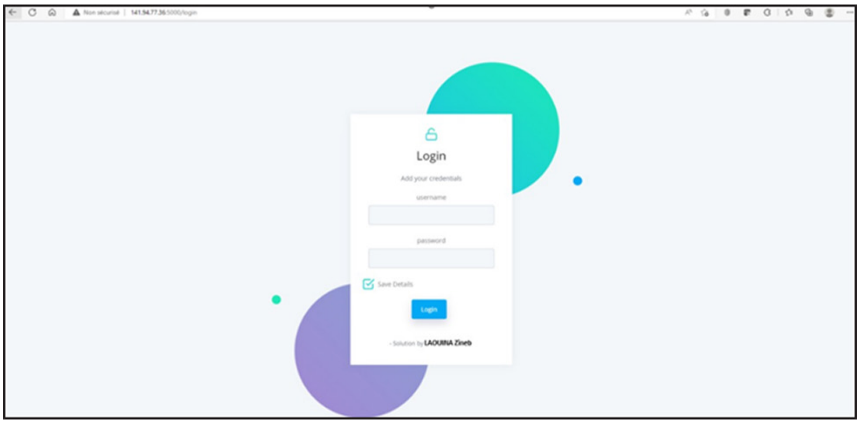

Fig. 11. Authentication interface

User selects the wanted experiment and picks a date to attend the session, show as Figures 12 and 13.

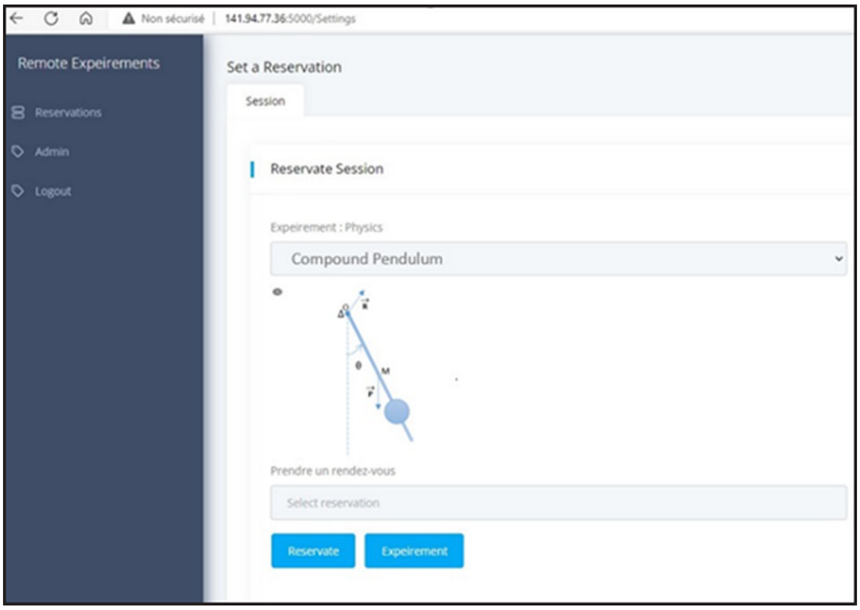

Fig. 12. Choice of experience interface

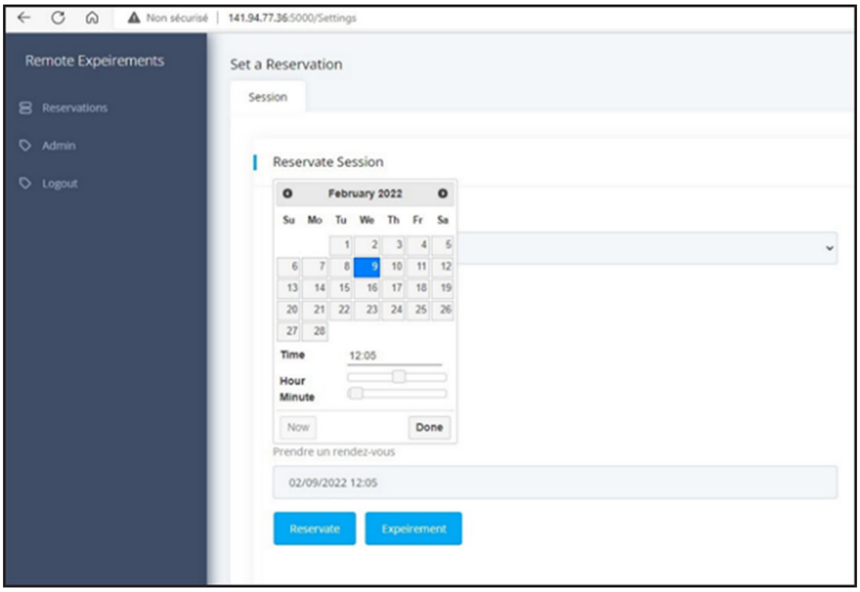

Fig. 13. Reservation interface

– User enters the session.
– User read the Theoretical part and discover the experiment as it will be (Figure 14)

