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Technical contributions in the design and realization of remote practical works using IoT systems

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Defended on Saturday, June 25, 2022 at 10:00 a.m. in front of the review committee:

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Dedication

To my inspirational father and loving mother

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Abstract

The challenges facing today's higher education institutions (HEIs) are undoubtedly numerous and difficult due to overcrowding and financial difficulties. The Internet of Things (IoT) is a new concept that is expected to contribute to the offensive improvement of educational quality in many facets. However, it has not been widely reported and validated in the literature. The main objective of this thesis is the development, implementation, and tests of low-cost IoT-based technical systems and open-source software to address some of the challenges related to engineering education in HEIs.

The technical contributions made during this thesis have been divided into three main parts. The first part refers to the low-cost IoT-based remote labs that have been developed specifically to address the challenges of overcrowding, lack of equipment, and equipped rooms for electronics practical works (PWs). The second part presents contributions to the communication process which is one of the main problems faced when creating virtual and remote laboratories. It presents an extension of the Remote Interoperability Protocol (RIP) that allows more precise and sophisticated management of communication and configuration in control systems. The third part presents contributions to blended learning that aim to improve teacher-student interaction and address the challenges of lectures, that do not produce the learning objectives they are intended to achieve. The technical contributions made during this thesis were validated according to designed studies to highlight the benefits and limitations of the developed systems and to investigate how the integration of low-cost IoT-based educational systems promotes student engagement. These types of studies make a very important contribution to the literature by providing low-cost architectures for educational systems, as well as evidence about student experiences in HEIs.

This thesis is structured as follows: Chapter 1 presents in detail the motivation, objectives, research questions, and an overview of the contributions made during this thesis. Chapter 2 presents a review of the literature on technology-enhanced learning, the architectures adopted and the tests methods followed in recent studies. Chapters 3 and 4, respectively, present the technical contributions and tests of the educational systems developed. Finally, Chapter 5 presents a conclusion and proposals for future research.

Keywords: Remote labs, IoT-based system, Event-based control, Networked control systems, Blended learning.

Résumé

Les défis auxquels sont confrontés les établissements d'enseignement supérieur (EES) d'aujourd'hui sont sans doute nombreux et difficiles en raison de la massification et des difficultés financières. L'Internet des objets (IoT) est un nouveau concept qui devrait contribuer à l'amélioration offensive de la qualité de l'éducation sous de nombreuses facettes, cependant, il n'a pas été largement rapporté et validé dans la littérature. L'objectif principal de cette thèse est le développement, la mise en œuvre et le test de systèmes techniques basés sur l'IoT à faible coût et de logiciels open source pour relever certains défis liés à l'enseignement de l'ingénierie dans les EES.

Les contributions techniques apportées au cours de cette thèse ont été divisées en trois parties principales. La première partie fait référence aux laboratoires distants à faible coût basés sur l'IoT qui ont été développés spécifiquement pour répondre aux défis de la surpopulation, du manque d'équipement et de salles équipées pour les travaux pratiques (TP) d'électronique. La deuxième partie présente des contributions au processus de communication qui est l'un des principaux problèmes rencontrés lors de la création de laboratoires virtuels et distants. Elle présente une extension du protocole d'interopérabilité à distance (RIP) qui permet une gestion plus précise et sophistiquée de la communication et de la configuration dans les systèmes de contrôle. La troisième partie présente des contributions à l'apprentissage mixte qui visent à améliorer l'interaction entre l'enseignant et l'étudiant et à relever les défis des cours magistraux, qui ne produisent pas les objectifs d'apprentissage qu'ils sont censés atteindre dans un contexte de masse. Les contributions techniques apportées au cours de cette thèse ont été validées selon des études conçues pour mettre en évidence les avantages et les limites des systèmes développés et pour étudier comment l'intégration de systèmes éducatifs peu coûteux basés sur l'IoT favorise l'engagement des étudiants. Ces types d'études apportent une contribution très importante à la littérature en fournissant des architectures à faible coût pour les systèmes éducatifs, ainsi que des informations sur les expériences des étudiants dans les EES.

Cette thèse est structurée comme suit : Chapitre 1 présente en détail la motivation, les objectifs, les questions de recherche et un aperçu des contributions apportées au cours de cette thèse. Le chapitre 2 présente une revue de la littérature sur l'apprentissage assisté par la technologie, les architectures adoptées et les méthodes de test suivies dans les études récentes. Les chapitres 3 et 4, présentent respectivement les contributions techniques et les tests des systèmes éducatifs développés. Enfin, le chapitre 5 présente une conclusion et des propositions de recherches futures.

Mots-clés: Laboratoires distants, Système basé sur l'IoT, Contrôle basé sur les événements, Systèmes de contrôle en réseau, Apprentissage mixte.

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List of acronyms

AAED	:	Association of Distance Education
BBB	:	BigBlueButton
CRS	:	Classroom Response System
DC	:	Direct Current
GUI	:	Graphical User Interface
HEIs	:	Higher Educations Institutions
HTML	:	HyperText Markup Language
HTTP	:	Hypertext Transfer Protocol
HTTPs	:	Hypertext Transfer Protocol Secure
ICTs	:	Information and Communication Technologies
IoT	:	Internet of Things
JSON	:	JavaScript Object Notation
LMS	:	Learning Management System
MOOCS	:	Massive Open Online Courses
NCS	:	Networked Control Systems
OLs	:	Online Laboratories
PWs	:	Practical Works
RDF	:	Resource Description Framework
REST	:	Representational State Transfer
RIP	:	Remote Interoperability Protocol
RLs	:	Remote Laboratories
RPC	:	Remote Procedure Call
SOAP	:	Simple Object Access Protocol
SSEs	:	Server Sent Events
STEM	:	Sience, Technology, Engineering, and Mathematics
TCP	:	Transmission Control Protocol
UDP	:	User Datagram Protocol
UNED	:	National University of Distance Education
UNILabs	:	University Network of Interactive Labs
VLs	:	Virtual Laboratories
VRLs	:	Virtual and Remote Laboratories
YAML	:	YAML Ain’t Markup Language

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Chapter 1

Introduction

Content

A general overview of the thesis is provided in this introductory chapter. Since this thesis contributes to the enhancement of teaching and learning in higher educations institutions (HEIs) using low-cost IoT-based technical systems and open-source software. The vital role of higher education and its challenges as well as the motivation that conducts the study are presented. This is followed by outlining the scope of the thesis which is regarding the integrations and use of IoT systems to build Remote Labs (RLs) and blended learning scenarios in smart classrooms. A brief overview of the gaps in the field, research objectives, and questions to be addressed in this study are then presented. Subsequently, the main contributions and methodologies that have been used as well as the way the research has been tackled are given. The chapter ends with the presentation of the thesis organization and the content of each chapter.

1.1 Motivation

Higher education is widely recognized as one of the main key drivers of growth, prosperity, and competitiveness [1,2]. It has always been considered a public good, as it contributes to society by improving human capital, encouraging civic participation, and fostering economic development [3]. Accordingly, HEIs contribute greatly to the economic strength of countries and their ability to compete in the global marketplace [4].

Over the last decade, the challenges faced by today's HEIs are unquestionably numerous and difficult in terms of achieving effective teaching and learning due to overcrowding and financial difficulties [5]. HEIs are inevitably experiencing a rapid increase in student enrollment which has occurred without an accompanying increase in financial, physical, and human resources [6]. Unfortunately, this situation has a direct and perceptible impact on the quality of the teaching and learning process, especially in developing countries where the scale of the challenges is higher [7]. Consequently, students frequently graduate from HEIs without the skills necessary for employability [8].

In the light of changing the face of higher education, there is no doubt that HEIs need to be innovative in dealing with their challenges. There has been a need to reform and change through a large array of innovative services and experiences to enhance the process of teaching and learning [9]. Several HEIs found on Internet a fertile ground for developing their application and courses, taking advantage of the advance in communication and computation technology to make the learning process easier [10]. Nowadays, numerous technologies are emerging that aim, these include, Massive Open Online Courses, Active Learning Forum platform, Collaborative Distance Learning Environments, and Learning Management Systems [11].

In Science, Technology, Engineering, and Mathematics (STEM) courses, experimental laboratory practices are very common and are a key element of STEM subjects. As these experimentations cannot be done without laboratory equipment this poses several problems for distance education in its early days [12]. Nowadays, remote experimentation is possible, and online accessible laboratories appeared to enhance the performance of remote education [13]. RLs are designed for remote experimentation over real systems using applications that provide a user interface to replicate the experience of handling the equipment on-site and allow the user to edit and see the behavior of the laboratory [14].

The severity of the challenges faced by HEIs and the integration degree of technologies to address these challenges vary considerably between developed and developing countries [15]. The majority of the technological solutions proposed come from active companies in the field of education or were born within the framework of well-supported projects in well-recognized universities. Accordingly, several platforms allowing for the enhancement of theoretical and practical teaching are proposed in the market of higher education. However, the price of these solutions is not affordable for all universities in developing countries, especially RLs platforms that seek to provide an answer to the problems of Practical Works (PWs) in STEM courses [16]. On the other hand, The integration of new communication technologies in higher education depends on the local policies of each institution, which are entrusted to project leaders or Vice-presidents. In several developing countries, the integration of technologies is not part of the modernization of higher education as often announced, but it is presented as a solution to the difficulties of education in many HEIs. Attempts to integrate technologies are generally carried out under difficult conditions due to the lack of local technical skills and the geographical dispersion of the institutions annexed to some universities [17].

Consequently, the ongoing changes in the educational system and the challenges faced by HEIs in developing countries are forcing teachers and researchers to consider and test the validity of open source software and low-cost architectures of technical systems according to well-designed studies. The results of this type of study should make it possible to determine the real advantages and limits of each system proposed for HEIs which consider these integrations as a solution to their technological, pedagogical, and financial problems. On the other hand, providing and validating students' experiences using free software and low-cost technical systems during theoretical and practical learning provides useful information, strategies, and technical solutions for other universities to develop their systems in order to deal with many problems. This furnished the launching point for the elaboration of the hypothesis discussed in the investigation described in this thesis.

1.2 Scope of the thesis

The main focus of this thesis was the development, implementation, and tests of open source software and low-cost IoT-based technical systems to deal with some problems in HEIs. The following study is part of studies seeking to investigate how the integration of low-cost IoT systems in higher learning environments supports the engagement of educators and students and how they can influence the way they collaborate, communicate and operate in HEIs. IoT is a blanket concept of networking electronic devices to provide smart environments, it has tremendous scope for deployment, and many sectors have already started to build smart and efficient ecosystems [18, 19]. Acceptance and adoption of IoT in HEIs are still scarce and present various challenges, especially in developing countries [20]. In the field of engineering education, the quality of learning by low-cost IoT systems can be improved through continuous monitoring and analysis of student feedback through well-structured studies and information sensing devices in order to offer well-defined paths for technical and pedagogical improvement [21].

The tests of the low-cost technical systems developed during this thesis was carried out with students enrolled at the Polydisciplinary Faculty of Beni Mellal in Morocco. The latter is a public institution of higher education created in September 2003, whose vocation is to meet the needs of the Beni Mellal-Khenifra region in terms of university training. It is worth noting that the training offered by this university is part of the reform of higher education in Morocco. The technical contributions made from 2017 to 2022 at the Polydisciplinary Faculty of Beni Mellal during this thesis were aimed at improving student engagement, especially in electronics and renewable energy courses. These contributions aim to improve the quality of teaching of PWs activities by setting up low-cost architectures of remotely controlled laboratories and to improve theoretical teaching by using videoconference systems, developing simulating tools, and IoT systems. The IoT-based system evaluation was conducted with students enrolled in the 3rd year of the "electronics and renewable energies" course and a study was also conducted with students enrolled in a master's degree in renewable energies.

Part of this research was carried out in the field of automatic control during a research internship at the National University of Distance Education (UNED), Madrid, Spain. Notably within the Department of «Computer Science and Automatic Control», at the « Higher Technical School of Computer Engineering, Madrid, Spain ». The work presented in this study is part of the development carried out by the University Network of Interactive Labs | UNILabs which is born in September 2013 from a previous project named UNEDLabs [22]. The research group within the Department of Computer Science and Automatic Control has been working in the area of Virtual and Remote Laboratories (VRLs) since the nineties [23]. RLs are designed for remote experimentation over real systems using applications that provide communication protocols and interfaces to replicate and manipulate the experiences remotely. The contribution presented in this thesis aims to level up an open-source software solution that implements the Remote Interoperability Protocol (RIP) used as a server implementation for online laboratories (OLs) in Python. It enables the use of Arduino, Raspberry, and various other IoT systems via the Internet as web services. The new extension of the RIP Python server allows more precis and sophisticated management of the communication process in control systems. The tests of the contribution was done in two steps. The first one consists to validate the new integrated functionalities using unit testing Python programs to determine that they are fit for purpose. On the other hand, the new version of the RIP-Python server has been integrated into an Air Levitation system which refers to an online laboratory for control engineering deployed in the UNILabs platform.

1.3 Aim of the thesis

Recent advances in information and communication technologies (ICTs) have forced HEIs to change the content of activities and adapt appropriate methods and technologies to enable students and educators to work more effectively in a digital context [24]. Several ample research has been conducted to design digital campuses that include, smart classrooms, and smart laboratories while facilitating student learning in recent years [25]. IoT integration in higher education has the positive capability to affect the structure design from traditional educational systems to one that is scalable and flexible to the rapid ongoing change [26]. In fact, IoT has a strong influence on higher education in comparison with other education levels mainly due to the specifications of HEIs that are more open and supportive of technology integration [27].

The IoT technology is an upcoming concept in education that has not yet been widely reported and consolidated [28]. The literature review has suggested that the effect of IoT is less in the case of education than in other sectors of its application [29]. Different challenges are involved in implementing it in the education sector as well as their acceptance and adoption in Higher education are scarce. The digital divide, which refers to differences in income and education, is one of the factors that most affect the acceptance and diffusion of IoT technology. Therefore, this difference must be taken into account and must not generate inequalities and possible rejection of IoT implementation [16]. As a result, HEIs with higher financial incomes have more positive thinking about actually buying and integrating IoT-based educational technologies. This also indicates that they are the first to develop the necessary skills for students' engagement with the use of IoT technology in a diversified way. It is conceivable that only a select group of universities are experiencing the IoT advantage, so it is critical to look at this step through the lens of digital inequality. Accordingly, the purpose of this study was to design, implement and validate interactive technical contributions based on low-cost IoT systems to improve the quality of practical teaching.

