IoT Implementation for Development of Remote Laboratory (Case Study on PV Solar System)

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Abstract. The higher education world has undergone significant changes in recent decades, due to the prevalence of technology and the constant capacity of university infrastructure despite high enrollment rates. With the added constraints posed by COVID-19 pandemic-related health and preventive measures worldwide creating a crisis in the education sector, many schools and universities were not prepared for the transition from in-person to remote teaching. As a result, it became imperative to adapt pedagogical resources to allow students and teachers access to virtual classrooms such as Moodle, Google Classroom, Microsoft Teams, Zoom, WebEx, and other online learning platforms.

Practical works (PW) are an essential type of teaching in scientific and technical training programs and provide a complementary need through real, remote, or virtual laboratories, allowing students to consolidate their knowledge and develop analytical skills by comparing empirical results with those obtained during hands-on manipulation. Pedagogically, remote laboratories are more beneficial compared to virtual ones since the latter only provide an approximate computer-based model of reality through simulations deployed for various modelling purposes.

Our proposed approach to address this challenge involves the implementation of a cloud-based platform, called LABERSIME. This platform aims to facilitate and simplify the transactions between learners and laboratory equipment, with the ultimate objective of enhancing the motivation of students.

Keywords: Remote lab, Internet of Things, E-learning, pedagogical innovation.

1 Introduction

In the world of education, there is a growing emphasis on practical learning, and practical workshops have become an essential tool for imparting knowledge and skills. These workshops allow students to apply theoretical knowledge in a practical setting, often through conducting experiments. In scientific and technical fields, practical workshops are particularly crucial, as they help students to develop analytical skills and

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consolidate their knowledge by comparing empirical results with theoretical models. However, providing practical workshops can be a challenging task for educational institutions, especially in resource-limited environments[6].

The LASIME laboratory at the higher school of technology of Agadir has developed a low-cost cloud-based platform that can be used to control real laboratory equipment and perform experiments [2]. This platform offers a practical and effective solution for educational institutions that wish to provide hands-on learning opportunities to their students without the need for expensive laboratory equipment, supplies, and facilities. One of the benefits of this platform is that it offers a flexible and convenient way for students to participate in practical workshops, as they can access it from anywhere with an internet connection. This feature is particularly valuable in today's world, where many students are learning remotely due to the COVID-19 pandemic[7]. Another benefit of this platform is that it provides an opportunity for self-directed learning, which can be a powerful motivator for students. By offering a creative approach to learning, the platform encourages students to take ownership of their learning and to explore topics of interest at their own pace. In addition, this platform offers an affordable and scalable solution for educational institutions that wish to offer practical workshops but are limited by resource constraints[6]. By eliminating the need for expensive laboratory equipment, supplies, and facilities, it makes it possible for institutions of all sizes and budgets to offer practical workshops to their students. Overall, this platform helps to promote self-directed learning and encourages students to explore topics of interest at their own pace, while also making practical workshops more accessible and affordable for educational institutions.

2 General context

In Morocco, as in many other developing countries, the lack of adequate laboratory infrastructure and qualified technical staff in universities can hinder the quality of practical education for students in scientific and technical fields. While there has been a steady increase in the number of students in these fields, the capacity of university infrastructure, especially in terms of laboratory rooms, remains constant. As a result, temporary solutions such as creating groups to optimize the use of available equipment in the room are often implemented, but the question remains whether these new students will have the same quality of hands-on learning.

The COVID-19 pandemic has further exacerbated the challenges facing universities in Morocco and around the world. Many schools and universities were not prepared for the transition from in-person to distance learning[12], and the highly recommended health and prevention restrictions have caused a global crisis in education [4]. While online learning platforms such as Moodle have become increasingly popular, they present their own set of challenges, such as the need for reliable internet access and digital literacy skills. Additionally, the concept of distance practical education remains relatively underdeveloped, and many students may still lack access to the necessary equipment and resources for hands-on learning.

