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Platform for hands-on remote labs based on the ESP32 and NOD-red

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ABSTRACT

Not only in Morocco, throughout the walks of the world covid 19 pandemics has seriously questioned policymakers from different sectors. Think-tank in the educational sector notably higher education addressed by such a wide range of challenges brought about by covid 19. The characteristic concern that educationalists in Moroccan universities have to reconsider in this pandemic period should not be beyond rethinking new pedagogical alternatives including approaches, methods, techniques and didactic materials which can successfully assist practioners of the teaching and learning process to keep up with the current alterations. Practical work (PW) is an indispensable type of teaching in scientific and technical training and meets a real complementary need through real, remote or virtual laboratories. Students can consolidate what they have learnt and develop analytical skills by comparing experimental results with those obtained during the manipulation. In this context, the Laboratory of Engineering Sciences and Energy Management (LASIME) at the Superior School of Technology of Agadir has developed a low-cost platform called LABERSIME installed in the cloud (LMS, IDE) and equipped with an embedded system to drive real laboratory equipment and perform experiments qualitatively more efficient than those in face-to-face mode. The ultimate goal is to stimulate self-learning motivation in students through a creative approach.

Introduction and literature review

Higher education has always been at the heart of all debates on education throughout the world, and is at the centre of several problems and debates [1]: massification, democracy, etc. It is increasingly playing a role as an essential lever for development, especially in a knowledge-based economy based on research and innovation [2]. It has been transformed over the last two decades under the effect of economic and financial globalisation and also the arrival of new technological advances, and we are already beginning to wonder about its probable continuity without ICT. Indeed, over the last twenty-five years, many countries have developed mechanisms to guarantee the quality of university education based on new innovative technologies [3]

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In this context, Moroccan universities are faced with several challenges and need to rethink teaching/learning methods to encourage greater student participation and promote innovative teaching practices. Given the growth in enrolment and the limited means of supervision, such an evolution leads to simultaneously take up pedagogical, technological and organisational challenges [4]. The Moroccan university must therefore succeed in facing up to the structural upheaval of the new modes of access, creation and dissemination of knowledge. It must think of following the train of such an evolution which is part of a partial transition towards the "all digital". The main objective of such actions is the development of new forms of active and collaborative learning based on nomadic and ubiquitous course tools [5].

In general, practical work (PW) is considered an essential part of teaching and learning science, this position has been confirmed by international researchers, teachers and curricula [6]. Furthermore, it is considered that students generally seem to enjoy practical work and this increases their motivation to study science [6]. Indeed, many researchers have found that science learning and understanding is enhanced when students are engaged in hands-on experiments in a science laboratory. In this sense, the sociologist Edgar Morin (1984) has even stated that "Science is a mode of knowledge based on the dialogue between theories and observed or experimental data". The results of science are therefore not to be taught as data to be believed but as results produced by experimental methods. Experimental know-how can only be acquired by students if they have manipulated during practical work sessions.

In science faculties, practical work should be carried out in small groups of students, to allow the theory learned in class to be put into practice through experiments [7]. Practical work stimulates students' curiosity by allowing them to observe and ask questions. They also help to develop a spirit of initiative and above all a critical mind when it comes to analysing and interpreting results. Indeed, the experimental approach helps, on the one hand, to master the concepts that manage the functioning of a device and, on the other hand, to articulate the experimental practices in order to achieve the appropriation of knowledge qualified as theoretical. However, the sessions of the TP in the Moroccan establishments are impacted by the massification. To the problem of the increase in the number of enrolled students is added the insufficiency of scientific equipment: materials that must be monitored throughout the experiments to avoid any damage. This situation has created some management complexities for both teachers and students. At the level of the teachers, the supervision rate increases as the number of enrolled students increases, we are talking about a number that varies from three to four trinomials per teacher, given the volume of time per session reserved for practical work, the time distribution is hardly sufficient to cover and achieve all the objectives with efficiency.

Faced with these imperatives, students are now required to deepen their understanding of theoretical concepts and to acquire technical know-how: to master the theoretical aspects related to the manipulation, to handle the material correctly, to read and interpret the results and finally to extract constructive conclusions. Achieving these various learning and behavioural skills cannot be achieved entirely and solely during the sessions reserved for practical work under the conditions mentioned above. Furthermore, the growing interest in the use of technology in higher education cannot be ignored, as today's students think and process information in a fundamentally different way from their predecessors.

Science and technology are based on the application of theoretical knowledge through the manipulation of objects and instruments. Practical work (P.W.) requires a special time and place. Due to the high enrolment in higher education and limited resources (number of rooms, equipment and human resources) [8], the acquisition of knowledge in the face-to-face mode is rather delicate. However, new strategies have been developed to motivate students to learn electronics and electrical engineering as one cannot limit oneself to classical classroom-based methods. In addition, the open-source hardware movement has gained popularity with the emergence of low-cost, high-performance technologies such as Arduino and Raspberry Pi, due to the community of manufacturers who actively share their creations for study, modification and application in educational projects [9].

In order to face these challenges, different remote laboratories have been developed for several years. Among these labs, we can distinguish between remote labs and purely virtual labs. And as we know, setting up a remote lab is more expensive and complex than a virtual lab [10] but on the other hand and pedagogically speaking, the added value in learning via a remote lab is more beneficial than the virtual lab [11] because the latter is only a computer model of approximations of reality via modelling to do simulations.

Remote laboratories offer advantages, especially in terms of reduced investment costs for equipment and instruments. Remote laboratories offer a number of advantages [12], not least in terms of reduced investment costs for equipment and instruments. One equipment can be used by many students and maintenance costs can also be shared if the equipment is used by different universities. Students who work and study part-time may also find remote labs useful in balancing their commitments. Using a smartphone or tablet, the student can continue learning from the classroom at home with flexible scheduling [13].

In recent years, remote laboratories have been deployed [14,15] as remote learning solutions. For example, the European Go-Lab initiative aims to enhance the classroom experience by using inquiry-based learning [3] through physical and virtual online manipulations [16] in universities.

- Laborem: developed at the University Institute of Bayonne, a platform installed in localhost via a Raspberry Pi board used as a server containing an open-source software (Moodle LMS) and an electronic board to ensure communication between the server and the equipment used in the practical work. LPyScada makes the control and data acquisition [17].