The low-cost IoT-based technical contributions in remote laboratories during this study were made in the Electronic discipline at the Polydisciplinary Faculty of Beni Mellal, Morocco. Their main objective is to fill the lack of equipment and equipped rooms, the teacher's warning on the equipment as well as the overcrowding which is of great magnitude for teaching PWs and makes the subject complex. On the other hand, these contributions aim to provide tests about the developed IoT systems by collecting students' opinions about remote experiences according to well-designed studies. Many of the results obtained in this work could be applied to develop low-cost systems for other engineering specialties, which require laboratories practices and active learning in the training of future professionals.

Remote-controlled laboratories are commonly and optimally web-based applications that are supported natively by web browsers for their access and convenience. This indicates that the technology used to communicate with the hardware needs to be HTTP. It is important to note that not all HTTP methods are equally effective at enabling control strategies, especially if the usage scenarios are intended to support separate experiments or strategies such as event-based control or self-triggering control [30]. In certain cases, delays in communication are not acceptable. In other cases, the transmission of a large number of requests from the client to the server is not acceptable either, due to the communication network and the client or server restriction. Accordingly, the event-driven contributions for control lab practice are intended to provide a tool that integrates the Server-Sent Events communication standard to both exhibit Internet control programs developed in Python and enable them to be available via web applications. The incorporation of Server-Sent-Events in RLs provides students in distance learning and blended learning scenarios with the ability to work effectively with event-triggered and self-triggered control schemes.

Blended learning contributions made during this study were made in the renewable energy discipline at the Polydisciplinary Faculty of Beni Mellal, Morocco. Their main objective is to enhance teacher-student interaction during presential and distance courses. In the presential course, the purpose of the study was to develop a classroom response system based on the Raspberry card to allow the instructor to interrogate the students with multiple-choice questions to evaluate their understanding of the concepts discussed in class. The results of the questions are displayed in real-time on the instructor's cell phone to allow him/her to specialize the content of the course according to the students' real understanding. On the other hand, in distance course, the study aims to design a hybrid architecture of a distance learning system that provides theoretical and practical learning on solar energy transformation as well as to validate its effectiveness according to a methodology that considers indicators at different levels of abstraction. Many of the results obtained in this work could be applied to develop a low-cost technological architecture for other engineering specialties during presential and distance courses to form future professionals.

1.3.1 Goals

The challenges faced by HEIs and the ongoing change are forcing education providers to look for new innovative and cost-effective ways to meet challenges and new demands. HEIs are turning to the next generation of innovative technologies and cost-effective systems to respond to the growing global pressures to maintain strong outcomes and improve performance levels while meeting expectations and respecting shrinking budgets. This study is intending to improve the quality of teaching and learning by providing other possible educational scenarios based on IoT systems. On the other hand, this thesis aims to evaluate the potential and effect of the IoT-based technical contributions provided in the field of RLs, event-based labs control, and blended learning according to well-designed studies in order to highlight their advantage and limitations. These kinds of surveys make an influential contribution to the literature by offering low-cost architectures and evidence of students' and academic staff's experience about the integration of new technologies.

The following specific objectives are addressed in this thesis:

- **Remote IoT-based labs goals**
    - Development, Implementation, and evaluation of low-cost IoT-based labs that allow several manipulations in analog electronics. The solution is based on the Red Pitaya IoT system to replace expensive laboratory instruments as well as to handle communication, remote measurement, and data acquisition through different protocols in order to maximize the available resource as well as to improve self-learning ability in electronic PWs.
    - Development, implementation, and evaluation of a remote lab based on the cooperation of Arduino and Raspberry to control PWs in electronics according to a client-server architecture. The client-side in the proposed architecture is developed using web technology and includes an open-source software oscilloscope developed using processing. The main goal of this work is to provide more possible low-cost scenarios to allow students to perform remote PWs in electronics based on light, feasible, and easy to duplicate architecture.
    - Conducting a comparative study of traditional, Simulated and remote online laboratories following a methodology that takes into account the interaction between students, teachers, and the PW environment at different levels of abstractions to detect the impact and satisfaction of students toward technology by looking at specific skills and indicators.

- **Event-based labs control goals**
  - Improvement and development of a new architecture that implements new features of the RIP Python server implementation for online labs, which allow the use of Arduino, Raspberry, Red Pitaya (AKA StemLab), and many other hardware and software via the Internet as web services.
    - Integration of the built-in trigger conditions, namely the periodic sending of events as well as the sending strategy based on conditions "Send-on-delta" in the new version of the RIP Python implementation.
    - Implementation of user session control to process every HTTP request that arrives at the server Independently and to track individual users' interactions with the server.
    - Detection of the disconnection of each user when disappearing via browser or via any connection problem, then generate lost events during reconnection based on each user.
    - Proposition a new form of the configuration of the server allowing the user to select the sampling method for each variable in the developed lab based on the RIP Python server implementation.
    - Development of Unit test scripts that validate the good operation of the new functionality implemented in the new architecture of the RIP Python server implementation.
    - Application of the new extension of the RIP-Python in an Air Levitation system to validate the correct operation of contributions made.
- **Blended learning systems goals**
  - Design and development of a mobile-based classroom response system using web-based technologies that make the system easy to use in an educational environment to test true understanding of a concept discussed in the classroom.
  - Implementation of the developed system on a Raspberry card and conduct of various tests to validate the effective use of the IoT system.
  - Development of a MATLAB user interface that describes the behavior of solar panel interfaces under various climatic interfaces. The interface must be distributed to students as an executable file that is configured to run on students' computers without the need for additional software to allow the study and design of hardware with well-defined specifications in terms of reliability and consumption efficiency.

- Development of a remote IoT system that allows students to measure the value of current and voltage needed to operate the MATLAB interface.
- Design of an architecture to allow the use of the MATLAB interface and the IoT system through the BigBlueButton videoconference system to provide and hybrid technological architecture that provides theoretical and practical learning on solar energy transformation.
- Evaluation of the effectiveness of the hybrid architecture according to a methodology that considers indicators at different levels of abstraction.

1.3.2 Research questions

Universities and educational institutions are adopting IoT-based smart devices to make their educational institutions smart and efficient. However, the acceptance and adoption of IoT in higher education remain rare [29].

The major motivating factors for the work presented in this thesis are the ongoing challenges faced by open access engineering universities and faculties, concerning the:

- Provision of meaningful remote laboratory experiences based on low-cost IoT systems for students, given the typically high costs of the traditional engineering laboratory, the large class sizes as well as the high cost of online platforms.
- An essential issue of every online laboratory is handling the communications, accordingly, the provision of an open-source implementation in Python allows the management of concurrent access to the technological devices, the security of material and humans, the real-time and remote restitution of events lost during students disconnect as well as providing an extension of a tool able to create remote laboratories where the communication is based events (SSE) rather than on time (related on pure HTTP, a request/response system protocol) was considered.
- Provision of meaningful and low-cost technology architecture for IoT-based systems to enhance interaction between students and teachers during classroom sessions in light of large class sizes and the need for alternative distance learning tools in engineering education.

Based on the motivations cited above and taking into account the need to reform the teaching methods in open access universities to cope with congestion and several challenges. This thesis attempted to address some of the difficulties by developing and implementing low-cost IoT systems to improve the teaching and learning process by developing RLs and blended learning scenarios. Indeed, the research questions were divided according to the context of contributions, namely in the remote electronic lab, in control laboratory practice, and in blended learning. Particularly, we targeted the following research questions:

- **Remote IoT-based labs questions**
    - ***RQ1: Educational value and effectiveness of the low-cost IoT-based architectures proposed for remote PWs.*** Are the IoT systems proposed in each contribution able to succeed in transmitting the same knowledge as in a hands-on lab? What are students´ perceptions/opinions about the remote lab's activities based on the proposed architectures?

    - ***RQ2: The low-cost IoT-based architectures melioration***. What are the issues faced when conducting remote PWs activities based on the low-cost IoT-based architectures? What are the limitations of these technical contributions and how can they be maintained and improved to meet the technical and pedagogical challenges?

- **Event-based labs control questions**
    - ***RQ3: Educational value and effectiveness of the RIP Python server extension.*** Are the new features implemented on the RIP python server work properly? What is the added value of the generalized sampling proposed for OL? Are the new architecture of the RIP Python server able to run properly on an OL prototype?

    - ***RQ4: The RIP Python server melioration.*** What are the issue and limits of the new architectures? Are the Unit testing programs validate the proper working of the integrated features in the RIP Python server extension? What are the issue and limitations when running the new extension on an OL (Air Levitation system) prototype?

- **Blended learning systems questions**
    - ***RQ5: Educational value and effectiveness of the blended learning systems developed.*** Are the technological architectures developed useful for improving teacher-student interaction during presential and distance lectures? How effective are these educational systems in improving the learning process? What are students´ perceptions/opinions about the blended system proposed?

    - ***RQ6: The low-cost blended learning systems melioration.*** What are the issues faced when using the classroom response system and the BigBlueButton based architecture and what improvement do students demand in the two technological architectures proposed?

1.4 Main Contributions

The contributions made by this thesis are both technical and pedagogical in the field of remote-controlled laboratories and blended learning. The implementation of new technologies is essential to meet the challenges of higher education, this thesis presents several prototypes IoT based RLs and blended learning systems implemented in lectures to improve the quality of teaching and practical learning. On the other hand, tests according to well-designed studies has been carried out to determine the real impact of the integration of these technologies on the learning and teaching process in HEIs. The majority of the technical contributions have been published as scientific articles during this thesis.

1.4.1 Remote IoT-based labs contributions

The first contribution aims to propose the design of an IoT system allowing several remote manipulations in analog electronics. This solution is mainly based on the Red Pitaya STEM-Lab board, in particular for communication and remote control for measurements and data acquisition through different protocols. The low-cost system provides an intelligent selection between the different integrated practical works on a developed board, as well as other ones carried out externally as extensions according to the professor's needs. The analysis of the integrated manipulations was done taking into account the minimum latency of the remote control as well as its portability to save time, space, and money without loss of quality.

The second contribution aims to present a low-cost architecture based on the cooperation of two embedded systems, Raspberry and Arduino, the student accesses the practical work via a web page developed with HTML/Javascript provided by NodeJs server hosted in the Raspberry. In this contribution, a software oscilloscope has been developed with processing integrable in the web page to visualize the measured signals from the practical work board.

The third contribution addresses the lack of empirical evidence supporting electronics education innovations in three practical work methods, namely, hands-on, simulation, and online remote real labs. This contribution reports the application of a methodology that takes into account the interaction between students and teachers at a different level of abstraction to evaluate a DC motor laboratory practice.

1.4.2 Event-based labs control contributions

The following contribution falls within the field of automatic control and focuses on the communication process of building VRLs. It presents a new extension of the RIP protocol that allows more precise and sophisticated management of the communication in the control system. novel control strategies have appeared in the literature intending to improve performance by reducing the communication between the different elements of a controlled system. In this regard, the RIP protocol offers a simple and powerful communication tool that defines a standard method to communicate and control an online laboratory based on HTTP methods The enhanced version of the RIP Python server implementation solution implements Server-Sent-event as an effective communication protocol to enable the use of event-triggered and self-triggered control techniques in educational RLs based on web applications that run on a web browser without any additional requirements. The new extension of the RIP Python server handles multiple user access, automatically reconnects, and resents lost event streams for the disconnected users, as well as the extension, proposes an architecture to implement generalized sampling in online Laboratories.

1.4.3 Blended learning contributions

The contributions made in this field aim to improve teacher-student interaction, test real understanding in lectures as well as design hybrid tools based on the videoconferencing system to provide theoretical and practical experience at a distance.

The first contribution aims to evaluate the effectiveness of a distance learning system that provides theoretical and practical teaching, following a methodology that considers in- indicators at different levels of abstraction. The low-cost developed system consists of three subsystems that complement each other to provide remote training on solar energy. The first subsystem is a virtual classroom based on the open-source BigBlueButton videoconference system, while the second and third subsystems are respectively, a MATLAB graphical user interface that describes the behavior of solar panels under varied climatic conditions, and a remote lab based on an IoT system to allow students to measure remotely the value of the current and tension needed for the operation of the graphical user interface.

The second contribution aims to propose a low-cost architecture-based Raspberry for the operation of a Classroom Response System. As a part of this contribution, a mobile-based CRS has been developed using web-based technologies that make the system very easy to use in educational environments. It allows the teacher to interview students using multiple-choice questions, to test their understanding of a concept discussed in class. An improvement of the tools to a techno-pedagogical instrument developed for learning purposes, which aims in particular, to optimize the process of interaction and interactivity according to an approach program. it appears that these conditions are not sufficient to promote the use and the fidelity of a technical system dedicated to the training by alternation. This solution takes into account the didactic and pedagogical constraints that hinder the process of questioning, to create favorable conditions for investment and cognitive engagement of students. This tool has a strategic character because it allows for improving the image of our university by pursuing the paths of smart cities.

1.5 Thesis overview

Figure 1.1 depicts the organization of this thesis intro various chapters. Chapter 1 provides an introduction to the area of the integration of the Internet of Things in higher education. It addresses the scope of the thesis, research goals, and main contributions of this thesis. Chapter 2 provide background into technology-enhanced learning in higher education, it also presents the related work done in the area of implementation of IoT-based system in higher education. Chapter 3 describes the main contributions made during the research period of this thesis, concerning the integration of low-cost IoT-based systems in order to enhance the learning and teaching process in open access universities. Chapter 4 is dedicated to the tests of the main contributions done in the previous chapter. Chapter 5 presents the main conclusions, i.e. answering the research questions, main learning, and possible future work.