To address these challenges, alternative approaches to practical education such as simulations, virtual labs, and gamification have gained popularity in recent years. These approaches may offer viable solutions to some of the challenges faced by universities in Morocco and other developing countries, but they also require investment in technology and software development, as well as training for instructors and students. Additionally, efforts to increase the number of qualified technical staff in universities could help to improve the quality of practical education and enhance students' skills and employability.

	Sciences	Sciences et techniques	Sciences de l'ingénieur
International Students	2 117	998	817
Doctorate	8 874	4 349	1 790
Master	9 668	3 511	775
Normal cycle	101 541	21 880	22 501
New Enrollees	38 096	6 422	3 725
Global	120 083	29 740	25 066
2019-2020	113638	29088	23272
Var [%]	**5,67**	**2,24**	**7,71**

Table 1. Student enrollment by area of study (2020/2021).

3 Types Of Laboratoire

3.1 Virtual Labs

Virtual laboratories are formed by virtual simulations, where students can run programs built using programming languages and software (such as LabVIEW, Simulink) on their computers [9]. This method promotes remote learning and understanding of fundamental concepts, but it is an incomplete alternative to hands-on laboratory work (El Kharki et al., 2021), as the models constructed are just approximations and models of reality.
However, virtual laboratories have their own advantages. They are cost-effective, as students do not need to be physically present in a laboratory to perform experiments. They also provide a controlled and safe environment, where students can experiment with dangerous or expensive equipment without any risks. Additionally, virtual laboratories allow students to revisit experiments and simulations as many times as they need, which enhances their learning experience. Furthermore [1], virtual laboratories can also be used for conducting cross-cultural and collaborative research projects, where students from different parts of the world can participate in virtual experiments

and simulations. Overall, virtual laboratories are an important tool for modern education and research, but they cannot replace hands-on laboratory work completely [8].

3.2 Virtual Labs

Distant Laboratories are typically platforms that are hosted on local networks through workstations or Raspberry Pi boards[5]. Remote access to the workstations is achieved through software such as the "Remote Desktop Protocol (RDP)." These laboratories provide students with a means of accessing laboratory resources and conducting experiments remotely, which is particularly beneficial for students who are unable to attend traditional laboratory sessions. The ability to access laboratory resources remotely allows students to gain practical experience[11], apply their knowledge and skills, and receive feedback on their work, making it a crucial component of modern education and a valuable tool for enhancing the learning experience.

4 The Advantages Of Remote Laboratories

- **Profitability**: Thanks to more efficient resource sharing, educational institutions can meet the demand for laboratories with less equipment. Furthermore, costly and bulky equipment can be shared and used optimally and more efficiently. In addition, educational institutions can benefit from reduced workplace safety costs and insurance fees.
- **Mobile Learning Courses**: that previously had to be taught in their entirety on campus now allow for remote teaching. Part-time students who work and study can also find remote laboratories very useful in balancing their commitments. With a smartphone or tablet, the student can continue their learning started in class at home or even while traveling, at a pace that is their own.
- **Equity**: With the use of automated management systems, it is possible to assign equal access time to all laboratory users during peak periods and to put them in line to ensure that everyone has an equal amount of time to conduct their experiments.
- **Personal Safety:** Many experiments can pose fire, electrocution, and safety risks for individuals.
- **Property Safety:** As the public does not need to access the laboratory, remote laboratories are well protected against damage, theft, and vandalism

5 The Approach Adopted

Our approach to addressing the problem discussed in previous chapters is the deployment of the LABERSIME platform, installed in the cloud. The platform offers a solution by facilitating transactions between learners and laboratory equipment, utilizing the MQTT protocol to enable real-time communication between students' computers and laboratory equipment . This allows students to control equipment and view data in real-time for remote practical experimentation. The platform provides increased flexibility and availability for students, with access to laboratory equipment without geographical restrictions.

The MQTT protocol is a publish-subscribe communication protocol used for transmitting real-time data between remote devices. It operates using a publish-subscribe model, where devices can publish messages on "topics" or subscribe to these topics to receive messages. The messages are transmitted through a central server known as a "broker," which manages message distribution to subscribers. MQTT is designed to be lightweight and efficient, making it suitable for IoT applications with bandwidth and processing power restrictions. Additionally, it ensures enhanced reliability through quality-of-service mechanisms, ensuring message delivery.