- IoT System for Remote Practical Works: the IoT system for remote practical works is mainly based on the Red Pitaya card. The remote communication is done by the RIP protocol for the control and acquisition of measured data, with the use of an electronic card so the teachers can choose the practical works for students [18].
- IoT4SMEs: based on MATLAB, integrated via ViSH is a social and collaborative platform based on creating and sharing virtual learning resources [19].
  ThingSpeak, a publicly accessible cloud-based data collector. This open-source application provides various services such as storage and retrieval of data from IoT sources via HTTP Protocol, and monitoring and analysis of data based on MATLAB numerical computation software [20].
- RemotElecLab: This is a newer remote lab platform for students to experiment with electrical and electronic circuits. This solution was created after studying the shortcomings of current remote lab solutions for similar tests in order to improve them, especially by using generic equipment. It is accessible through a generic interface in dependable on the circuit under test [21].
- Another example is the LabsLand1 network, a commercial venture that aspires to construct a broad worldwide network of remote laboratories from various supplying institutions, allowing schools and universities to access them via a single and trustworthy platform [22,23]. These endeavours can build upon the numerous breakthroughs in the literature about remote laboratories. Today, remote laboratories may be entirely web-based, making them accessible to the majority of users [24]
- Similarly, iSES2 has established its own online teaching system [25] that contains a number of remote laboratories with particularly specialized physics applications. Among these are the ability to validate the Heisenberg uncertainty principle, perform the Franck-Hertz experiment, and do microcontroller experiments [26]
- The GOLDi3 provides access to a remote laboratory with multiple setup choices. Here, different control units (a CPLD, an FPGA, a microcontroller, an FSM, etc.) and physical systems can be selected. This provides the user with a great level of flexibility in executing various experiments [27]
- The University of Lisbon has developed e-lab, its own remote laboratory initiative. It is an online platform that allows access to remote physics and chemistry laboratories. This laboratory allows working with AC and DC electrical panels, as well as engineering laboratories for programming microcontrollers using Arduino uno boards [28].

As described above, remote labs can guarantee the same pedagogical objectives as classical labs [29,16] as long as they maintain a certain quality of service, but when remote labs are down, have connection problems or are not able to support user management, it is not possible to ensure an adequate quality of service and a better user experience, which may lead users to abandon remote labs in favour of other solutions such as virtual labs or classical practical labs,

In addition, the implementation of the above-mentioned projects is complicated for teachers and requires the mastery of the technology and the architecture adopted so that they can use it and postulate new manipulations.

To solve this problem, the Laboratory of Engineering Sciences and Energy Management (LASIME) at the Superior School of Technology of Agadir has developed a low-cost platform called LABERSIME that is installed in the cloud (LMS, IDE) as a complementary solution with a simple architecture (experimentation based on the ESP32 microcontroller and other electronic components) designed to reduce costs and share hardware components in an optimal way with the platform users. The ultimate objective is to encourage students' self-learning motivation through a creative method.

To this end, the contributions of this work are:

1) The description of a set of remote laboratories created as part of the set of technological solutions previously presented above.
2) The description of a remote laboratory, which is based on the IOT architecture, first tested in the practical work of photovoltaic systems for the students of the first year of electrical engineering at the Agadir Higher School of Technology.
3) Conclusions, based on the previous quantitative analysis, taking into account mainly the availability and quality of service provided by the laboratory from the user's point of view.

This article is organised as follows: Sect.2 presents materials and methods of the remote laboratory solution. Then Sect.3 describes the experimentation and implementation of the Platform. Finally, Sect.4 presents the main results summarised and the conclusion.

Materials and methods

We propose in this context, the design and the realization of a platform for the remote practical works for the students of electrical engineering. Our proposal consists in reinforcing the preliminary preparation of the manipulations outside the face-to-face sessions. The evaluation-test of our approach is carried out initially for the practical work of "characteristics of the photovoltaic cells" for the students registered in first year of electrical engineering at the higher school of technology of Agadir, the objectives of this self-training are the following three points:

- Knowledge and prerequisites: students are invited to review basic scientific concepts, definitions, units, models.
- Working methodology: it concerns the reasoned use of laws and formulas, calculation of uncertainties, exploitation of curves, reasoning methods.

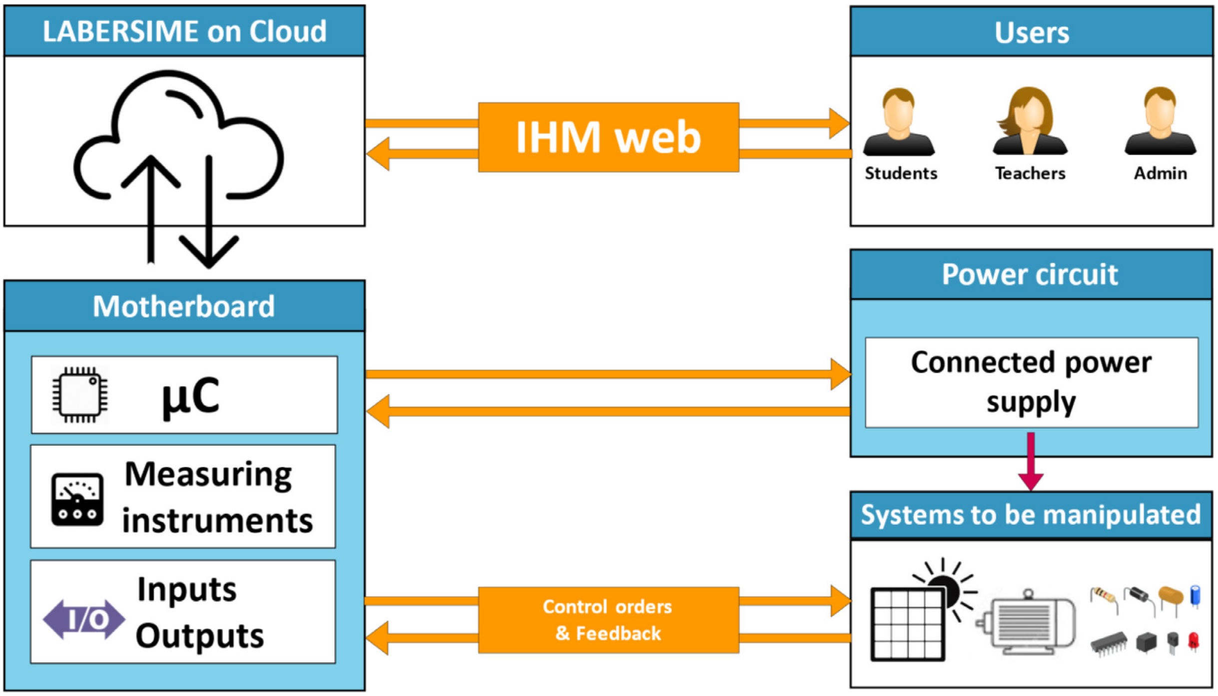

Fig. 1. Platform architecture.

- Experimental methodology: it targets practical know-how concerning the use of measuring devices, the graphic representation of measurements.

The platform consists of a human-machine interface via LMS that allows students and teachers to access the laboratories remotely via the MQTT protocol [30], a motherboard based on an ESP32 microcontroller, connected instruments and input/output devices to manipulate the targeted systems. Users of the platform can control the equipment through pre-actuators that distribute the energy required for their operation. The feedback chain ensures that the commands issued are executed or not in an interactive process. In addition, electronic components (ADC's) have been integrated to allow the acquisition of data from different sensors.

The software and hardware used are open-source, and have been developed to meet the growing demand from electronics developers. Students and teachers find it easy to use, adaptable to different scenarios depending on the description of the manipulation.

The architecture of LABERSIME is presented in Fig. 1. A cloud-based VPS is used as a server containing the LMS Chamilo and Node-RED, the motherboard has different input/output ports to connect all the necessary devices (components, measuring devices, power supplies, oscilloscopes).