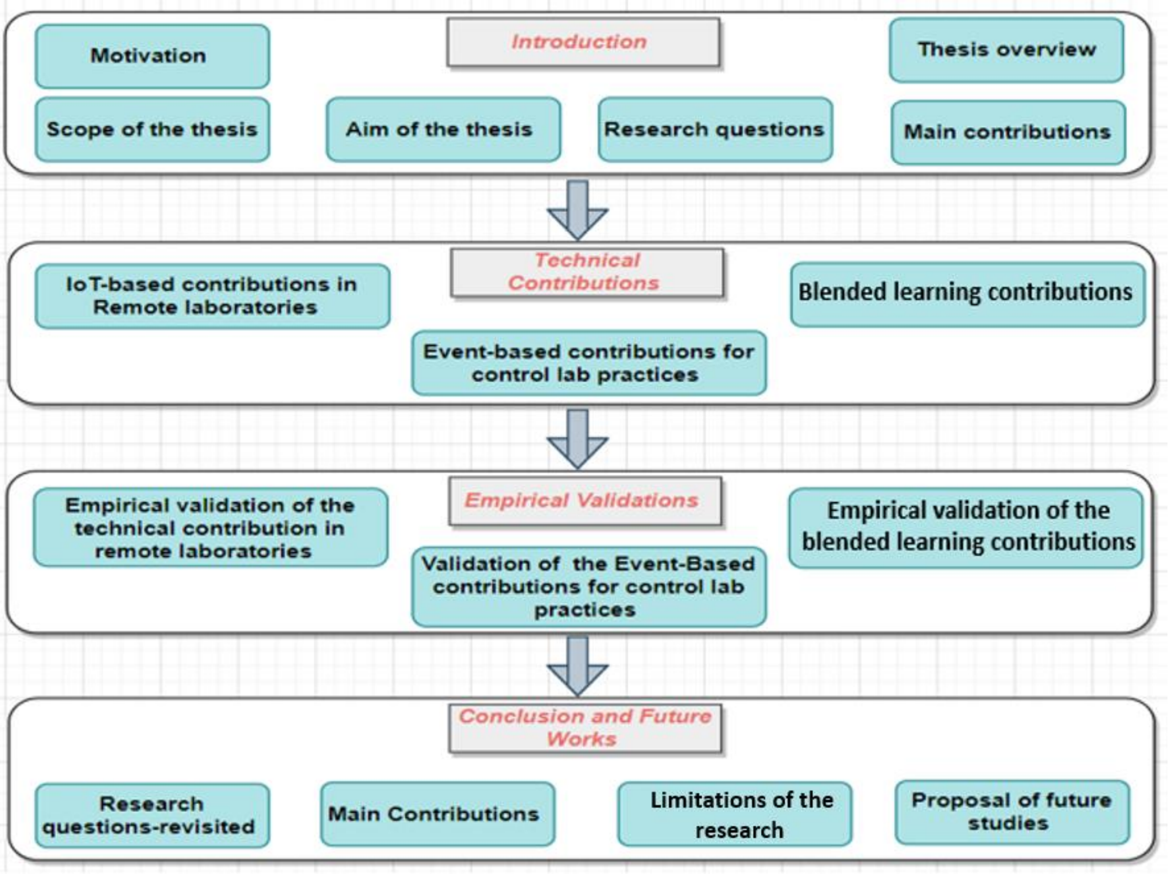


Figure 1.1 — Thesis structure

Chapter 2

Background and Literature Review

Content

2.1 Introduction

Around the world, HEIs are turning to the next generation of innovative technologies and cost-effective technological systems to respond to the growing global pressures to maintain strong outcomes and improve performance levels, while meeting the expectations of students and respecting shrinking budgets [31]. Higher education enables individuals to build more prosperous lives and societies to achieve economic prosperity and social welfare. Thanks to the Internet, which is a fundamental key factor in improving education and realizing the vision of the future [32].

Interactive teaching and learning methods, supported by the Internet, enable the teacher to give more attention to individual students' needs and support shared learning. On the other hand, students' demographics and behavior have been changing with increasingly mobile individuals looking to learn at their own pace, wherever they are located. The growth of educational resources and online courses are clear examples of the role technology can play in improving access in the field of higher education [33]. Accordingly, new teaching and learning methods and practices are being implemented to encourage greater student-teacher interactions and collaborations inside classrooms and laboratories. The educational project touched by technologies must be viewed through the lenses of quality, access, and cost [34].

The costs of delivering higher education should be a topic that teachers and administrators on HEIs are concerned about. The challenges faced by the HEIs and the ongoing change are forcing education providers to look for new innovative and cost-effective ways to meet challenges and new demands. Education technology is helping to provide technical and pedagogical solutions to enhance students learning experience. Undoubtedly, technology in classrooms and laboratories of practical works opens ups opportunities for much more fluid learning experiences to develop the necessary skills for the digital world. In addition, it helps contain costs, which, from a practical point of view, is extremely important for educations providers in higher education institutions facing numerous funding cuts [35]. These budget constraints, together with the need to deliver continuous improvement are driving higher educations institutions to seek out proven new low-cost possible scenarios for delivering learning [36].

The existence of the digital gap between HEIs in developed and developing countries should be considered a matter of concern. Several studies focus on the digital gap in terms of the faculty's access to information and communication technology [37]. The initiative aimed to equip classrooms and laboratories, built teacher capability in technology use encounter acceptance, sustainability, and scalability challenges. Among all these issues, the most critical challenge is meeting digital equity among students, teachers, and administrators. IoT is an emerging technology and a changing dynamic in the field of education. It is advertised in the literature as one of the technologies that can reduce the digital divide between developing and developed countries. IoT based systems have a feature of storing and formulating data in an application form with special software and in the form of a sign-in of website that enables anyone from anywhere to access that with a user id and a password which can be provided by the institution to their distance students [38].

The pressures from students, authorities, and teachers, education providers are constantly on the lookout for ways to enhance the learning experience and make efficiencies through new low-cost emerging technology. The integration of emerging technologies in higher education institutions must be validated by solid studies making it possible to highlight the advantage and limits of each type of technology. This type of study helps to improve the technological system designed to support higher education and it helps in selecting the best method and practice to use technology to obtain the best results and reduce the gap in digital technology access between HEIs [39].

2.2 Technology-enhanced labs and classrooms

2.2.1 Concept of smart campus

The educational field has taken great advantage of digital technologies and many applications have been created to enhance teaching and learning experiences at all levels. The emergence of digital learning and teaching technologies has redefined and expanded educational opportunities, making high-quality resources available to a global audience and promoting peer-to-peer feedback. Over the past few decades, traditional campuses have moved from paper to digital to smart campuses, depending on the campus location and resources [40]. Recent advances in IoT technologies have created many changes in our society and it's considered the backbone of any smart infrastructure in smart cities. The main vision of IoT is a smart world where society's real, digital and virtual systems converge towards a better standard of living by connecting objects and thereby providing control and better performance of things and infrastructure in society [41].

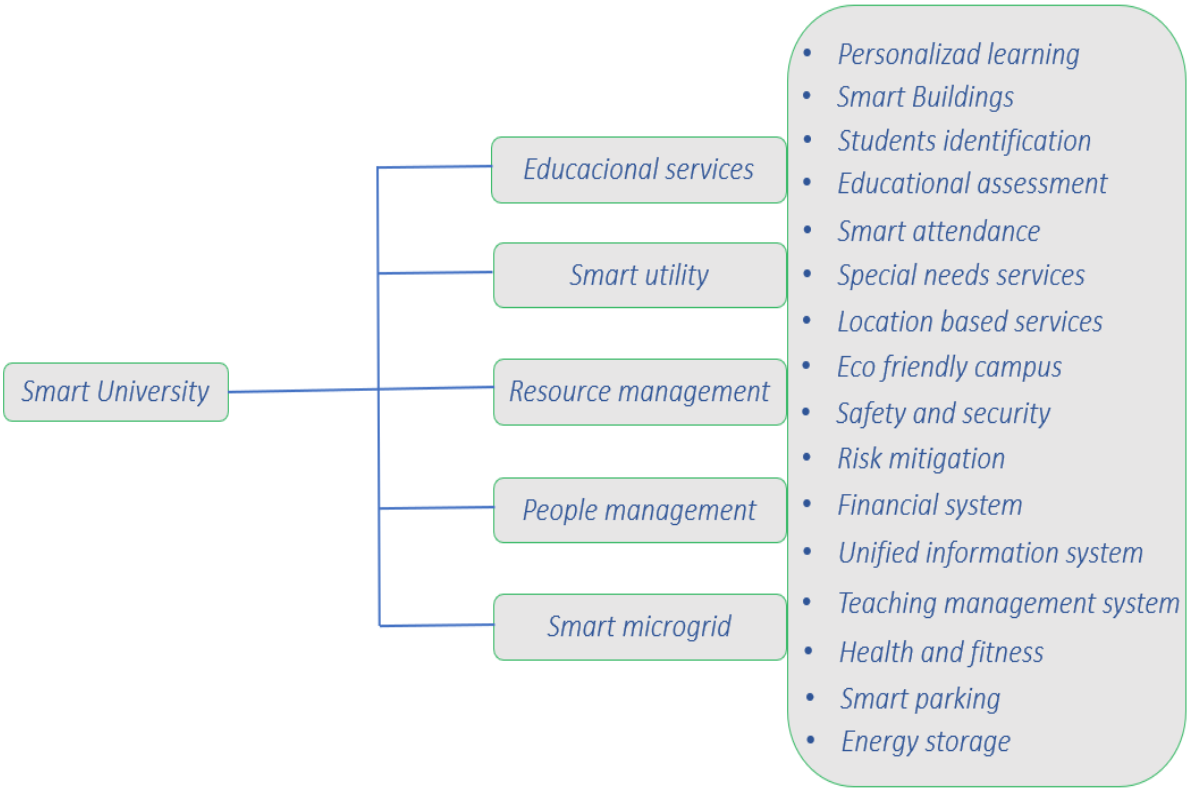


Figure 2.1 — Components and characteristics of a smart-university

IoT presents a great opportunity to transform the university campus in an intelligent new way, which has led many universities around the world to develop smart campus approaches that not only make the campus operation more effective but also enhance the experience of students and academic staff. The smart campus concept helps higher education institutions differentiate themselves from their peers by enabling efficient practices and removing antiquated transactional processes. The digitization of the educational process is providing students with the power to decide when and where they want to engage in learning, they can attend classes and complete assignments remotely. IoT technologies can also inform school officials of students who are struggling with their grades or not attending class regularly [42].

Smart universities are an upcoming and rapidly developing field that innovatively integrates advanced concepts, smart software and hardware systems, smart classrooms and remote laboratories with the latest technologies and technical platforms, and smart pedagogy based on modern teaching and learning styles. The main benefits of the smart university are: (1) knowing the traffic of students and academic staff in relation directly to the university, (2) controlling the academic flow which includes classrooms, laboratories, classes, and practical work hours, among others, (3) analyzing risks and making decisions through statistics, (4) systematizing all processes, and (5) reducing energy consumption [43]. Figure 2.1 illustrates the components and characteristics of smart universities.

In [44], wang has suggested constructing a green infrastructure campus with IoT designs, developing an architecture to handle application systems that supply data to computational labs to facilitate the decision-making processes and hence reduce energy consumption. Additional examples are the project focused on providing an architecture for a smart library based on RFID technology that protects and standardizes the selection of books at Donghua University [45]. Jaume I University in Castellón, Spain, is a smart campus focused on locating areas of interest and consulting useful information, through maps on responsive web pages. The related challenges in building smart universities suggested the need for a global organization to set standards and unify efforts related to the smart university campus, such as the IEEE Smart Cities Community. In 2014, the University of Lille presented a case study to the world bank for the smart city and advocated that a smart campus could be an initial step towards the realization of the concept of a smart city [46].

2.2.2 Distance education

Distance learning is the educational modality in which students and instructors do not have to share the same physical space during the teaching and learning process. This educational model has been used for a long time when people who wanted to study were limited in their ability to attend schools due to lack of time, remoteness, transportation costs, incompatibility of work and school schedules, and so on. At that time, the idea of providing instruction without requiring the student's physical presence in a classroom emerged. The first steps were taken in the United States in 1728. The professor of Calligraphy Caleb Phillipps, in an advertisement in the Boston Gazette, proposed to send several lessons weekly by correspondence to people who were interested in learning this art. The course, which was called "The New Method of Short Hand", included the possibility of tutoring by post and guaranteed perfect learning of calligraphy" [47]. This method was called education by correspondence and it was formalized in 1980 in England, Where Isaac Pitman proposed the teaching of shorthand through the ‘’Phongraphics corresponding society‘’ using postcards containing the fundamental principles of the subject. These cards were sent by post to students to translate short passages from the Bible and return them for correction. This teaching modality also appeared in Germany in 1856, with a correspondence language learning course. More later, in 1890, a correspondence course on ''Mining and prevention of accidents''. Directed by the journalist Thomas J. Foster. The main objective was to train the workers of the mines of Pennsylvania on the prevention of occupational risks. Later, the so-called international correspondence schools (ICS) appeared in this city, of which subsidiaries were created on all continents. Its objective was to provide an educational opportunity to workers who, due to different causes were unable to attend conventional schools [48].

By the end of the 18th-century and the beginning of the 19th-century, correspondence education was becoming increasingly popular. In 1891, the University of Queensland in Australia offered comprehensive distance learning programs in several subjects. While in 1892 the Pennsylvania State College begins its correspondence courses in agriculture. By 1906 the University of Wisconsin offers its distance extension. Later, in 1915, the National University Continuing Education Association was founded. While in 1922 Pennsylvania State College begins with its radio courses as well as Columbia University. In turn, in 1925 the State University of Iowa did the same. At the end of World War II, there was an expansion of this modality to facilitate access to educational centers at all levels, especially in western industrialized countries and in central Europe. This was due to the increase in the demand for registered skilled labor [49].

The period, from 1720 to 1950, is known as the first generation of distance education, based primarily on correspondence teaching. After this period, correspondence began to be replaced by other means that become available due to technological advances. For example, in 1950, the Ford Foundation begins with educational programs on television. In 1965 the University of Wisconsin teaches courses based on telephone communication. While in 1968 Stanford University creates an educational television network and in 1969 the Open University of London begins. During this period there was a lot of mistrust regarding these teaching methods. It was argued that education had to be interactive, that in one sense it was impossible to teach with quality since teachers needed to receive feedback from their students to verify the effectiveness of the teaching process. learning. Thus, in the 1970s, the concept of interactivity was introduced in teaching and the use of electronic media such as audiotapes, videotapes, radio, and television was deepened.

At the beginning of this decade, the Universidad Libre a Distancia (Free Distance University) was created in Spain, which later became the current National University of Distance Education (UNED) [50]. Its main objective was to bring higher education to population centers, far from the large metropolises. At the end of the 1970s, the Argentine Association of Distance Education (AAED) was created, which holds annual meetings to share experiences in this modality [51]. In the 1980s, distance education spread to official organizations, private institutions, and the university, with several universities developing distance education programs; It is in this period that distance education evolves into a truly interactive tool with the use of computers and the application of videoconferences.

Since the 1990s, with the development of communication networks and the Internet, the emergence of a new model of education has become increasingly evident, which many believe will converge traditional face-to-face education and distance education, directly influenced by Information and Communication Technologies (ICTs). In the field of engineering education, distance education has also evolved to such an extent that nowadays it is common to find engineering specialties that are taught at a distance in several universities; such is the case of Control Engineering, Electronics, and renewable energy. The teaching of these specialties requires that the theoretical concepts, which are taught through lectures, are complemented by practical activities in laboratories. Through these experiments, students can observe in practice some theoretical contents that on many occasions are difficult to assimilate employing traditional methods. In distance learning, it is a disadvantage to incorporate practical experimentation, because the students have to be physically present in the laboratory to develop this type of activity. This is why distance teaching in the Engineering field can benefit from the current conditions provided by ICTs. In this context, the experiments can be adapted so that students can access them remotely via the Internet. In this way, the disadvantage that implies the physical presence of the students at the university to perform the laboratory practice disappears. In turn, the laboratory practice can be complemented with a simulation of the process that the student will face during the experimentation with the real plant. These simulations allow the student to get to know the process and interact with the system virtually before facing the real equipment. These types of applications that have a simulation of the process and allow access to real plants remotely are known in the world of engineering education as virtual and remote laboratories [52].