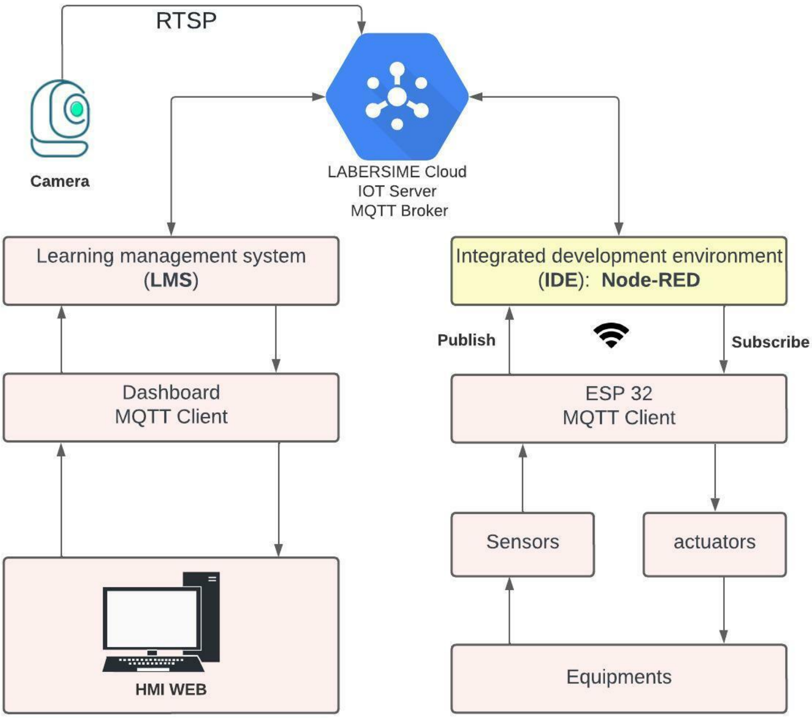

Fig. 1. Platform architecture.

The deployment of platform has the potential to revolutionize traditional methods of conducting laboratory experiments in educational settings by enabling remote access to laboratory equipment through an internet connection. With an interactive interface that allows students to interact with laboratory equipment in real-time, the platform provides a simulated physical laboratory experience. The user-friendly interface facilitates easy connection to the server, experiment conduct, and result access for students. The implementation of LABERSIME is expected to significantly enhance the learning experience for students, providing new opportunities for experimentation and discovery. Remote learners connect to the server via a computer, tablet, or phone interface connected to the internet, and have three inputs available through the interface (as depicted in Figure 1).

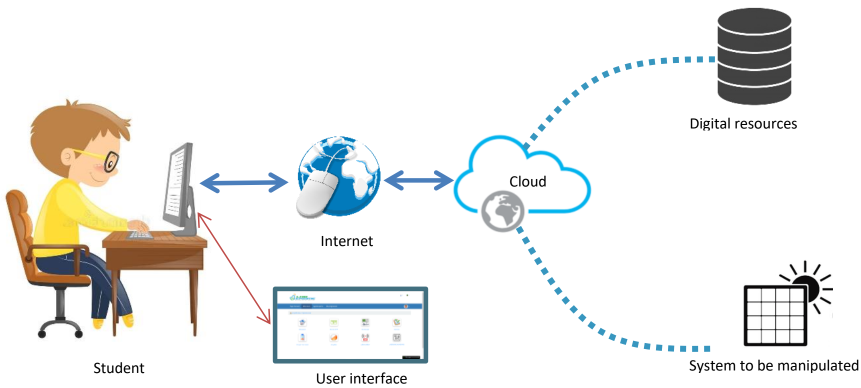

Fig. 2. The operating principle of the platform.