Hardware parts

For the hardware we have chosen components and equipment that are easy to integrate in the systems as shown below: As shown in the figure above, hardware composes of the following:

- **ESP32 Microcontroller:**

ESP 32, which is a low-cost microcontroller that replaces the previous version ESP8266, is at the heart of the architecture of hardware. Along with integrated Wi-Fi, ESP 32 offers a variety of functionalities compatible with a wide range of sensors for a different use, including IoT and streaming its specification. It as well offers programmers a powerful toolkit [31] with dual cores,240 MHz, 520 Kbyte SRAM and peripherals including: I2C, DAC, ADC, I2S, SPI, UART, 34 physical GPIO pins (Fig. 3). The power management unit and the lower power controller enable the ESP32 to run lower than 1mA in deep sleep mode. These advantages make the ESP32 a better device for low power applications.

- **ESP32-CAM**

The ESP32-CAM is a low-cost card that includes an ESP32 microcontroller and an OV2640 camera. One of the most interesting features of the ESP32 is the ability to communicate by Wi-Fi, an obvious use of the ESP-32 CAM is to transmit live video images via Wi-Fi (surveillance camera, etc.). In addition to an OV2640 camera, the module is equipped with a micro-SD card reader that can be used to store images or video sequences [32].

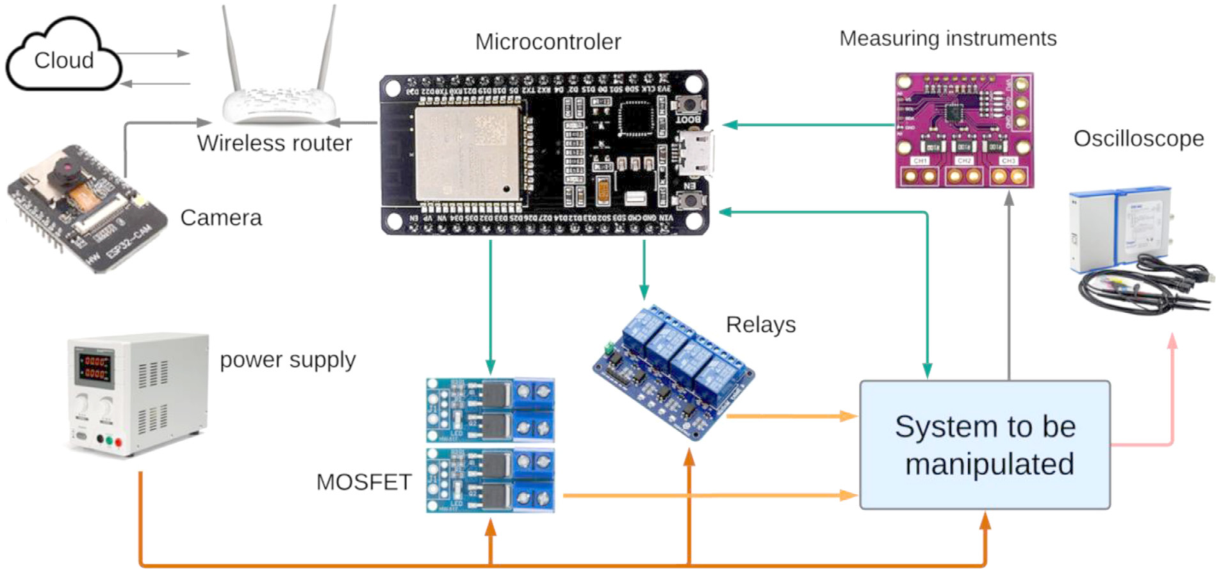

Fig. 2. Schematic view of the hardware components connected to the microcontroller.

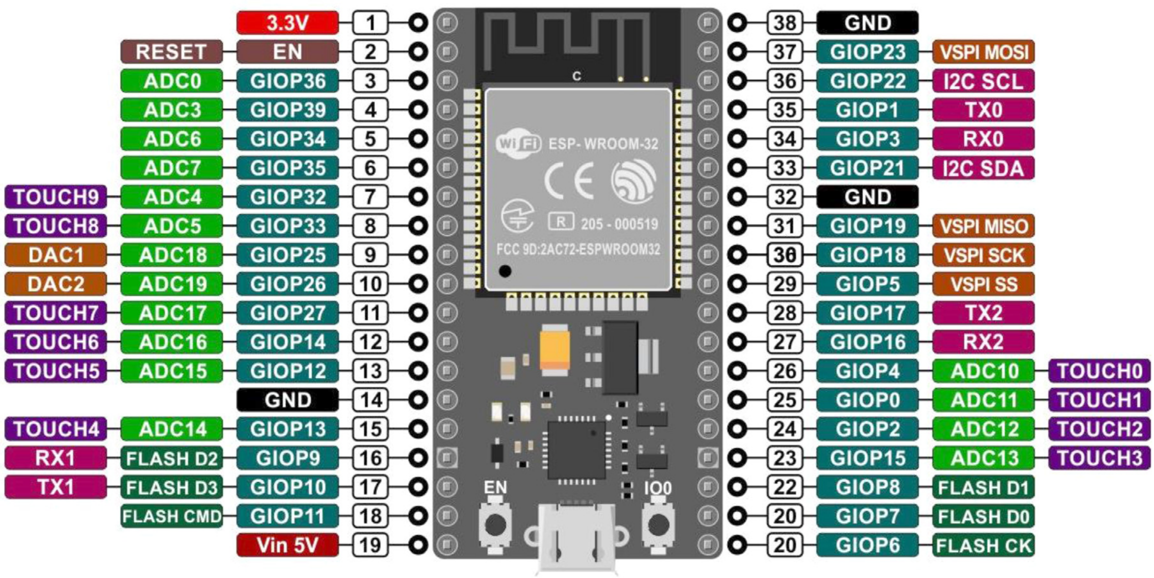

Fig. 3. ESP32 board.

- **INA219**

INA219 is a High Side DC Current Sensor Breakout circuit for measuring the power consumption The INA 219 can measure DC current up to 26V / 3.2A. It is equipped with an I2C bus, which makes it very easy to retrieve measurements using an MCU (Arduino, ESP8266, ESP32) or a Raspberry Pi [33].

- **MOSFET D4184**

The component can be used in applications such as controlling the output of DC electrical equipment, DC motors, light bulbs, LED lights, DC motors, micro-pumps, solenoid valves, etc. The input voltage (V_{IN}) is 5V to 36V DC and the rated output current (I_{Load}) is 15A with a maximum power of 400W. The trigger control signal is 3.3 to 20V DC and the standard operating frequency is 20Khz [34].

- **INSTRUSTAR ISDS210A Oscilloscope:**

An oscilloscope is used to visualize electrical signals during manipulations [35]. The device connected to our platform is the digital model attached to the USB port (INSTRUSTAR ISDS210A) which stores the received signals and displays them on a screen for consulting and studying them remotely via the RDP protocol.