2.2.3 Distance learning technologies

Distance education is distinct from traditional education and needs different technology, methods, and pedagogy to maintain active student engagement. The delivery technology was originally used in the development of distance education by creating the tools to enhance student support services. Examples of these services are electronic access to library services, radio, television, teleconferencing, and email contact with the tutors and subsequent students. The technology used in education has evolved from print to today's interactive technology through various stages [53].

In the early days of distance learning, most universities offered distance learning courses by correspondence in Europe, and then all over the world. Radio and television broadcasting has been used for educational purposes for a considerable time. There are various types of distribution: public, cable, and satellite. The advantages of radio and television transmission are based on the fact that audio and video cassettes have become one of the most important media for distance learning. The computer-based conference enables students and trainers to interact via a computer network. These transactions can take place via e-mail messages, file transfers, chat rooms, actual audio, and video recordings, etc. With the continued rapid advancement of computer technology, computer conferencing is taking its place in educational technology. Web-based education is recognized as one of the fastest media for teaching and learning, it offers cost-effective technologies and is an attractive medium for distance education. E-learning which means « Training on the Internet » makes use of several technologies, and certain of these technologies have been designed specifically for it, while others are dedicated to appropriately complementing the learning process. Different types of media are used in providing training online each one has its strengths and weaknesses. How these technological tools are used is more important than the particular technologies chosen [54].

Online educational resources have become an indispensable part of most courses today. Whether it is distance learning or traditional classroom teaching. These resources can be used to demonstrate a concept, explain a theoretical notion, or complement a speech. As we know, a picture is worth a thousand words, but when pictures are not sufficient, we can take full advantage of the Internet. In this context, distance education universities have found the o Internet a fruitful ground for the development of their applications and courses, taking advantage of the advances in communication and computer technologies to facilitate the learning process. Online learning has not only changed the way users are accessing materials. This technology has also altered the way students plan their studies during the week. It has also influenced the age range of students and their economical status [55].

In this sense, every year more students come to the university to attend courses, and many of them have grown up with the Internet. Several courses now incorporate the use of a Learning Management System (LMS), which allows students to become familiar with online education. In short, it is a web-based software platform/application that provides the framework to handle all aspects of the learning process in institutions, it provides an interactive online learning environment and automates the administration, organization delivery, and reporting of educational content and students outcomes [56]. Additionally, some universities have expanded their educational niches by developing massive open online courses (MOOCs), where students can learn their competencies from a distance. MOOCs are one of the most prominent trends in higher education in recent years. The term first appeared in 2008 by Stephen Downes and George Siemens and based on the connectivist approach, the learning in a MOOC is enhanced by participation both in the creation and sharing of personal contributions and in the contributions of others but the participation is voluntary, the participation is free and open to anyone who has access to the internet [57]. The educational social media networks have also affected the way education and sharing are perceived, these tools are a good way for new students to be engaged because they are very familiar with them [58].

Videoconferencing is a digital communication technique between two or more locations in which audio, visual, and data signals are transmitted electronically to provide simultaneous interactive communication between two or several users. All participants involved can see the facial expressions and body language that are so essential to the way we communicate. Videoconferencing works by using a couple of different technologies. Some of these technologies are hardware related while others are software-based. In addition to audio and visual transmission of meeting activities, related videoconferencing technologies can be used to share documents and display information on whiteboards. Educational video conferencing systems offers teachers greater flexibility as they can transmit ideas and topics without being limited by distance. The daily trip that some teachers make to their workplace is eliminated when their options for reaching students are broadened [59].

A major component of scientific subjects is the need to learn theoretical concepts that are practically applied in the form of procedures and practices. A very common strategy for teaching these real-world applications is to use exercises, tests, and practical work in laboratory sessions. Laboratories and simulations are the primary differentiators from non-scientific fields in higher education, these practical work experiments cannot be conducted without laboratory equipment. Today distance experimentation is possible and common in the distance education paradigm. Laboratories accessible online appear to improve the performance of distance education, allowing students to pass their practical work through simulations and remote laboratories. In this regard, remote-controlled laboratories play an important role in distance education for engineering students [60].

2.2.4 Benefits and challenges of laboratories

Practical works activities performed in the laboratory are a very prevalent and important component of STEM courses. The main aspect that distinguishes scientific subjects from other subjects is that the content of the lectures is related to practical activity and experimentation. It is required to have a suitable place with all the necessary equipment and circumstance for the students to be able to carry out the activities and experiments. The laboratory has become an established and enforced part of physics courses taught in higher education. It is an organic part of the educational process and is of great benefit in transforming the abstract into the concrete, enhancing the experience of both teacher and learner, and helping to develop tendencies and better skills for students. In fact, during the educational process, laboratories play a critical role in linking theory and practice and developing the sense of engineering. The overall purpose of engineering education is to train students to perform engineering and, in particular, to work with natural forces and materials. Most education training in the field of engineering, whether initial or continuing, are forced to provide their students with training sessions where they are confronted with real-world situations so that they can put their knowledge to practice and judge the operationality of several systems [61].

The PWs activities work can be defined as « The activity which consists, for the students to carry out one or several experiments, i.e manipulations of experimental devices to highlight a phenomenon ». The importance of laboratory experience in STEM education programs has been highlighted in a large number of scientific research and articles in the literature [62]. STEM education gained from advances in science and started to incorporate deeper theoretical concepts towards the end of the 19th century, particularly in American HEIs. PWs activities encourage the acquisition of scientific knowledge and promote the development of various scientific, technical, and social skills and abilities. Researchers and educators affirm and recognize the central and distinctive role that assignments play in science education because they help to achieve specific goals and competencies, they also aim to develop and embed scientific reasoning in students [63]. The laboratory pedagogy has recently been reported as a fertile area of research for the years to come, especially in the light of the expanding use of new developments in ICTs to enhance laboratory training. The literature concerning laboratory instruction shows a close alignment of the goals of laboratory instruction. Feisel and Rosa listed many general purposes of laboratory instruction, such as connecting theory and practice, motivating students, and developing engineering acumen [64].

An opposing view to the benefits of laboratory-based education is held by Abrahams and Millar 2008, who cite some drawbacks of laboratory-based education as it is an inefficient teaching method that cannot properly represent scientific inquiry and should rather be taught through direct lectures. In addition, Hodson 1990 claimed that PWs can be applied in a way that students only follow the teacher's instructions, which means they do not need creativity or cognitive thinking to process the information. Thus, PWs are a time-waster, confusing, and counterproductive [65, 66].

Notwithstanding the significance and value of the hands-on laboratory PW in the process of teaching and learning in STEM courses, these activities still face several challenges that make them ineffective in several developing countries. From the literature, the following challenges were noted.

- Limited comprehension and control of practical concepts by the learner: these behaviors are noted especially in the first years of PW sessions in HEIs. Science and its processes should allow students to develop thinking and process skills, including deduction and logic which includes deductive thinking. Unfortunately, these goals are hardly achieved due to the poor understanding of practical concepts by students.

- Lack and insufficient laboratory space in higher education institutions: it is evident that without laboratories it is difficult for a teacher to engage students in practical activities. Several HEIs especially in developing countries have smaller laboratories that could not accommodate the practical learning for the number of students contributed.

- Insufficient laboratory equipment and resources: the constraints related to the equipment of PW and its implementation to ensure experimental activities are a very important issue that is widely indicated in different research within the literature. Indeed having the right resources at the right time is an obvious prerequisite to the implementation of experimental activities in laboratories. HEIs that are under resources tended to do fewer PWs compared to normal ones.

- Limited funds allocated to purchase, repair, and maintenance of laboratory equipment: Higher education institutions in several countries are inevitably experiencing a rapid increase in student enrollment which has occurred without an accompanying increase in financial resources.

- Limited and untrained laboratory technicians: the financial challenges of several higher educations institutions are forcing us to limit the number of technicians in charge of the different manipulations and equipment in the laboratories. In this situation, teachers are forced to assume the role of technicians, as such laboratory practice and instruction are compromised due to time constraints in balancing between teaching and being a technician. On the other hand, effective laboratory practice requires skills and professionalism that may not be achieved by untrained personnel as such instruction is compromised.

- Waste of time: it was established that due to constraints emanating from other challenges cited above, time is wasted during shifts and in many cases, practical activities wouldn’t be as conclusive as required.

Providing distance laboratory PWs was one of the main problems of distance education in its early days. In engineering, the first distance education graduate programs do not include laboratory experimentation, the question of how to deliver laboratory PWs did not arise. When distance learning programs began to develop, this problem inevitably required a solution. The traditional approach was to have students complete practical activities at alternative institutions or to spend time at the university or the institution in charge of delivering the course as a part of condensed laboratory PWs sessions. Other programs gave away remote kits that they could use at home to conduct the course PWs, students purchased kits at a cost considered comparable to what they would spend to travel to campus to take regular lab classes. With the advances in technology over the years, other forms and styles of practical laboratories have emerged to enhance the student experience. The following sections focus on virtual and remote-controlled laboratories.

2.2.5 Virtual laboratories

Hands-on experimentation is an extremely significant portion of the learning and learning process in STEM courses. Nevertheless, the time and financial resources often required to set up and build laboratories are not within the reach of many institutions. A remedy for this challenge could be provided in the adaptation of Virtual Reality technology to simulate and create virtual laboratories that could replicate the processes and actions that take place in real laboratories.

The advanced features that a virtual environment can provide, combined with the growing research interest in distance education, have led to the development of a wide range of applications that use virtual reality technology to support the learning process, forming what are known as virtual educational environments [67]. Virtual Laboratories (VLs) are used to conduct experiments without the real system providing simulated data to the user. They usually contain animations or dynamic diagrams to provide a graphical representation of the system state. Often, a simulated lab has fewer constraints than the real one and also has more configurable parameters because the VLs are not integrated into a fixed configuration. Therefore, high configurability is one of the strengths of VLs and usually provides enough configurational freedom to allow different behaviors.

The proper role of traditional laboratories activities in training and understanding educational problems is currently being questioned. Advances in information technology have led to the replication of some learning processes to various degrees in the form of learning programs available via the Internet, overcoming some of the limitations of the traditional PWs systems. The VLs offers a user-friendly representation of the provided information, interaction with the system, which requires advanced knowledge of the computer's technology to provide experimentation with reduced cost compared to other technologies [68].

In the following cases below, the adoption of VLs appears to be preferable to hands-on laboratories:

- Recourse to work simulations is essential when learning procedures through a real laboratory endanger students' lives.
- When some experimentation cannot be performed due to time and financial challenges.
- In some cases, There is practical experimentation that can only be simulated using computer technology.

A virtual laboratory can be based on a simulation of a real laboratory or a theoretical simulation. Both are valuable resources for explaining concepts without the cost of building and maintaining a real system. In the first case, the virtual laboratory provides a safe environment for explaining concepts and procedures in detail and can be useful for preparing students to use the simulated system. From a pedagogical perspective, the two labs are valuable resources that can be used together in a step-by-step approach:

1. Students learn systems theory and procedures for the laboratory in an earlier part of the course or by studying all available material.
2. Students arrive in a virtual lab to understand theoretical concepts in a vast testing arena where they can fully explore the opportunities of the system.
3. Finally, when students pass the virtual laboratory experimentation, they have access to the remote control, where the knowledge gained can be useful to fully exploit the time and resources of the lab session.

From a data standpoint, virtual labs do not need access to hardware or disks and are easier to embed in a web page. Nevertheless, the consumption of computing power by mathematical simulation, graphical elements, or both can be the high consumption of computing resources in virtual laboratories. or both. Therefore, developers must consider the requirements to run on low-profile devices [69].

2.2.6 Remote laboratories

The PWs activities play a fundamental role in enabling students to fully grasp the material taught in lectures. Nevertheless, conventional laboratory experimentations are bound by time, space, and several other limitations, namely, lack of material needed for the required experiments, lack of information about the safety rules and the steps that should be followed to avoid accidents during PW sessions, lack of information and techniques to perform correctly the experimentation. In addition, students should perform laboratory activities at a predetermined time and in a specific room, as well as hands-on experimentation, which are not suitable for all students because some of them need more motivation factors to get the most out of the practice and improve their learning outcomes. This is not always best accomplished in hands-on labs due to the lack of motivating factors, a large number of students, a lack of technicians, and the presence of only one instructor who must work hard to address the needs of individual students [70].

The RLs represent an attractive new alternative to learning and conducting PW experimentations by eliminating time and space constraints and exposing students to an innovative way of experimentation by operating hardware remotely. Remote-controlled laboratories allow distance students to conduct experiments using real equipment at any time, from any location using the Internet. This technical solution can supplement or replace some of the hands-on PWs by providing students with individualized, flexible learning applications opportunities to introduce what they are learning in the real world. Considering that RLs are remote-controlled systems, they require interactivity components to control the state of the experimentation in the laboratory. In this perspective, the graphical user interface must allow the user to change and observe the behavior of the system studied. To establish a strong connection between the graphical interface and the real system, remote controlled laboratory usually includes webcam images to display data during remote experimentation. The data delivered is real (from a working system), the camera images and data display provide the information needed to change the state of the experimentation system and correlate actions and responses. Lab experimentations on real systems are more restricted than in virtual labs because the intervals for changing parameters tend to be tighter and noisy signals, delays, and fewer switching data points [71].

Once the objective of the laboratory experiment has been identified by the teacher team, the practical work may follow a common pattern, laboratory practices generally have a common pattern.