- **Asynchronous Experimentation**: These are Digital Resources that offer students the opportunity to explore and study various systems and experiments. The experiments have been previously created and established by teachers, and students can access them at any time. This type of experimentation allows students to learn at their own pace, and can be particularly useful for those who prefer self-paced learning.
- **Synchronous Experimentation:** These are Practical Experiences that provide students with direct and real-time access to experiments on embedded systems. The experiments are controlled by the learners themselves, and they can perform them whenever they want. This type of experimentation offers a hands-on learning experience and can help students understand complex systems and concepts more effectively.
- **Digital Experiences:** Allows direct access to experiments on digital or analytical models, built in specific software. The parameters of these models can be modified by the learner, allowing them to explore different scenarios and observe the effects of their changes. Digital experiences provide a flexible and interactive learning environment, and can help students develop analytical and problem-solving skills.

6 Learning Steps Via The Platform

Students are expected to assess their prerequisites prior to attending the sessions[13], followed by a quiz and practical exercises that conclude the end of the module in order to obtain a final score (Figure 2). These activities are generated through the use of the "Learning Management System (LMS)" with the exception of hands-on manipulations, which are addressed within the "Integrated Development Environment (IDE)". The LMS and IDE provide a comprehensive platform for students to evaluate their understanding of the material, while simultaneously enhancing their technical skills through practical exercises [3]. The final score is a crucial factor in determining the student's progress and success in the course.

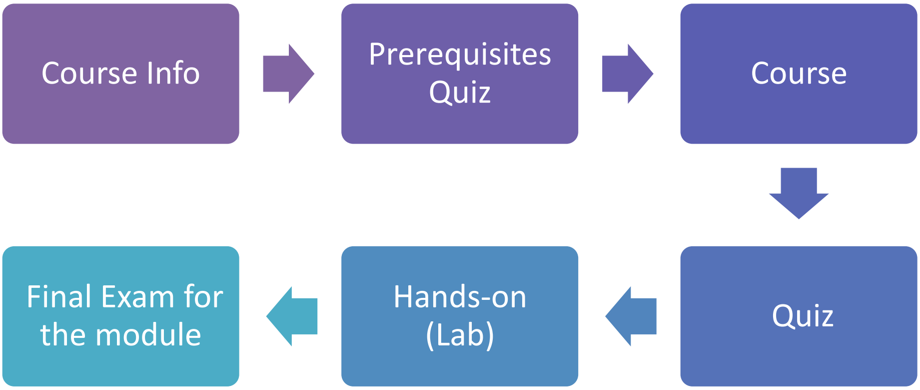

Fig. 3. Learning steps through the platform.

- Prerequisites Quiz: Before starting the module, students must take a quiz to verify they have the necessary foundational knowledge to follow the course.
- Course: The course provides the theoretical knowledge required to perform manipulations (practical work). It may be in the form of videos, presentations, or reading materials[14].
- Quiz: After the course, students take a quiz to evaluate their understanding of the knowledge covered.
- Manipulations (Practical Work): Students can now perform manipulations (practical work) using the LABERSIME platform and its online equipment, allowing them to put their knowledge acquired during the course into practice and develop analytical skills by comparing their experiment results with expected results[15].
- Final Module Test: Finally, students take a final test to evaluate their overall understanding of the module and verify if they have met the learning objectives[10]. The test may include multiple choice questions, short answers, or manipulation (practical

work) questions to measure their ability to apply the acquired knowledge in real-life situations.