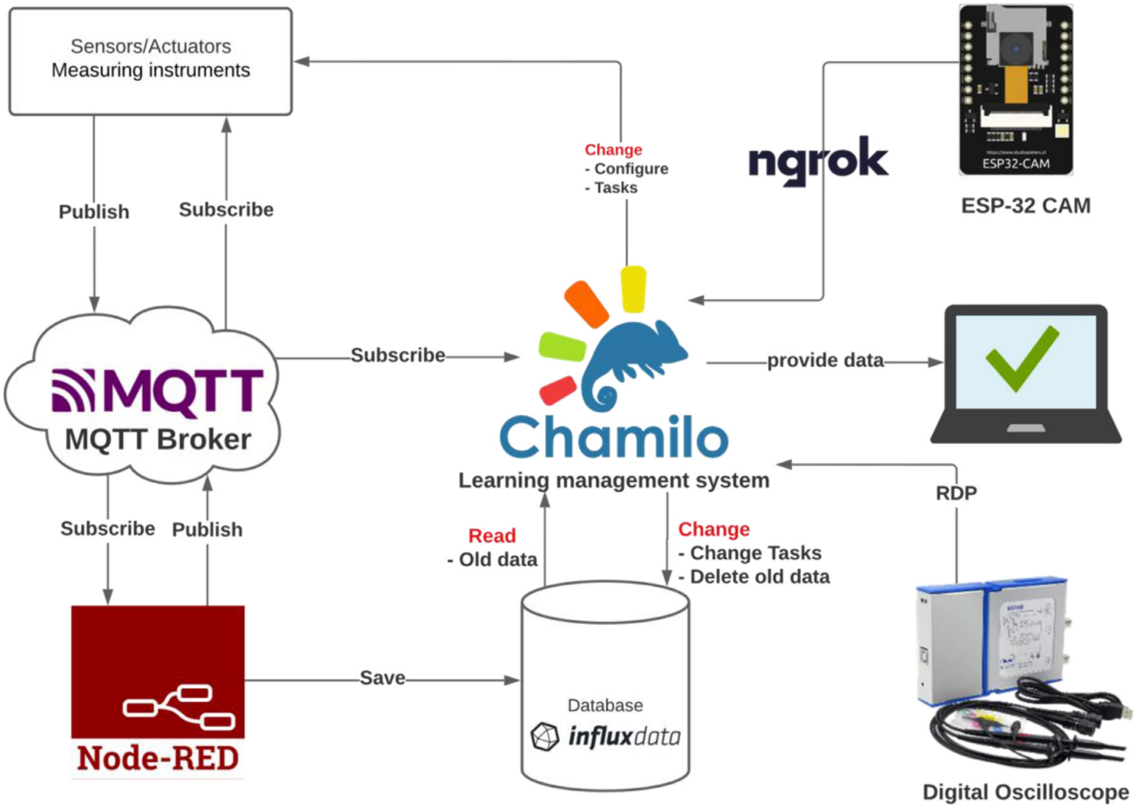

Fig. 4. Software Architecture.

Software Parts

Built on a Node.js framwork, Node-RED is a stream-based programming interface. Input and output nodes allow scenarios of any kind to be built graphically, providing a JavaScript function editor for further customisation. As illustrated in Fig. 4, the Node-RED transforms messages acquired from UC ESP32 into JSON format via MQTT Protocol, Mosquitto acts as a broker that runs with the Node-RED on the Cloud.

- **Chamilo LMS**

Chamilo is platform known for its ease to use (3 times less learning time than Moodle) [36] and its light weigh. It is also one of the three most popular open-source educational platforms globally. Chamilo is an intuitive and comprehensive platform for managing courses and learning content. Each course has a minimum of 24 tools to choose from, which you can select with a mouse click. This educational platform meets the needs of all types of structures (both public and private), from the autonomous user to large companies. Many features are available, such as Course tools (courses, courses, announcements, class diary, attendance sheets, synchronous and asynchronous communication, glossary, survey, forum, documents, groups, chat, wiki), and numerous monitoring tools (reports, statistics).

- **Influxdata**

The choice of the right type of database is crucial to managing IoT data efficiently [37]. For this purpose, we used InfluxDB, which is known for its reliability and is generally used for real-time applications.

- **Micopython**

MicroPython is a Python interpreter optimised for microcontrollers such as ESP32 boards with thread support. Script [38] can be upload directly on ESP32 board. By simply flash the microcontroller board with firmware available on micropython.org. An IDE software (e.g. Thonny IDE which embeds the latest version of Python) [39] with built-in communication to interact with REPL.

The algorithm for controlling actuators and the acquisition of the sensors is shown in Fig. 5, the flowcharts illustrate the operations executed at the Cloud, from the initialization of the server until the end of the processing of the received data and the control of the pre-actuators (Fig. 6).