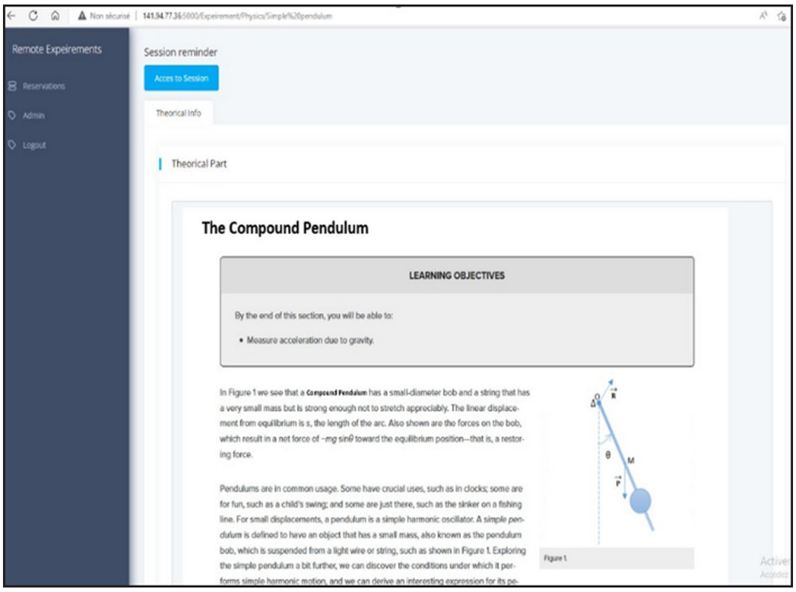

Fig. 14. Interface of the theoretical part

- User is ready to attend the session virtually and visualize the streaming of the experiment
- User has 3 tries and questions to answer (Figure 15).

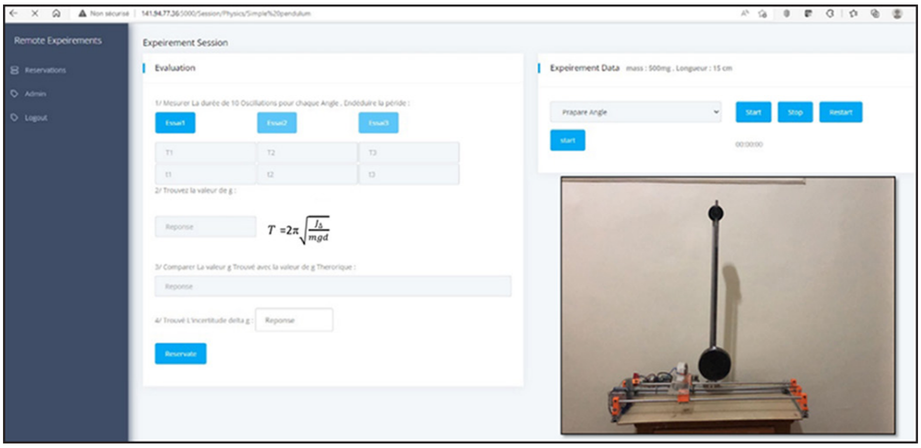

Fig. 15. Remote experience interface

- The platform will generate based on the user answers an evaluation note that will be downloaded as PDF, show as Figure 16.

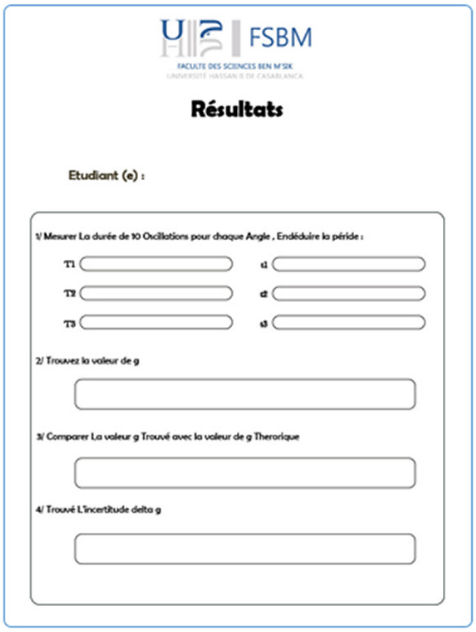

Fig. 16. Review of experiment

4 Conclusion

The work we present in this article is part of a series of experiments aimed at developing the e-lab of our institution.

Our objective is to design, realize and implement online the prototype of the pendulum complex, considering that this experimentation is empowering for the students of the first year in terms of learning impact.

In this article, we present first the Remote lab System design work, then the Control system design and finally the Web based remote lab application online to integrate the experimentation in the e-laboratory platform.

This work has required the collaboration of several expertises in the field of conception, design, electronic processing and software development. We have taken care to integrate the pedagogical dimension of the scenario of the manipulation for the learners and for the pedagogical team.

This prototype will be evaluated on a restricted group of students under the supervision of a teacher in order to measure its impact and its relevance for a later dissemination.

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