1. Reserve access to the laboratory in advance, following the rules of the timetable
2. Access the laboratory activity.
3. Interact with the laboratory through the graphical user interface

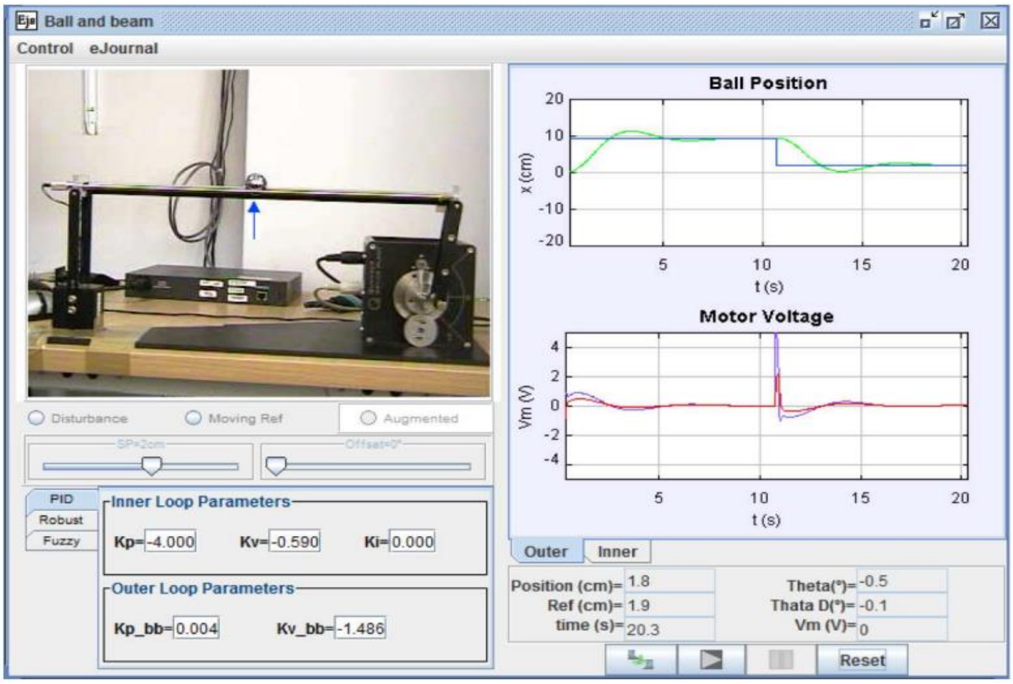
4. Use of the information obtained from the remote experimentation. This may include analyzing data qualitatively/quantitatively, and/or performing additional tasks to increase knowledge of the system.
5. Preparation of a laboratory report to reinforce acquired skills and knowledge

Practical work activities are generally associated with touching and seeing real systems, accordingly touching the equipment elements of the laboratory causes changes that have to be perceived by the student. Replicating the feeling of real interaction with the equipment is not an easy mission and "the psychology of presence can be as crucial as the technology. Designing a graphical user interface that gives the feeling of being in a lab is not a simple task, but it can be related to the way data is obtained and presented to the student. Hence, the question of when, how, and how much data should be shared is a crucial factor. The laboratory users can find a different mode of experimentation and several interactive user interfaces on the Internet. As a result, the way they conduct their experiment can vary greatly from person to person, but in any case, a lot of data is usually generated and collected.

The data acquisition method depends on the controlled system, architecture, developer design, and learning objective, but in all instances, the interface must access data from real devices. Data acquisition involves a direct or indirect connection to hardware. The number of solutions and approaches to creating virtual and remote laboratories is enormous, there are also many platforms on which labs can be deployed. We are interested in remote laboratories and smart classrooms in all its form, but this work will make a special emphasis on remote-controlled laboratories.

Today, advances in ICTs have enabled many universities to develop their own personalized remote labs to provide new and more appropriate learning experiences. The next lines introduce some of the well known RLs in different educational institutions below:

- ***UNILabs***: University Network of Interactive Laboratories is the lab located at the National University of Distance Education UNED in Madrid that presents many remote experimentations in automatic control [50]. It was born in September 2013 from a previous project, UNEDLabs [72]. The latter was created within the "Computer and Automation" Department of the Higher Technical School of Computer Engineering. Madrid, Spain, has been working in the field of remote-controlled laboratory experiments and virtual laboratories since the 1990s. One of these RLs is the Ball and Beam system control process, which helps automatic control engineering students practice several advanced techniques, including (robust, fuzzy, and reset control) and compare their performance against conventional proportional-integral-derivative control [73].



Inner Loop Parameters

Kp=-4.000 Kv=-0.590 Ki=0.000

Outer Loop Parameters

Kp_bb=0.004 Kv_bb=-1.486

Position (cm)= 1.8
Ref (cm)= 1.9
time (s)= 20.3
Theta(°)= -0.5
Thata D(°)= -0.1
Vm (V)= 0

Figure 2.2 — Ball and Beam remote laboratory

- **EOLES**: (Electronics and Optics e-Learning for Embedded Systems) project is a 3-year joint project involving 15 institutions, four from Europe and eleven from the North African countries of Algeria, Morocco, and Tunisia, whose aim is to create a 3rd year Bachelor degree in Electronics and Optics for Embedded Systems. The project started in October 2012 and is scheduled to end in October 2015. One of the biggest challenges to a full implementation of an e-learning course in engineering is the laboratories [74] .

- **ArPi LAB:** is a remote lab for control engineering and automation developed at the Slovak University of Technology in Bratislava. It is designed for practical experimentation in automation and process control. The Low cost and extensibility are the main advantage of this RL because it is physically built on Raspberry Pi and Arduino boards. The Raspberry Pi plays the role of the lab server whereas each Arduino chip interacts directly with the hardware associated with an Experiment. When a new experiment needs to be created, an Arduino board is added to the network to control the new hardware without any architectural changes [75].

- ***VISIR:*** Virtual Instrument System in Reality, is an Open Lab Platform developed at the Blekinge Institute of Technology, wiring an electronic circuit remotely was the main problem in this kind of lab. It allows the user to design the scheme of the electronic virtually, using a switching matrix to transform the student's design into a real circuit and then enables him to retrieve real measurements. The student can change the setting of power sources and measurements by manipulating buttons on a virtual power source or instrument on his user interface [76].

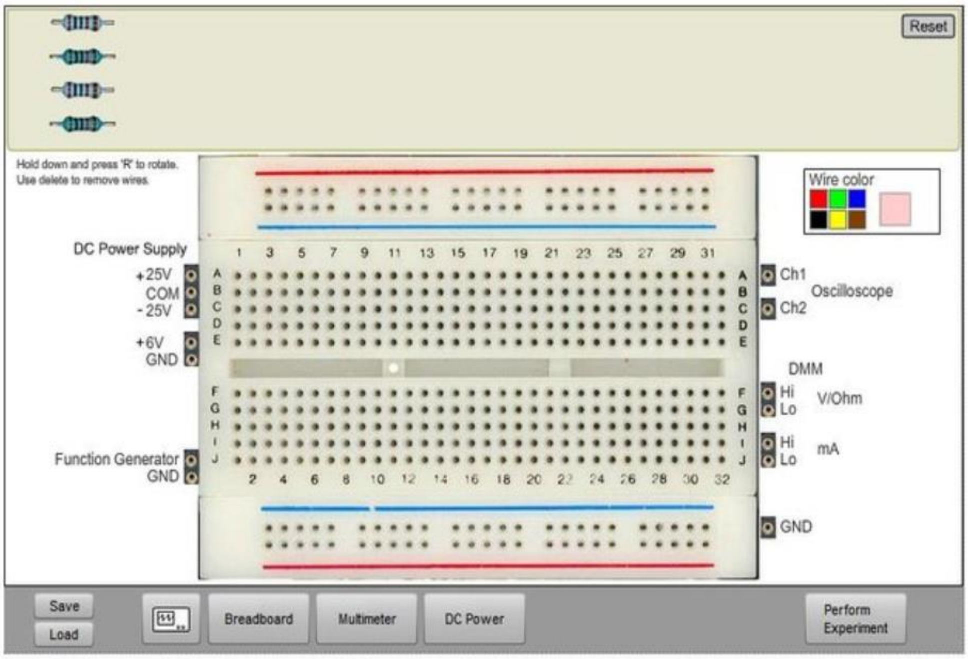


Figure 2.3 — VISIR Interface- Breadboard

- ***WebLab-Deusto:*** Developed by a multidisciplinary research team at the University of Deusto to increase experimentation learning by RLs. It is an open-source remote laboratory management system that delivers a scalable software infrastructure and utilizes web standards adapted to popular web browsers. It provides an inter-institutional alliance of remote labs and can house remote experiments being developed by other projects [77].

- ***RemotElectLab:*** Developed at the University of Porto, it is a reusable, easy to replicate, and very flexible remote laboratory platform for experimenting with electrical and electronic circuits. It presents an accurate duplication of the real laboratory that allows students to change some predefined parameters in the circuit under test. In order to implement and test all the circuits proposed during the normal teaching of electronics in the laboratory, the remote measurement of voltage or current at different nodes of the circuit and graphically possible on the control interface [78].

- ***NetLab:*** Has been developed at the University of South Australia. It has several similarities with VISIR. It also uses a switching matrix as a solution to replace the student's hand in wiring electronic circuits. The switching matrix used is composed of 16 rows and 16 columns. It is used by instructors for demonstrations during lectures and provides a way for students to conduct their experiments remotely. It provides the user with the feeling of performing hands-on experiments through its realistic graphical user interface that incorporates buttons and knobs that behave like real equipment [79].

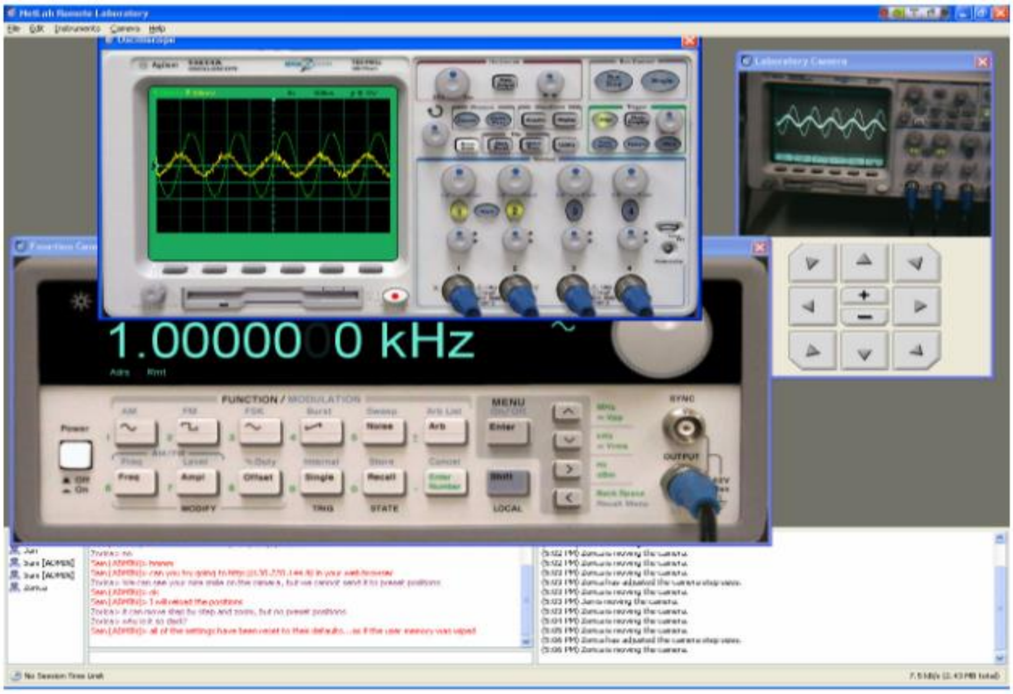


Figure 2.4 — Netlab user interface

- ***LaboREM:*** is a remote laboratory in electronics developed at the Bayonne Technological University Institute in France. The main objective of laboREM is to enable students to wire, test remotely electronics circuits, make measurements and characterize each circuit by its time or frequencies response. The remote lab application is developed using NI-LabVIEW software and the simple and easy-to-use RFP protocol is used to pilot the remote devices. It is based on the design and control of Virtual Instruments for the management of remote experimentation through the web [80].

- ***ISES*** (the Internet School Experimental System): Led by the Charles University in Prague, it is an open remote laboratory system that allows the simple construction of remote experiments via the paste and copy approach of pre-built typical blocks. It uses basic ISES hardware and ISESWIN and ISES WEB Control kit as software for control and data transfer and supports real-time remote data acquisition, data processing, and control of experiments [81].

2.3 Architectures and approches

The following section covers the differences in architectures and approaches adopted for the development of RLs in order to enhance practical teaching and learning processes in HEIs. It discusses also the use of IoT in the functional architecture of remote-controlled laboratories and smart classrooms systems. In fact, Accessing hardware remotely from a user interface can not be considered as a single issue because it groups different problems together.

In order to analyze the situation of remote access of hardware from the area of remote experimentation, we can divide the process into four major classes:

- *Hardware access:* Obtaining/transferring data to/from any system involves the utilization of sensing and actuating devices. Without supplemental components, the control of the laboratory is typically limited to hands-on activities, such as observing sensor values and modifying buttons to interact with the lab.
- *Remote system access:* Consider the process to make a face-to-face lab remote. Although, it commonly implies involving more actuators and sensors, to control the system. In addition, the system will need connectivity capabilities to allow remote access.
- *Control from the interface:* The process of making an application to control a laboratory involves finding a design that meets the pedagogical and procedural goals set by the developers and teachers.
- *Concurrency and load management:* Once the system is accessible from the network and many users seek to access it, developers may be faced with problems related to the number of users and scheduling.

Developers, researchers, and teachers have been addressing these problems since the early 90s. They have discovered many ways to achieve the goal, but there is no best option, as each solution faces different problems. The emergence of the IoT has also spurred the development of libraries and tools, moving closer to sensor, actuator, and device networks, which are directly related to virtual and remote experimentation.

2.3.1 Data exchanges

Providing a graphical user interface that makes students feel as if they are physically in a laboratory is not immediate. In fact, it is associated with the way data is acquired and displayed to the user. Therefore, the question of when, how, and how much data should be exchanged is a critical factor. The manner in which all data are obtained can affect the overall structure of the laboratory, the purpose of the experiments, or the pedagogical setting. As the transmission of data is a central issue in remote experimentation, the data format, i.e., how the information is encoded, plays an important role in the communications process. Since these formats can be either proprietary or free and can be either unpublished or open, this thesis considers only open and free formats, as they allow for better integration into other systems and are more extensible.

The majority of the data transferred in remote experimentation is encoded as numeric data or strings in binary form. In general, these data have a tree structure and are autonomous. Therefore, a solution must be found to bundle several types of data, transmit them and use them on the client side. Therefore, it is important to discuss the source and format of the data. Figure 5 shows a summary of all the data sources that are classified according to whether the data is received from a real or non-real device.