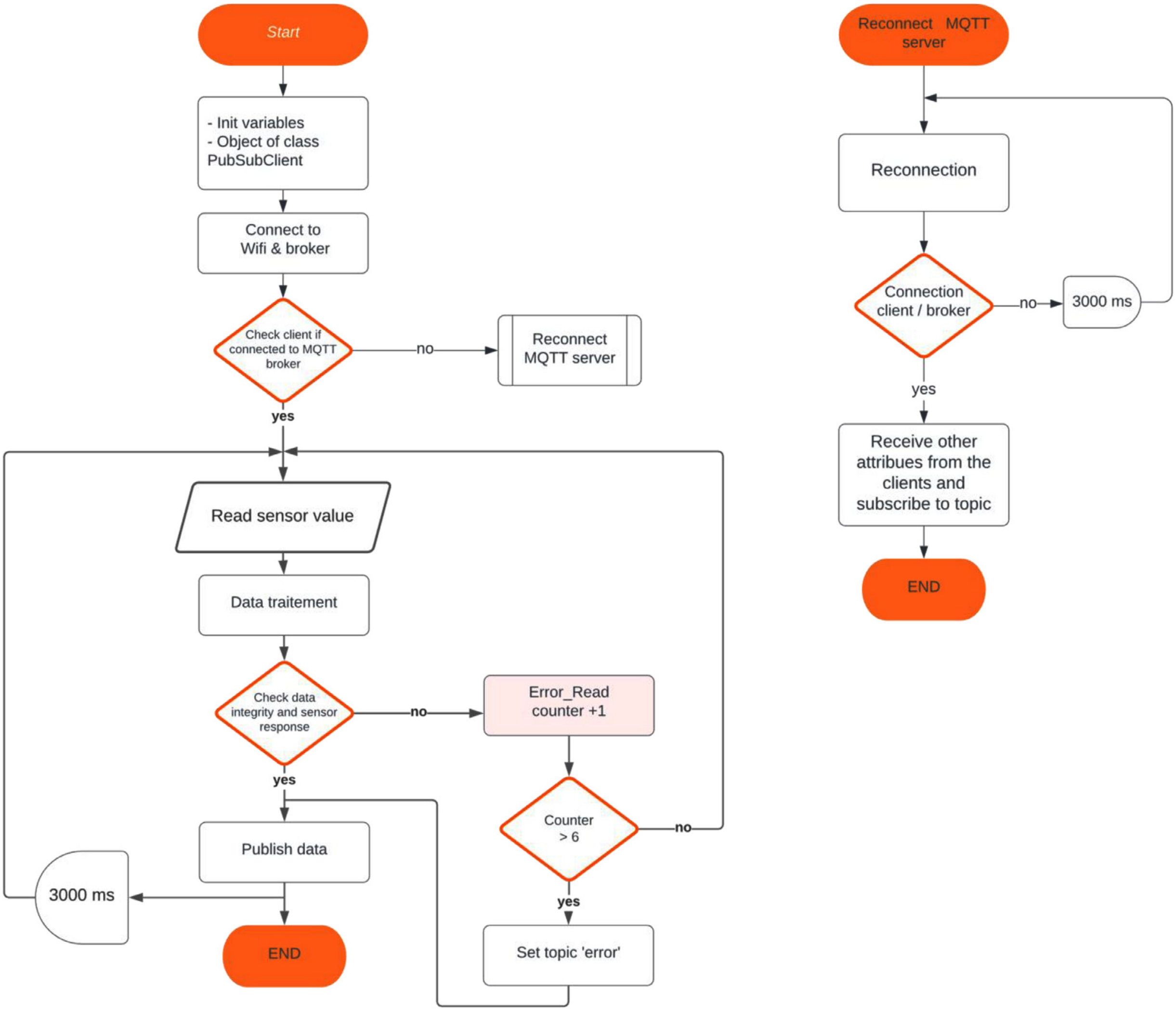

Fig. 5. Algorithm for sensor acquisition.

Experimentation and implementation of the IoT platform

By and large, to get students exposed to experiments in the platform, professors are required to consider the following phases respectively. First of all, the availability of not only adequate but also motivating and resourceful activities should be within reach. So doing would not take place beyond lecturers' engagement via preparing beforehand so that learners can be familiar with new forms of learning. If successfully learners get accessed to suggested materials in advance, they can have sufficient time to work at ease and get prepared to deal with proposed activities. The social network function provided by Chamilo comes as supporting equivalent LMS that provides learners to exchange and interact with each other via discussions, debates and forums. However, having effectively created such kind of experiments is conditioned by having an administrator role in LABERSIME platform; not all professors can do the task if not subjected to such a role. With so they can modify existing resources or create new ones, the administrator can also consult the list of users or add a new group of students.

The pedagogical approach-based

The process of teaching and learning does only rely on competence- input- but also performance- output-; the two necessitate an effective method which cannot be segmented from technique as well. Within a huge number of approaches, I thus opt for applying the so-called ludic approach, it best works to improve, immerse and motivate students while learning process [40] The choice is not out of the ashes, rather it keeps learners within the process and then become into the centre of the teaching and learning. Learning in an atmosphere which makes learners feel their sense of being human is thus given

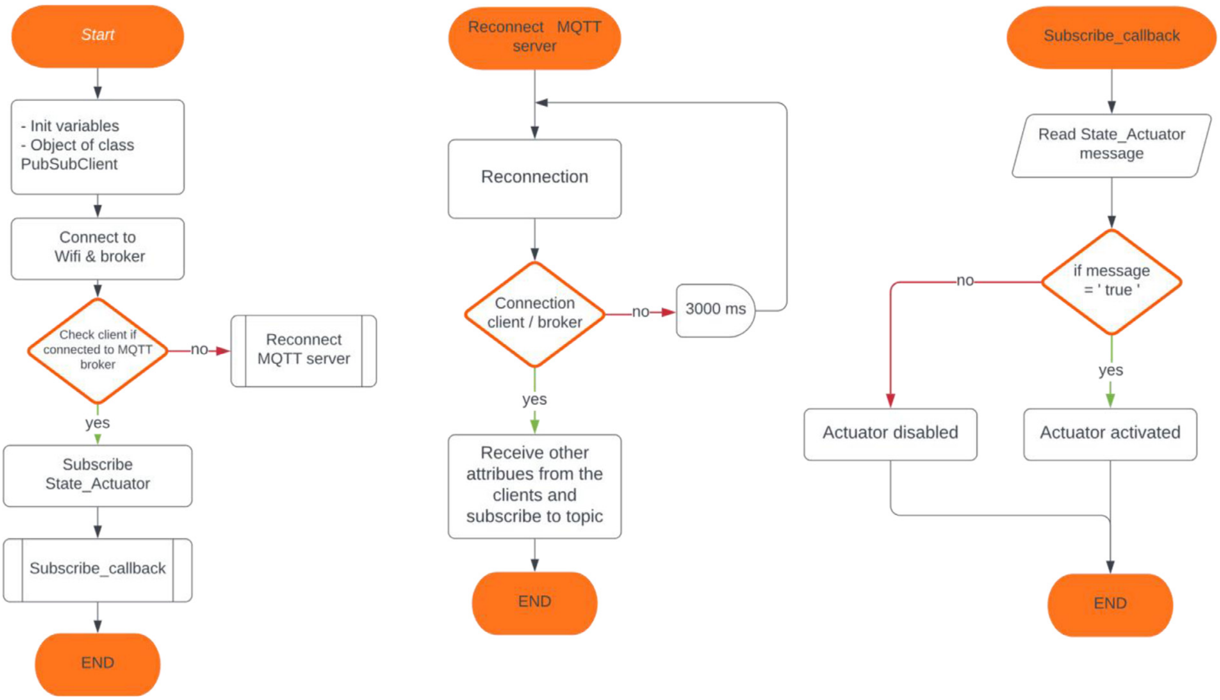

Fig. 6. Algorithm for actuator control.

by ludic method, as it leaves them learn at ease and additionally enjoy. Like other approaches, ludic method suggests the following stages:

- Pre-requisites: learners are asked about their prior knowledge.
- New theories: learners get exposed to new input.
- Quizzes: learners sit for quizzes as forms of assessment.
- Remote experiments: learners get engaged in practical works.
- Final exam: learners are in the process of evaluation; be it pertaining to one module.

In each activity time allocated should be respected, as the number of allowed attempts should not exceeded. An adopted scenario is described in Fig. 7 below:

Interaction interface

Fig. 8 shows the client interface screen when exposed to a sequence (Remote Laboratory).

The menu describes the learning scenario, the student may or may not be allowed to access to a course. These conditions depend on the student's results and course choices.

The central area is for manipulation and access to the results of the experiment. In this dynamic area, the user can interact with the remote laboratory by getting position in the queue, setting the parameters of the experiment, and view the equipment located in the laboratory, participate in the PW by making measurements and export graphs to enrich report of his experiment. subscription to a topic (sensor/MQTT/publish) [41] on the MQTT broker is done by Node-RED to publishes data received from ESP32. We design the flow to manage and process the device's sensor data. Example of the split method to separates a received string into an ordered list of substrings, each string represents a particular value of a sensor.

A flowing design for handling INA219 data is shown in Fig. 9. First, a subscription node subscribes to the topic (MQTT/publish). This node will get data from the MQTT broker whenever the device publishes it from the INA219 Breakout [42]. Then the acquired data will be displayed on the gauge and graph node. Finally, a dashboard will be shown as a user interface and present the physical quantities measured (voltage, current, power).