7 Result And Discussion

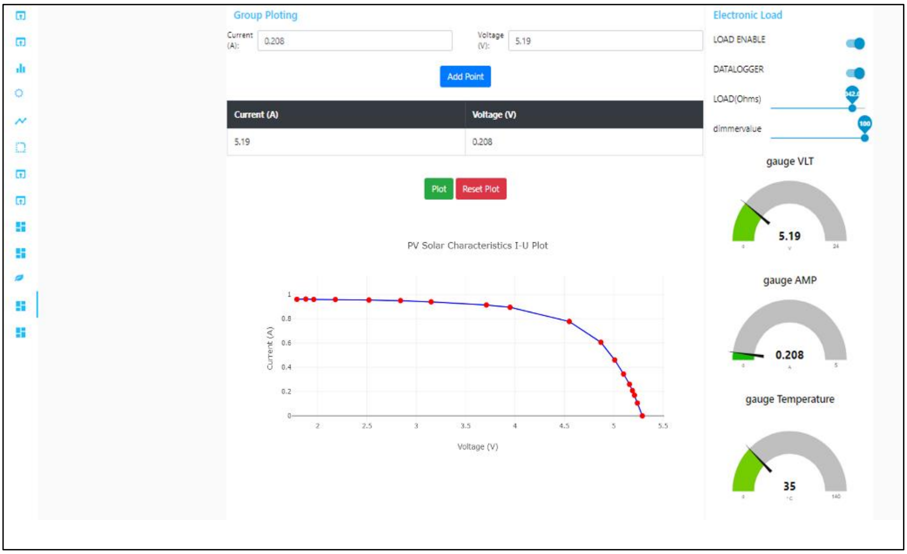

Fig. 4. The interface of the platform.

The above figure depicts a screenshot during a manipulation which displays a set of features such as the values of physical quantities acquired by the server and processed and displayed in the form of gauges and graphs. The student can also control the systems to be manipulated through actuators through this dashboard.

As you can see, this window is specifically designed for learning the course titled: the characteristics of a photovoltaic cell. The student supplies the halogen bulb which resembles a sunbeam to expose the PV cells which generate an electrical current so that the student can take readings and deduce the characteristics.

To further enhance students' experience with distance practical work, it would be wise to consider implementing additional measures. Offer more technical support: Students who encounter technical difficulties may become frustrated and less likely to continue. It is therefore important to provide dedicated technical support to help them overcome these challenges:

- Encourage active participation: Distance practical work can become boring if students are only passive spectators. It is therefore important to encourage active participation by encouraging students to ask questions, discuss with their peers, and actively participate in activities.

- Favor collaboration: Group practical work can be more productive and more fun for students. It is therefore important to establish mechanisms to encourage collaboration between students, such as online forums or chat rooms.
- Improve the quality of online resources: Online resources must be of high quality for students to understand concepts and apply them correctly. It is therefore important to monitor and improve the quality of online resources to ensure that students have access to reliable and useful information.

By following these suggestions, universities can significantly improve students' experience with distance practical work and prepare them for success in their future careers.

8 CONCLUSION

The emergence of the COVID-19 pandemic has resulted in a significant shift towards e-learning, which has become a necessity for students across the globe. As a result, the need for remote laboratory work has become increasingly essential to provide students with practical learning opportunities. E-learning has proved to be a valuable tool in increasing student motivation, providing greater flexibility in learning, and reducing stress levels. With the use of modern ICTs, educational institutions can create more individualized pedagogies that address the specific needs of each student. Remote laboratory work is one such approach that has gained popularity in recent years, offering a cost-effective solution to traditional laboratory work. The remote laboratory work experience provides students with the ability to learn at their own pace and convenience, and eliminates the need to travel to a physical laboratory. This feature can significantly reduce the financial burden for students, making education more accessible to individuals from different socio-economic backgrounds. Furthermore, remote laboratory work can help to bridge the digital divide by providing equal learning opportunities to students who may not have access to traditional laboratory facilities. It allows students to gain practical skills and knowledge in scientific and technical fields regardless of their location. While the benefits of remote laboratory work are numerous, it is important to note that it should not replace in-person laboratory work entirely. Remote laboratory work should be seen as a complement to in-person laboratory work and used in situations where it is not feasible to have physical laboratory facilities. This hybrid approach can offer students a well-rounded learning experience that addresses both theoretical and practical aspects of their studies.

In conclusion, e-learning has become an integral part of modern education, and remote laboratory work is an essential component of practical learning opportunities. The use of modern ICTs has made it possible to provide a more individualized and flexible learning experience, while also bridging the digital divide and providing equal learning opportunities to all students. By combining in-person and remote laboratory work, educational institutions can offer students a comprehensive learning experience that prepares them for future success in their chosen fields.

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