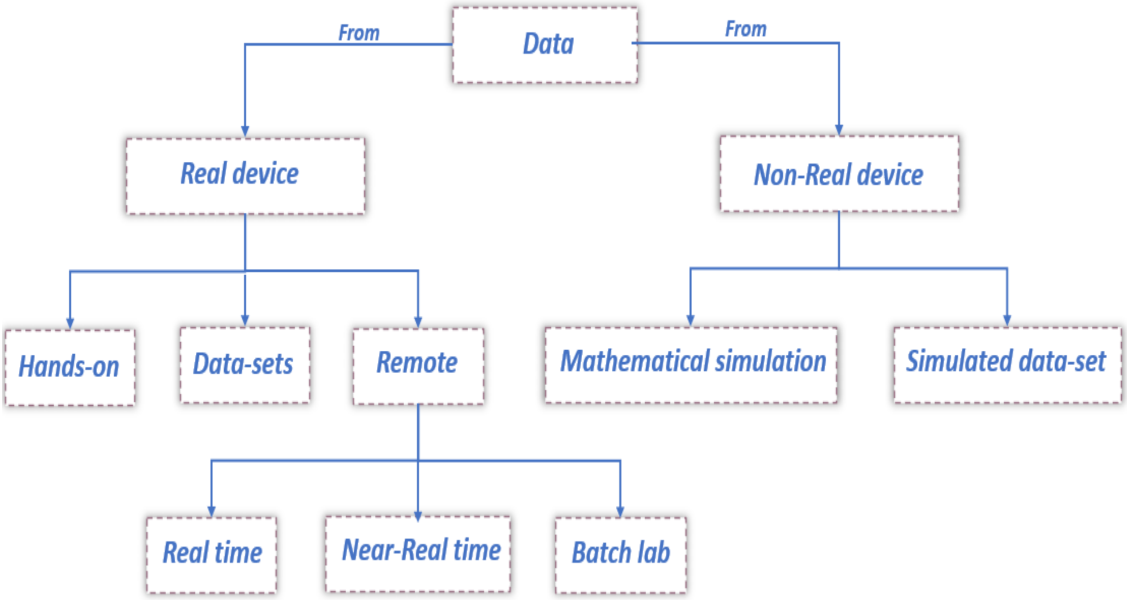


Figure 2.5 — Data sources

- ***Data gathered from non-real devices***: This includes virtual laboratories or simulations, where the data is not obtained from physical hardware, but from computer simulations. Therefore, the change in the system can be obtained from:
  - ***Mathematical simulation***: The laboratories are based on a mathematical and the state of the system is calculated at each period time step.
  - ***Simulated data-sets:*** The data are not calculated but obtained from a previously calculated dataset that contains all possible modifications of the simulated system.
- ***Data gathered from the real device:*** The information provided by the physical machines/devices, sensors, actuators, etc., is classified into three categories:
  - ***Hands-on:*** This is the classic experimental situation, where students physically interact with the real equipment. The data acquisition is done locally and the data collected depends on the user interaction.
  - ***Data-sets:*** The user does not actually perform the experiment, but rather works on data previously collected in another laboratory experiment. This approach is common when the process is complex to replicate or when the goal of the lab practice is not to learn the process but to extract information from the data.
  - ***Remote:*** Remotely accessible laboratories have become so widespread of this kind of experimentation has driven the launch of different approaches:
    - ***Real-time:*** It considers that if some data is not captured on schedule,

it may cause the system to fail. these systems include timing constraints and permit the observer to watch data that is captured at the same time from real hardware.

- ***Near-real time:*** It allows smoother time constraints, and the schedule enables infrequent losses or delays. Near-real-time systems assume some delays that are mostly harmless to the system or the user experience. Non-time-critical systems are aggregated in this classification.
- ***Batch lab:*** This approach is a time delay data acquisition from experimentation hardware. Batch experiments are generally preferred when the time required to run an experiment or process is so long that an interactive session is impractical or impossible.

The purpose of communication between systems is to exchange information, but this information or data is of various types, some of those are complex structures, such as files or objects. Sending complex elements that must be used on both sides involves a methodology to translate and reconstruct these elements. These processes are called serialization and deserialization and are used in many communication systems because of their flexibility to be used in many different systems. Serialization formats are used extensively to send data. The following lines contain four main data formats that have been selected because they are the basis for a large number of other data.

XML: Extensible Markup Language, defines a set of rules for encoding, storing, transmitting, and reconstructing data in a document. It is both human and machine-readable and provides strong support via Unicode for various human languages. This language is widely used to send data from devices or machines to web services [82].

JSON: JavaScript Object Notation, is a language-independent data format derived from JavaScript. JSON is a human-readable text format composed of attribute/value pairs and serializable data types. It is widely used for asynchronous browser-server communication and is included in all popular browsers [83].

YAML: Ain't Markup Language, is a data serialization language based on many other formats and languages (XML, JSON, HTML). It is human readable and is available to create configuration files for multiple programming languages. This format is now being used in metadata, log evaluation, model-based information, and storage [84].

RDF: Resource Description Framework is used extensively in semantic web and Big Data tools. While their knowledge models for data exchange in remote experimentation may be similar to using sledgehammers to crack nuts if the remote system has only a few sensors and actuators, they could be useful for large remote monitoring frameworks [85].

2.3.2 Transmission protocol

In computer networking, a protocol is a set of guidelines for defining and restricting how one system communicates with another. Some famous protocols that have been used in the development of virtual and remote systems are presented in this subsection.

TCP: Raw Transmission Control Protocol streams are being regarded as one of the very popular protocols in the development of web-based applications. In addition, a couple of works have based their real-time systems on this protocol. Nevertheless, one of the main drawbacks of using a TCP stream is that developers have to code other capabilities, such as connection failure detection or security layers, from scratch.

HTTP/HTTPS: Hypertext Transfer Protocol is one of the stronger and more famous protocols in the development of web-based applications that follows a client-server structure. It was initially designed for communication between browsers and web servers, however, it is now being used in almost all web browsing applications. The widespread of HTTPS to obtain secure communications has incremented the difficulty to connect dumb devices to the internet and has no additional security layer. Nowadays, Server-Sent-Event (SSE) is based on HTTP to enable the client to receive messages from the server, making SSE also a good option to implement communications in remote lab experimentation, being the trend nowadays in some applications which need this feature in their applications [86].

Websocket: This protocol allows for an exchange of data between the client and a server that can be done without prior request from the client. Thanks to the good reception of the users, the principal navigators support the WebSocket protocol and are very widespread in the applications of data exchange. Nevertheless, WebSockets have advantages and disadvantages in their use in communications. sing any available port.

RIP: Remote Interoperability Protocol offers a simple, yet powerful communication solution usable by web clients. In another word, RIP defines a standard method to communicate and control an online laboratory (OL), based on HTTP methods such as GET or POST [87].

2.3.3 Programming language

The client-side in a virtual or remote-controlled laboratory refers to the software application or the graphical interface used by the user of such a laboratory. According to the experiment, the client user interface needs to send and receive several types of data to/from the remote lab server to show exactly what is happening in the real laboratory.

Programming languages form the basis for the development of various properties and functionalities in virtual and remote laboratories. Since these types of labs are generally based on a client-server architecture, the programming process distinguishes between the user interface and the system software implemented as a server. On the one hand, the user interface must use a programming language suitable for Web browsers to integrate the resulting application into a Web page, since the general trend in recent years is to move the application to Web browsers. On the other hand, the server-side interacts with the actual hardware and/or with the devices involved in the data transfer. Therefore, the server-side programming language must be compatible with the hardware interactions.

In the early 1990s, the concept of remote experimentation was considered a futuristic approach. A few years later, the first remote lab, designed as a proof of idea, was established. That same year, the first remote lab using Java technology in a web browser was created, clearing the way for the development of remote and virtual labs using the Internet. Java-based remote and virtual labs provided the basis for the development of various prototypes, but two decades later, when numerous remote labs were developed, the use of Java was restricted to the server-side rather than the client-side. This was the result of Java vulnerabilities discovered when using applets to execute code in a Web browser [88].

Modern virtual and remote laboratory development can be done with one or more programming languages, some of which are used to interface with the hardware, such as LabVIEW, MATLAB, and others that can be used in the browser on the client-side, such as Javascript. Other languages have also been used in this area, some of which are very well known: the C family, MATLAB, PHP, Python, SQL. Others have recently gained importance, such as Python, a versatile interpreted programming language with multiple paradigms that can also be used for remote experiments [89].

2.3.4 Architectural styles

Communication between systems is crucial in remote-controlled systems and IoT-based systems integrated into smart campuses to enhance the learning and teaching experience. The architecture of the proposed solution must take into account the exchange of information with sensors and actuators, both inside and outside the campus. Architectural styles are a set of concepts and models for solving common problems that arise during application development. They give abstract frameworks for developing strong solutions and improving the reusability of the design. The following outlines some common architectural styles that have been used in the remote experimentation domain.

RPC: Remote Procedure Call, is a key tool for establishing operational and work-sharing structures in networks and client-server architectures. It is widely used in distributed systems and allows procedures to be invoked on the local system or a remote system. Therefore, when a computer program invokes a procedure on a remote system, it is coded as a normal or local subroutine, so that the process of communication with the other system remains transparent to the user [90].

REST: Representation State Transfer, is an architectural style for deploying standards between computer systems on the Internet to facilitate communication between systems. REST-compliant systems, often called RESTful systems, are characterized by their statelessness and separation of client and server concerns. They are used to design networked applications that use only the HTTP protocol to communicate between systems. The concept is based on resources that can be addressed through a stateless, client-server using URL [91].

SOAP: Simple Object Access Protocol, is a facility for transmitting information between applications in an XML format. SOAP messages are forwarded from the sending application to the receiving application, usually over an HTTP session. It is used for Web services, uses XML for the message format, and relies on HTTP. SOAP enables the client to invoke Web services and receive messages independently of the operating system [92].

2.3.5 IoT in remote laboratories

The Internet of Things is considered the next step toward the smart city, in which objects and humans interact through various communication protocols in a digitalized environment. It is widely recognized as one of the most powerful drivers of success in the so-called Industry 4.0 sectors. Significant developments in the IoT field allow researchers and educators to attempt to use this technology for a diverse range of innovative deployments in the educational domain. The integration of IoT systems into the operational architectures of remote laboratories is one such application that is primarily aimed at addressing certain technical and pedagogical issues in the field of remote-controlled laboratories [93].

Researchers, developers, and academic groups are making considerable progress in the development of several architectures of remote-controlled laboratories. Traditionally, the majority of the proposed architectures adopt personal computers and workstations as the primary unit and the local server for databases and user management in the experimental part of the remote laboratory system. In the client-server architecture, the maintenance burden of the server would be heavy because special monitoring software must be installed on each remote monitoring terminal. In addition, the computerized monitoring system has disadvantages, namely high cost, unsatisfactory stability, and reliability [94].

The developments of embedded processors are becoming more and more powerful, fast, and ingenious. Researchers and developers tend to use these new technologies instead of traditional computers and servers for the development of remote-controlled laboratories because they can control the remote device without any restriction and give its real status. In various applications based on Client-Server architecture, it is better to use an embedded web server than a computer server for decreasing volume, cost, and power consumption. The embedded web server has advantages over the traditional remote monitoring system. The next lines present some of the IoT technologies that are used in several IoT-based architectures for remote-controlled laboratories.

Arduino: is an open-source electronics prototyping platform based on flexible and easy-to-use hardware and software. It is a single-board microcontroller, designed to make the experience of using electronics in a multidisciplinary project more achievable. The hardware involves a simple open design for the Arduino card with an Amtel AVR processor and facilities programming and incorporating other circuits by input and output circuits.

Raspberry: is a credit-card-sized nano-computer that can be connected to a screen and used as a single board computer. It is developed in the UK by the Raspberry Pi Foundation with the idea of encouraging basic computer education. Its small size and affordable price make the Raspberry Pi a great product for testing different things, including creating a web server at home. It has been used in the development of several remote-controlled laboratories.

Sensors: they can be characterized as the eyes, ears, and skin of the virtual world. Sensors are physical devices that act as receivers of real-world states and events and translate what they observe into a suitable format for the virtual world of information technology. The data received from the sensors helps to create and maintain a virtual world that, to the same extent, reflects the physical world.

Actuators: present the ‘limbs’ of the virtual world. In a machine or a remote control device, semi-automatic, an actuator is the organ of the operating part that, receiving a command from the control part through a possible pre-actuator, converts the energy provided to it into work useful for the execution of the tasks. The growth of the automation industry has led to exceptional growth in the use of actuators and automation components.

2.3.6 IoT in smart classrooms

The competitive environment in which we live requires considerable efforts to improve the quality of education. In the daily teaching routine, teachers typically try to figure out whether the students were satisfied with the course, which part of the lecture was engaging, and which delivery approaches and techniques were more productive and appealing than the others. Therefore, helping each student individually and detecting the exact area in which he/she has difficulties is one of the main challenges of education during the course sessions, as students are different and each one will encounter difficulties in different areas during the learning process. It is nearly impossible to provide an educational environment with such a learning experience for students. Previous research has shown that students' attention starts to wane after about 15 minutes, which makes finding technical and pedagogical solutions to improve student engagement during lectures extremely important [95].

The concept of a smart classroom has appeared in the literature as an Internet-based distance learning system or smart environment consisting of an assembly of many hardware and software modules of different types. IoT can support classroom teaching by enhancing the learning environment, extending learning resources, improving learning methods and techniques, raising management efficiency, and saving academic costs. It is transforming classrooms into smarter learning environments by connecting classroom devices to several applications locally or through the cloud, redefining how students, teachers, and administrators interact, measuring educational outcomes, and providing ways to improve them at a lower cost. Data collected from multiple IoT devices embedded in classrooms can be used to make intelligent decisions during lessons, as well as stored for later use [96].

Throughout the literature, various studies have put forward different applications of IoT systems to enhance the learning experience in classrooms. Automatic capture of blackboard slides and handwritten notes by capturing audio and recording video during a live lecture is proposed in [97]. Usually, the activities in the traditional lectures do not record in any form. Some platforms can currently measure several aspects of interaction, by analyzing the tone of voice, gestures of the person, and facial movements with a handheld device. Mobile devices are very powerful in improving the accuracy and response time of educational evaluation [98]. works have put forward the idea of collecting data from different equipment at the campus and analyzing them through the implementation of IoT and turning the campus smarter. Raspberry and Arduino have been used as a server that implements software applications allowing to provide interesting information, like the behavior of students using big data and machine learning to analyze the facial expressions of the students. Through smart e-learning configurations, students can attend classes from anywhere through video conferencing software. Further work on improving the learning process by integrating technologies based on the Internet of Things is described in the following article [99].