The same principle is used to control the pin status of the ESP32, so relays can be activated and deactivated to control equipment or to ensure connectivity between electronic components.

Results and discussion

This work's outcome is provided in two parts. The first stage is to determine the final user interface as well as the technology that will be utilised to undertake the distant practical work. The platform is then evaluated in the second stage,

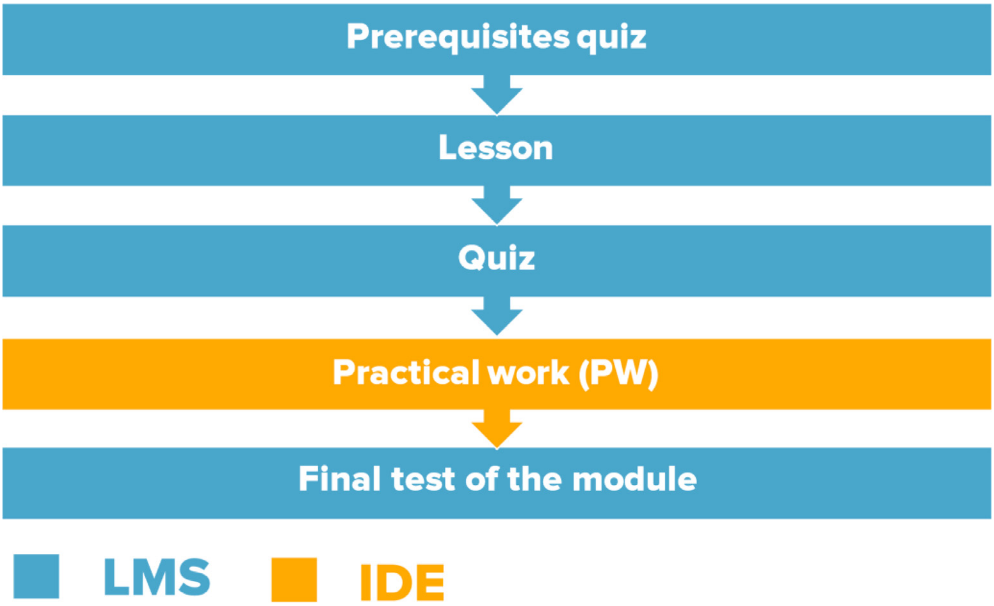

Fig. 7. Pedagogical scenario describes the learning sequences via LABERSIME.

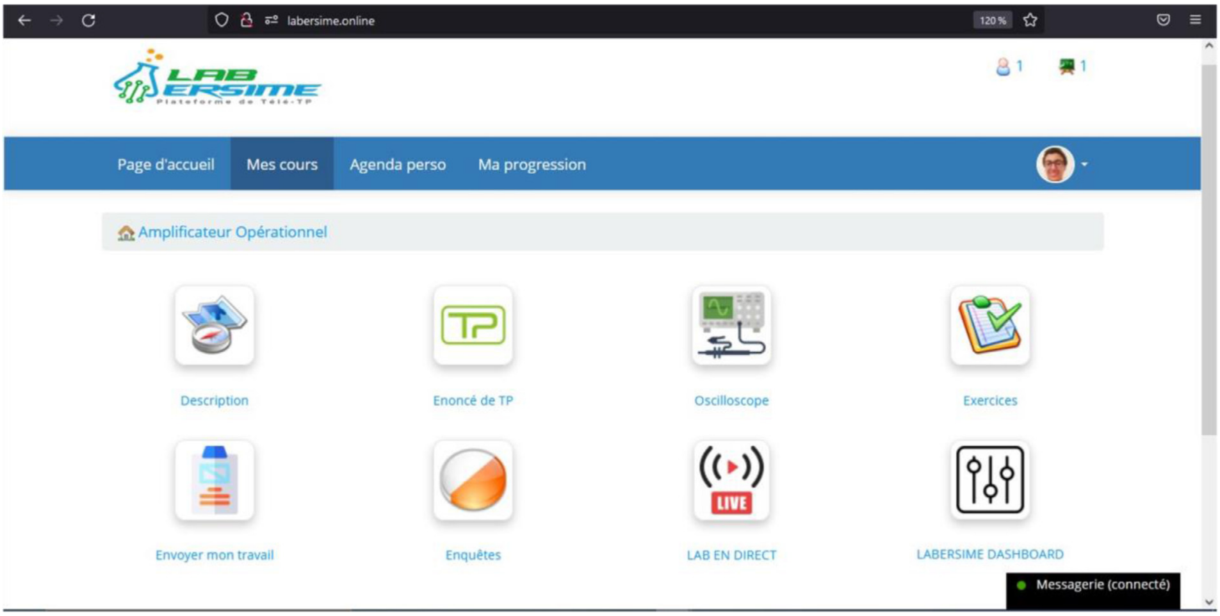

Fig. 8. Client interface (LMS + Interface for interaction with the remote laboratory).

which involves remote manipulation a photovoltaic panel (Fig. 10) and compare the same practical manipulations that are performed in the classical system under the same conditions.

The user interface

To test the platform, we proposed two practical works on operational amplifiers and photovoltaic panels for the students in the first year of electrical engineering. The first practical work aims to study some assemblies in a non-linear regime. The objective of the second one is to plot the current-voltage characteristic of a photovoltaic cell, and determine the characteristic quantities of short-circuit current I_{CC}, open-circuit voltage V_{CO} and maximum power, and calculate the efficiency of the photovoltaic panel.

After completing the required lab exercises, and work has successfully been validated, students can perform commands, record measurements, plots, and integrate results in their reports. The last developed graphical interface is shown in Fig. 11.