2.4 Evaluations tests

This section discusses the integration and evaluation process of recent information and communication technologies in the field of education. It highlights the relationship between pedagogy and the implementation process of technologies in HEIs as well as the methodologies for assessing the impact of these technologies on the teaching and learning process. Multiple varieties of digital learning may be categorized under the roof of IoT-based technology. For example, E-learning is related to the learning process that incorporates electronic equipment such as computers and network channels of communication such as the Internet, Intranet, and Extranet. M-learning involves any form of knowledge that is delivered using portable devices. U-learning refers to ubiquitous learning and represents some form of simple mobile learning. Adopting these technologies into education programs has been touted as a key to bridging the digital divide. Despite the considerable increase in the number of technologies acquired by higher education institutions in developing countries in recent years, and the sacrifices made to fund them, there has been little evaluation of their effectiveness.

2.4.1 Pedagogical practices

The latest technologies are affecting students' lives in various manners. On one hand, students are more inclined to games, social media, drones, the Internet of Things, and many other types of technologies. On the other hand, traditional teaching methods appear to be antiquated and less interesting for students since they do not keep up with rapid technological advances. Therefore, one of the most significant consequences of the new technologies, especially IoT-based learning and teaching environments is that the traditional responsibilities of students and teachers are undergoing a fundamental shift. In fact, the real and virtual objects connected allow students and teachers to interact virtually anywhere, at any time, and participate easily in academic projects and scientific research. The high demand on educational institutions to integrate technologies in the learning process to meet the need of students belonging to the digital generation has positively affected modern industry demands [100].

The technology integration to improve the educational process involves more than just incorporating software and hardware solutions into the learning and teaching process. It demands the inclusion of theories about technology integration and the application of recent research findings accompanied by an understanding of pedagogical principles specific to the use of technology in an instructional setting. The integration process should include strategies for selecting required technologies, the ability to demonstrate the use of the selected technology and to evaluate properly its impact on the learning process as well as the skill to personalize the use of such technological systems to solve a specific instructional problem. The learning and teaching process based on pedagogical techniques helps the teacher to understand the role of learning theories in the design of the course and the selection of adequate technological tools during the educational process. Much of the problems associated with technology integration are manifesting because most educators have not addressed the pedagogical principles that guide technological use during the teaching and learning process [101].

Pedagogy can operate at various educational levels. It can relate to broad perspectives relating to how knowledge is acquired, to approaches that are used to structure learning tasks, or to instantaneous classroom instructional strategies. Exploring the relationship between educational technology and pedagogy allows increasing teachers' critical thinking in the process of technology integration. On one hand, The teacher is required to be able to assess the adequacy of any technology used for teaching and learning regarding a particular educational program. On the other hand, appropriate instructional technology resources must be identified at the planning stage when course objectives are determined as well as when methods and assessment strategies are decided. In this sense, several studies have shown that most teachers have a limited view of technology adoption because they don't relate it to pedagogy when they are asked to briefly explain why they should adopt technology in their teaching [102]. The description below provides a brief overview of the most recognized pedagogical perspectives.

Behaviorism is an approach that assumes that human actions are triggered by environmental stimuli. It is also known as behavioral psychology because it is based on the idea that learning is an observable change in behavior caused by the students’ responses to stimuli in the learning environment. A stimulus might be a prompt from a teacher and the learner provide their response in a word, symbol, or action. Behaviorists assert that when a stimulus-response pair is reinforced by a rewarding positive behavior and providing negative reinforcement in the absence of the desired behavior, the learner is conditioned to be forced to produce the appropriate response. This approach focuses on meeting well-defined educational results, but also positions students in the role of passive recipients and does not allow them to motivate their internal thinking. Typical behavioral applications of the technology include flashcards and multiple-choice questions to provide feedback in order to promote understanding [103].

Cognitivism is an educational approach that emerged in the 1950s especially to give a satisfactory understanding of particular modes of learning in which behaviorism fails (e.g problem solving). It is an internal mental activity in which knowledge structures are formed and reorganized to build a solid understanding. In fact, scientists aimed to open the black box of the brain and investigate what happened exactly between stimulus and response. Cognitivists adopt an information-processing view of the acquisition. According to which understanding occurs through the reception, retrieval, and recall of information. From a technological perspective, employing a cognitivist approach refers to designing and implementing technology in a way that takes into account the information processing capabilities of the mind. Web-conferencing environment can be redesigned to align with cognitivist principles in order to better account for how people select and process information, improved attention through audio communication, co-located related information for synthesis, and easier comparison of related tasks for better abstraction [104].

Constructivism is an educational approach in which learning occurs through the process of acquiring and modifying cognitive structures to make sense of the environment. Its basic principles are that individuals actively construct their understanding from their experience. From a technological point of view, technology facilitates constructivist teaching and learning by providing virtual learning manipulations, this can give rise to experimentation where technology can constitute a mindtool that encourages students to think deeply about phenomena and help them to establish interrelationships [105].

Connectivism is a new pedagogical approach in which the process of learning knowledge is a networked phenomenon. This approach has been proposed because recent pedagogy has not sufficiently taken into account the networked digital world in which we live today, including access to vast amounts of knowledge, the hyper complexity of information, and the nonlinear nature of learning. Proponents of connectivism argue that a connectivist vision aligns more closely with the way people learn in today's networked world. MOOCs are one of the well-known technologies that adopt this pedagogical approach [106]. In addition, other pedagogical approaches are available to educators, namely, Collaborative learning, problem-based learning, inquiry-based learning, constructivist learning, design-based learning, and game-based learning [107, 108, 109].

2.4.2 Evaluation practices

Emerging information and communication technologies have shifted learning modes from traditional to digital in a remarkable way in the last decades. The expansion of connectivity and interoperability of devices has paved the way for the development of IoT-based educational systems, which is one of the recent implementations contributing to the offensive upgrade of learning and training processes. The latest trend in technology development has also led to a change in user behavior and usage in diverse domains of life, and accordingly in the area of education. IoT is largely predicted to have a strong impact on many facets of education, and as a result, several intrinsic benefits to the educational environment are not yet well provided in the literature [110].

The mainstreaming of digital learning technologies into the educational process has been highlighted as a key step in reducing the digital divide [111]. Despite the considerable growth in the number of technologies acquired by higher education institutions in developing countries in recent years and the sacrifices made to fund them, there has been little assessment of their effectiveness [112]. Numerous types of digital learning can be classified under the umbrella of the IoT. It offers several opportunities for educational institutions, educators, and students, where the typical responsibilities of students and teachers are basically changed as the real and virtual elements, are linked and allow interaction from anywhere, anytime, and from multiple tools connected to the Internet.

The significant diffusion of new digital technologies in higher education has led to the need to examine the added value of various technological tools for quality teaching and active, individual, and collaborative learning. Using technology to enhance the educational process is not restricted to learning how to use particular hardware and software, it also requires an understanding of the pedagogical principles specific to the use of technology and the identification of well-designed studies that answer specific questions about the effectiveness of the technology being used. The ability to evaluate these emerging technologies, as well as the ability to customize the use of these technical skills to solve instructional problems, is very important to the integration of technology in education [113].

The importance of a clear understanding of the theory and context of evaluation is critical to the successful design and conduct of an educational evaluation. Similarly, there is no substitute for a clear evaluation purpose that is based on defining the right question. Originally, there were two distinct approaches for conducting an investigation, the scientific approach, and the illuminative approach. The scientific approach is focused on measuring the effects of particular variables concerning the outcomes that result from them. It attempts to assess the accomplishment of set objectives regarding the learner's previous learning and skills. The scientific approach is oriented towards measuring the effectiveness of the educational activity as well as the effectiveness of the learning outcomes. On the other hand, the illuminating approach focuses on exploring and examining the process of the educational intervention. In fact, both approaches can be combined to design well-defined studies to investigate the effectiveness of technological tools [114].

Multiple systematic reviews and meta-analyses have been performed to evaluate the use of digital technologies on various topics in education [115]. These kinds of surveys make an influential contribution by offering evidence of students' and academic staff's experience regarding the integration of different types of technologies. The effects of technology on the teaching and learning process are most often obtained by examining teachers' and students' perceptions of the usefulness of the proposed technology during the teaching and learning process, assessing their level of technology integration, determining the motivational factors that drive them, and identifying the challenges that inhibit them. It is generally encouraged that technology impact assessment studies use a combination of quantitative and qualitative approaches so that each can compensate for the shortcomings of the other in order to achieve detailed outcomes. The effectiveness of establishing IoT-based learning frameworks has been proposed and verified in several studies. Even though several educational institutions have applied IoT-based learning on their campuses, the acceptance and adoption of IoT and its potential users are still low, especially in developing countries [116].

Academic staff of institutions of higher education must be able to analyze the needs of students, propose and design the necessary sensors and software for IoT implementations, and set the directives for their efficient and effective use. RLs is one of the educational areas that have recently integrated several IoT-based systems. Experimentation needs to be designed, implemented, deployed and evaluated. The first three steps mainly concern the engineering area but the literature on remote laboratories evaluation is limited [117]. Learning evaluation is consistent and concludes that distance labs have positive impacts on teaching and learning. in fact, factors and variables received from user experience are not systematically collected and analyzed. In practice, it is usual to use questionnaires to measure student contentment with the remote laboratory after experimentation sessions. Such questionnaires generally include subjective questions related to students' experiences with remote experimentation [118]. These surveys aim to find out whether using this technological way in performing practical work was easy or not and if the learning activity was a satisfactory experience in most studies. A large number of these questionnaires have been used, however, a rigorous analysis of these questionnaires is still lacking. In addition, the various groups in the remote and virtual lab community have never agreed on a common assessment tool. Finally, In 2021, Jordi Cuadros and all have been able to provide a short questionnaire that can be useful to evaluate the user experience in remote-controlled laboratories. The questionnaire is now named UXQ4RL v. 1.0 [119].

2.5 Conclusion

Over the past few decades, traditional campuses have moved from paper to digital to smart campuses, depending on the campus location and resources. Recent advances in the Internet of Things technologies have created many changes in our society and it's considered the backbone of any smart infrastructure in smart cities. The educational field has taken great advantage of digital technologies and many applications have been created to enhance teaching and learning experiences at different levels. This chapter presented the background and literature review on the integration of new emerging technologies that are enhancing the teaching and learning process in laboratories and classrooms courses of higher education institutions. More specifically, it highlights the IoT-based learning technologies that are being deployed in remote labs and classrooms to respond to specific problems in developing countries or to implement smart universities in developed countries. It provides an overview of the architectures and approaches being taken to develop remote labs, as well as literature studies that have implemented this new technology in remote labs or smart classrooms. Since technology integration to improve the educational process involves more than just integrating software and hardware solutions into the learning and teaching process. This chapter presents the pedagogical practice and assessment of integrating simple technologies in higher education. It is generally encouraged that technology impact assessment studies use a combination of quantitative and qualitative approaches so that each can compensate for the shortcomings of the other in order to achieve detailed outcomes. The effectiveness of establishing IoT-based learning frameworks has been proposed and verified in many studies. Although several educational institutions have applied IoT-based learning on their campuses, the acceptance and adoption of IoT in HEIs are still low, especially in developing countries. The next chapter presents technical IoT-based contributions made during this thesis research.

Chapter 3

Technical Contributions

Content

3.1 Introduction

The following chapter presents the set of low-cost IoT-based technical contributions that have been developed and implemented during the research period of this thesis. The technical contributions aim to provide other possible teaching and learning scenarios to address certain problems related to practical work activities and interaction processes between teachers and students. The chapter is divided into three main parts. The first part refers to the low-cost remote IoT-based laboratories prototypes that have been developed at the Polydisciplinary Faculty of Beni Mellal, Morocco, especially to meet challenges related to performing practical works in the field of Electronics and to fill the lack of equipment and equipped rooms of performing this kind of important activities. The second part presents our contributions in the field of automatic control realized in the UNILabs network at the UNED, Madrid, Spain, It highlights the communication process in the field of VRLs and presents mainly some improvements made to RIP Python implementation and architecture to implement generalized sampling in Online laboratories. The third part presents blended technical contributions that combine online educational materials opportunities for interaction with traditional place-based classrooms method.

Part I: Remote IoT-based labs contributions

Content

3.2 Remote lab of electronics based on Red Pitaya

3.2.1 Contribution purpose

The following contribution aims to present the design and the implementation of an IoT system allowing several remote manipulations in the field of analog electronics. This solution is mainly based on the Red Pitaya STEMLab board, in particular for communication and remote control for measurements and data acquisition through different protocols. The low-cost system provides an intelligent selection between the different practical works (PWs) integrated on a developed board, as well as other ones carried out externally as extensions according to the professor's needs. The analysis of the integrated manipulations was done taking into account the minimum latency of the remote control as well as its portability to save time, space, and money without loss of quality and quantity. The purpose of this study is the development of a control system to maximize the available resource as well as to improve self-learning ability in the electronic field in open access HEI.

3.2.2 Architecture of the IoT systems

The following section describes the set of different technical elements that complement each other to provide a remote-controlled IoT system for analog electronics PWs. The proposed architecture is based on a Client-Server communication model and consists mainly of two main hardware subsystems on the server-side, and a software graphical user interface (GUI) on the client-side. The two hardware subsystems are respectively, the STEMLab Red Pitaya board and a smart electronic board that we have designed to host several practical works activities in a small space. In short, the two hardware subsystems complement each other to provide remote measurement and data acquisition experiences in analog electronics. The proposed architecture presented in Figure 3.1 allows the students to use the GUI to control the Red Pitaya, which in turn controls the set of PWs manipulations implemented on the developed board.

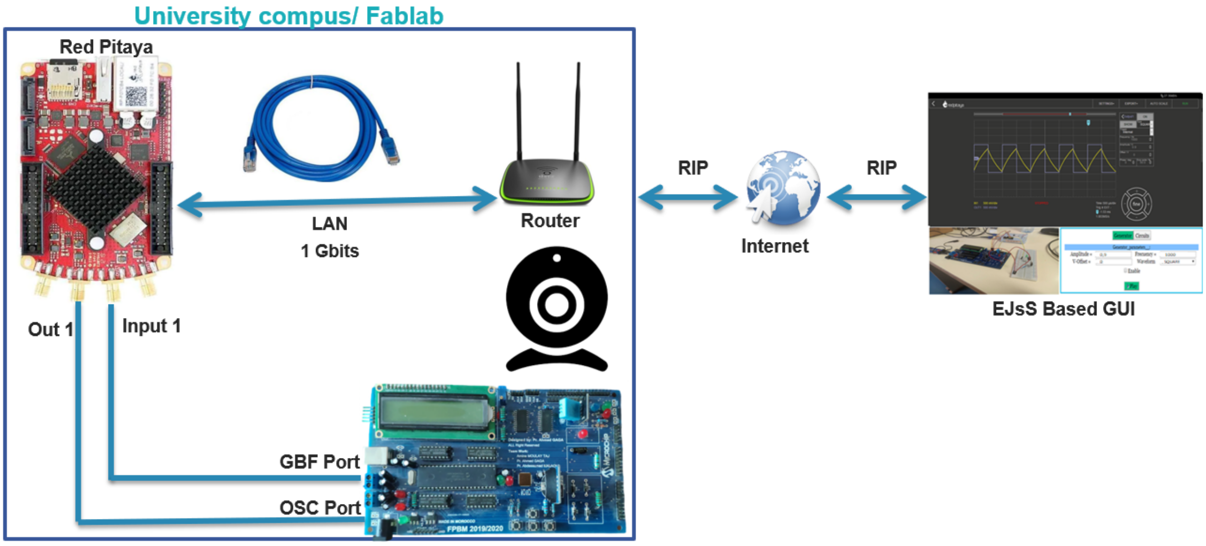


Figure 3.1 — A general architecture of the remote IoT system for practical works

The Red Pitaya is an open-source project designed to replace many expensive measurement tools and control instruments in laboratories [120]. The Red Pitaya has its own GUI that simulates a generator, oscilloscope, and many other devices that are essential during the educational process of performing electronics PWs. The hardware components of the Red Pitaya card are presented in Figure 3.2.