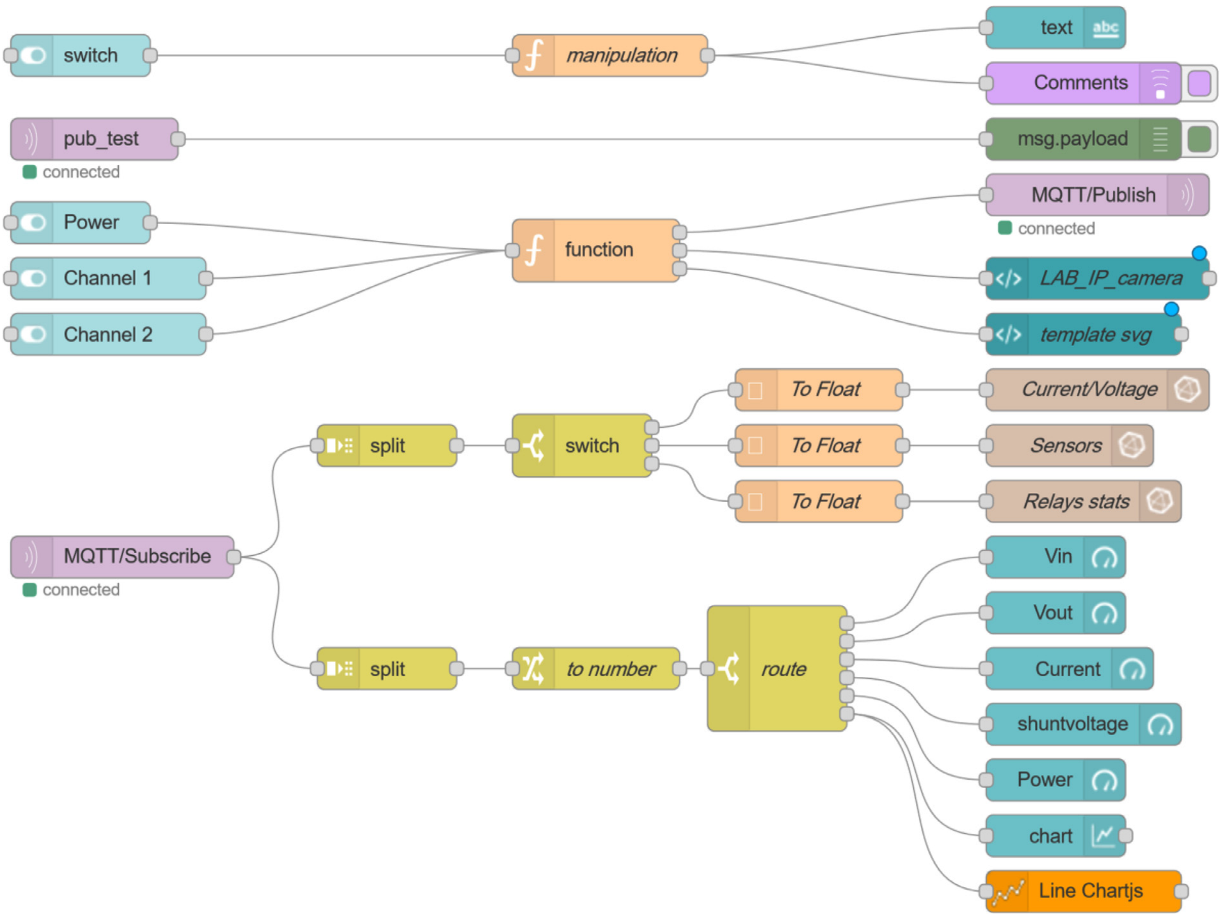

Fig. 9. Node-RED's Overall Flow Management Design.

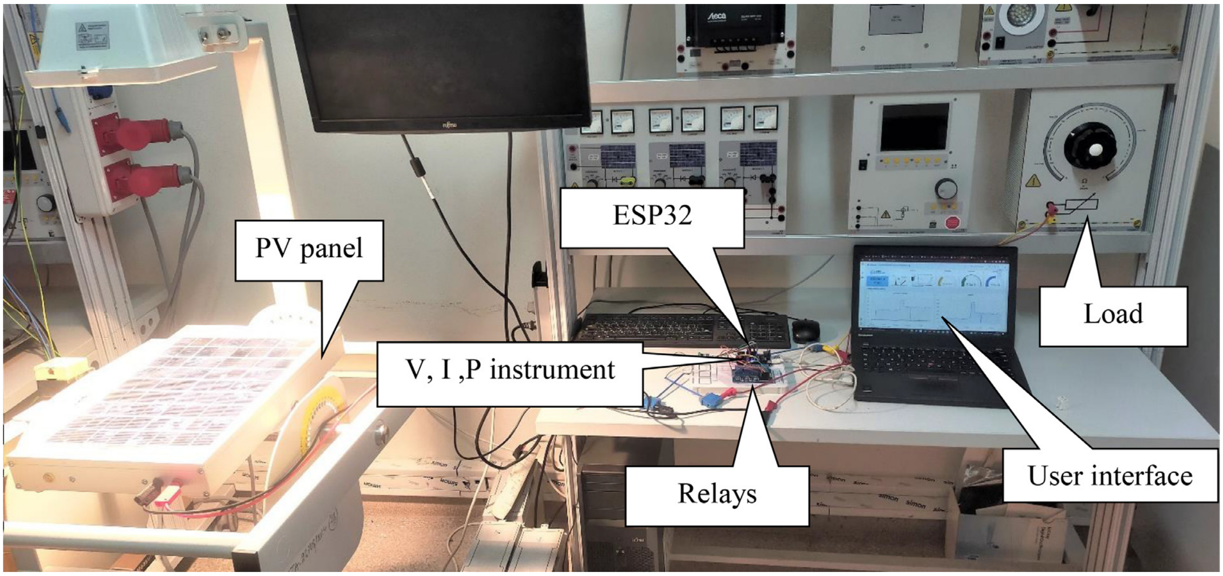

Fig. 10. Remote hands-on experience of photovoltaic cell characterization.

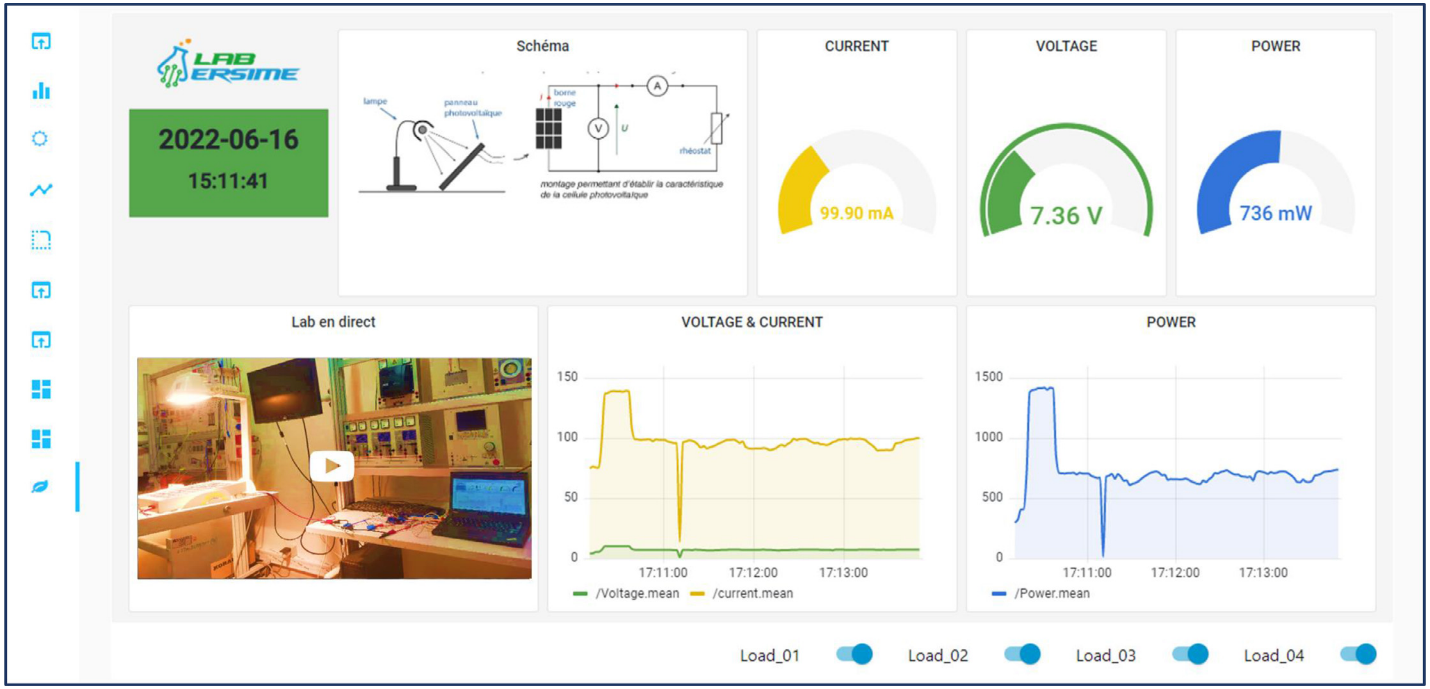

Fig. 11. Dashboard and control panel for remote photovoltaic cell characterization hand-on.

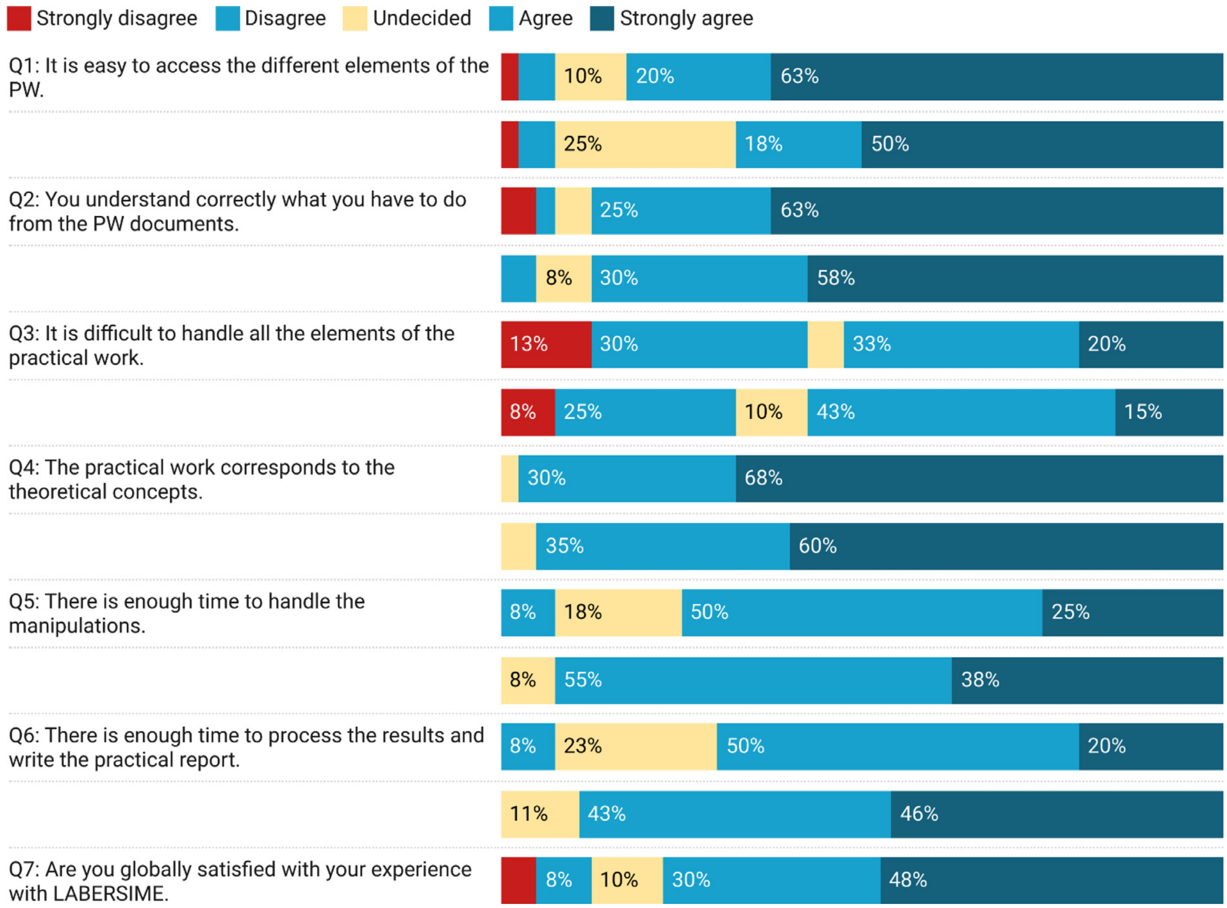

Fig. 12. Data from the online surveys of students on the LIKERT scale.

In addition, the LMS allows tracking of each student: number of connections, time spent, number of attempts, progress, level of difficulty taken, and answers to tests.

Most connections take place the day before; the deadline for accessing the remote laboratory. To this end, it requires a solid platform to manage multiple connections.

Student follow-up and satisfaction survey

In order to demonstrate the usefulness of the remote laboratory, from a technical and pedagogical point of view, we tested the platform with 40 students of the first year of electrical engineering during photovoltaic cell characterisation experiments.

The students who completed the previous experiment filled in questionnaires that allowed us to identify important indicators: remote control of real physical systems, space-time constraints, collaborative work, autonomy, online activity and prerequisites. All these indicators allowed us to evaluate the efficiency of the platform and to improve it for future activities so that the manipulations can be more motivating and significant.

Likert scales were used for questions concerning the platform [43], its usefulness, its functionality, the time it takes, and whether students would use it again or not.

The analysis of the data in Fig. 12 reveals some essential points. According to the responses to the survey, most students favor choosing between the first and second options to answer each question in both practical systems. The results of the practical lab are always higher than those of the remote lab, which leads to two conclusions: firstly, the practical lab is the most favored by students; secondly, the slight difference in the choice of the remote lab and the practical lab shows that the platform has succeeded in transmitting the same knowledge at a distance and that it can be adapted to unforeseen cases, such as the case of covid'19, to avoid interruptions in the students' practical learning. From the two questions presented in Fig. 12, it is clear that practical distance work saves time for students.

Conclusion

Based on experimental survey undertaken, The LABERSIME board is mainly used for remote communication and control using the MQTT protocol for measurements and data acquisition.

The implementation of this remote experimentation has helped to increase students' motivation. If this positive point was noted thanks to our monitoring, we are not claiming that the best solution for practical work is an entirely remote solution. Indeed, the LABERSIME platform comes as a complement to the practical work done in classes. LABERSIME adds possible functionalities since the evolution of ICT that allows a differentiated pedagogy more focused on each student. Moreover, this prototype is used as a demonstrator during the open days of the IUT of Agadir and seems to be of a great significance to high school students as well. This contributes to an increase in the attractiveness of our STEM courses.

In brief if any objective conclusion can be drawn it as follows: our attempt cannot be considered neither perfect nor final. It is a rather a starting point which paves the way for us to think of developing it in the forthcoming works. the ultimate goals are in a nutshell to generalize it by and large in wider scale on the one hand, and on the other hand to stimulate professors to get low-cost device into use and finally make the manipulations easy to deploy via a simple architecture.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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