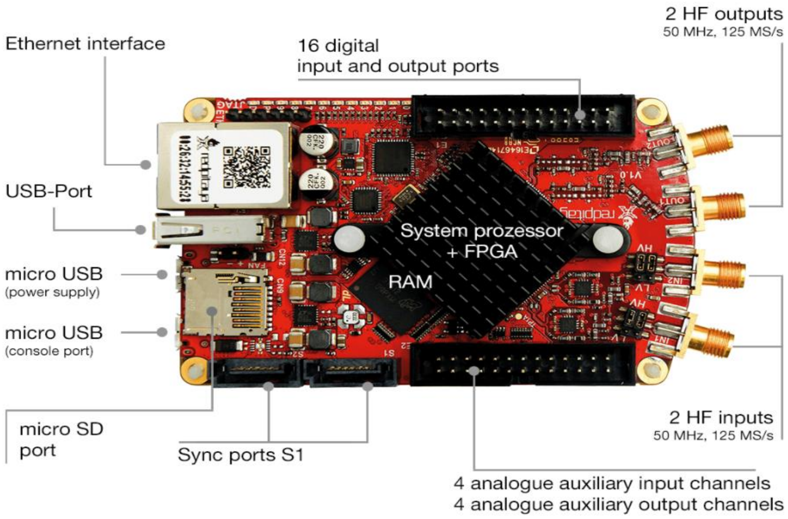


Figure 3.2 — The components of the Red Pitaya card

It is part of the open-source hardware family that uses readily available components and materials, standard processes, open and unrestricted infrastructure to maximize the content and quality of information as well as people's ability to build and use computer equipment. The proposed architecture in this contribution is based on the Red Pitaya board mainly because it can be controlled remotely via a LAN or wireless interface using Matlab, LabVIEW, Scilab, or Python. The developed board has been designed to complement the Red Pitaya by implementing several PWs manipulations in a small board and allowing the selections between the different integrated PWs as well as other manipulations carried out externally as extensions realized according to the teacher's needs. Figure 3.3 presents a simulation of the board designed to be a complement for the Red Pitaya in the remote laboratory architecture.

Figure 3.3 — A simulation of the developed board

The developed board address mainly the wiring of electronic circuits which is one of the main problems of this kind of laboratories practices that consumes considerable time and effort. The students have access to a web interface that allows them to select a practical work, which presents an interactive electronic diagram and a description of the practical work and the tasks required to complete the practical work.

3.2.3 Description of the IoT system

This section focuses on the description of the developed board and the added value it brings compared to the traditional method of performing PWs manipulations. A detailed description of the integrated components, as well as the design adopted, is presented.

During the first two years in electronics PWs activities, students generally need time to become familiar with the equipment and overcome the fears of manipulating buttons, spinning wheels, and connecting cables. Unfortunately, the time dedicated to these activities is usually short, because every week there are new practices and it is always necessary to have assimilated the above. Besides, the labs are often busy with classes and many students need extra time outside of class hours to do the practices. In this scenario, a remote lab can help manage and resolve the tensions inherent in practicing remotely [121]. In fact, when designing a practical remote work in electronics according to a client-server architecture. The standard way is to translate the electronic schematic of the work on a breadboard in which all the components containing the electronic schematic are placed and connected with wires as shown in Figure 3.4. At this stage, two problems related to size and configuration are posed.

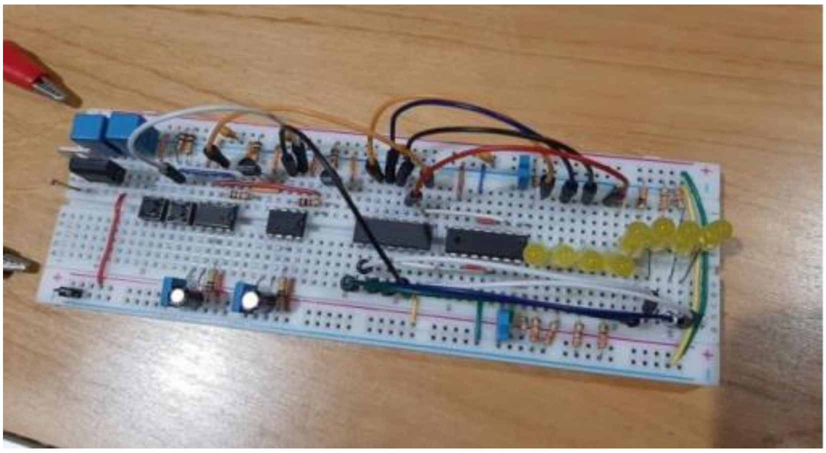


Figure 3.4 — Example of an electronic practical work on the breadboard

Allowing the students to configure and change the values of the components, the inputs of the signal generated by a generator, and the outputs displayed on the oscilloscope. The tutor must set different values for each component and use a large number of links that will be controlled by the student interface to configure the electronic schematic to work with the defined values of the components to allow students to deduce the impact of these changes on the output signal of the oscilloscope. For example, in the case of studying the transient response of the RC circuit, the value of the resistor and capacitor in the circuit should be multiple, for the resistor a series of values such as (10 ohms, 20 ohms, 50 ohms….). The teacher's effort in preparing the practical design of the work is not insignificant in this situation. We propose as a solution an electronic board that gathers six practical tasks in a single small plate with fluidity in the way of controlling the electronic parameters and inputs/outputs of each manipulation. This solution allows for setting up a remote-controlled laboratory in analog electronics without the use of the relay and allows students to perform PWs remotely.

The integrated manipulations are the:

- ✦ Transient response of RC circuit
- ✦ Transient response of RL ciruit
- ✦ Voltage division

- Single-ended rectifier
- Inverting amplifier
- Full-wave rectifier

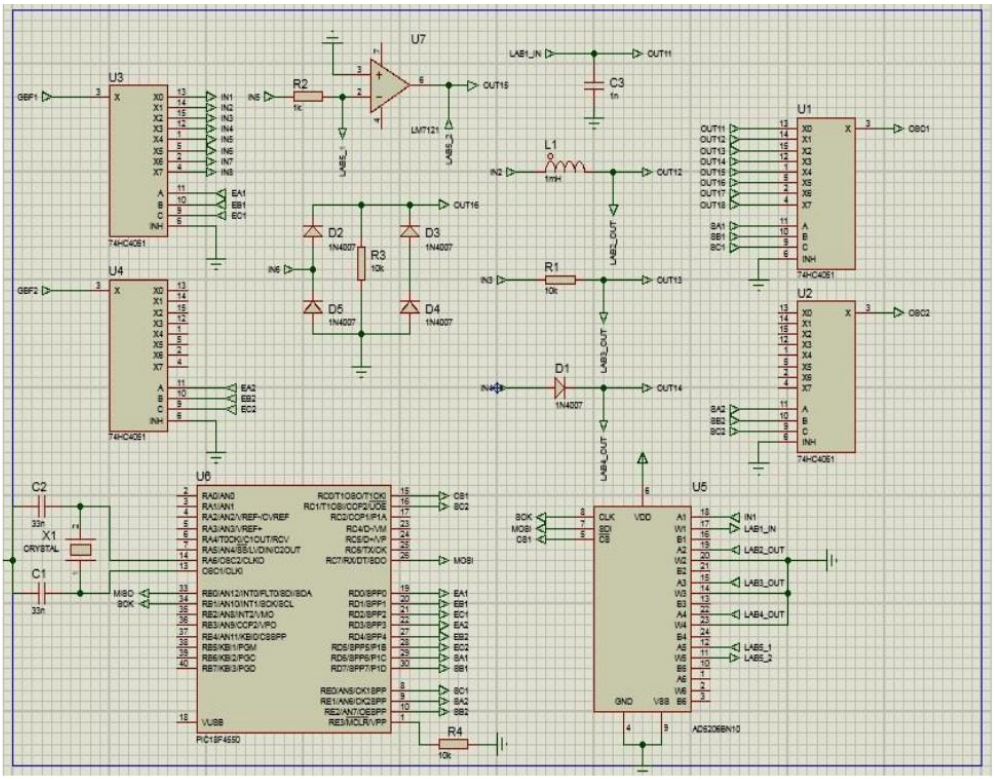


Figure 3.5 — Electronic schematic of the proposed board

An analog multiplexing technique to route input/output signals to and from the selected manipulations has been integrated. It supports two inputs and outputs signals, increasing the number of possibilities offered by the system.

The selection is made by a control system which is a kind of microcontroller responsible for two main tasks:

- The selection of the desired manipulation among the six integrated manipulations and for N possibilities created by the teacher outside the board.
- The control of the values of the passive elements is used via the SPI (Serial Peripheral Interface) protocol.
- The proposed board integrates two digital potentiometers that are controlled via the SPI protocol to control the resistance value continuously, the first one is connected to the six integrated manipulations, and the second one is dedicated to modifying the resistance value in the extensions created by the teacher outside the board.

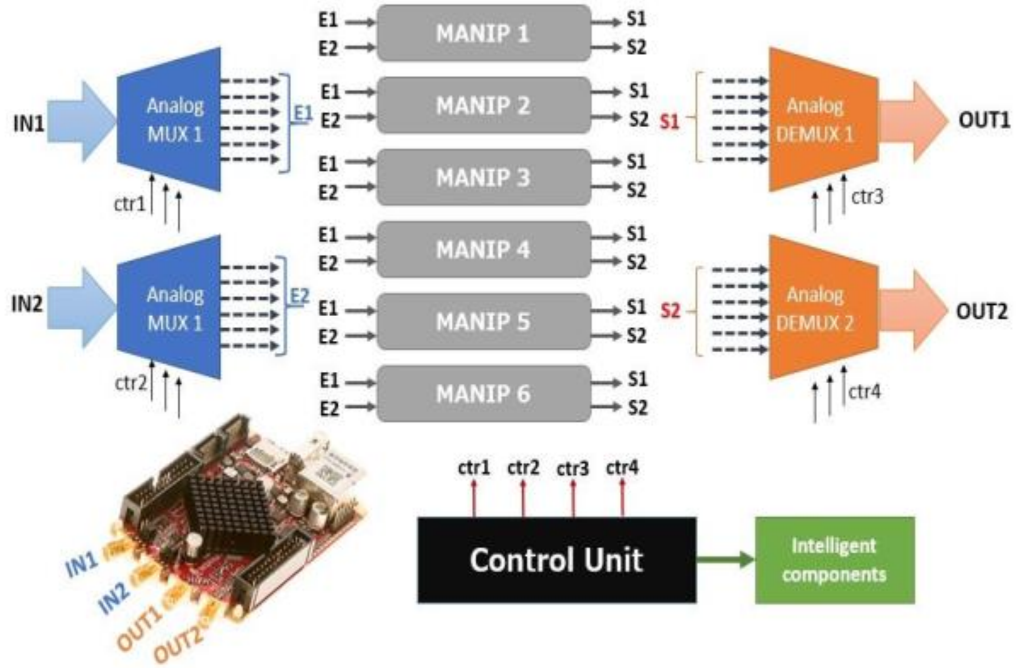


Figure 3.6 — Synopsis illustrating the multiplexing technique adopted on the board

The Red Pitaya card is used in the proposed architecture as a mini-computer that can be remotely controlled via a GUI. Students can control the input signal, then this signal passes through an analog multiplexer which is in charge of its distribution in all integrated manipulations. Next, students can choose the desired manipulation and change the values of the parameters of each circuit, then visualize the output signal in the same interface. Figure 3.7 shows the realized board that implements electronic PWs.

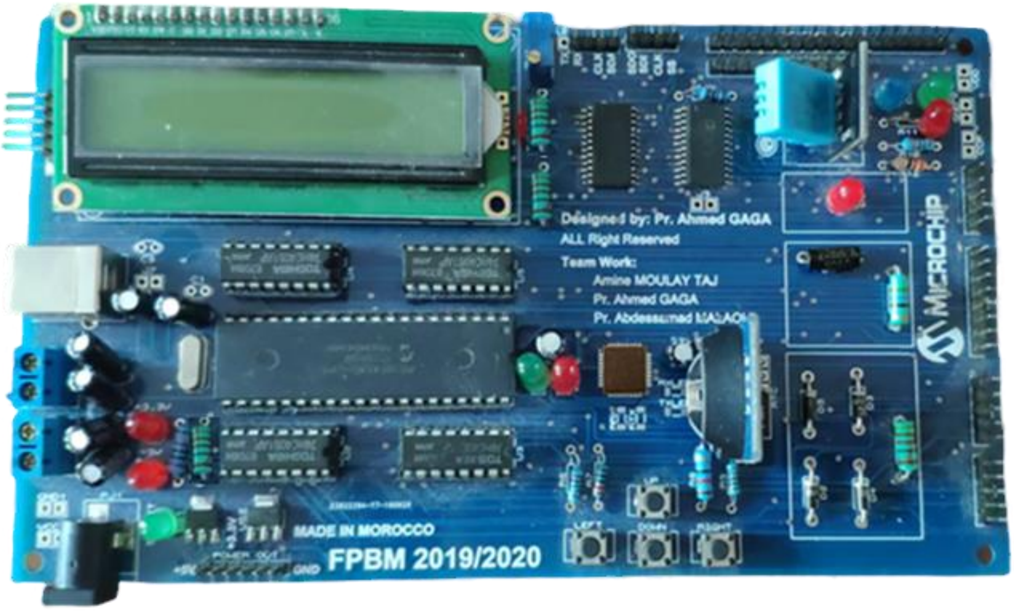


Figure 3.7 — The real developed board

The overriding importance of creating remote labs focused on creating an easy and flexible environment as possible for students at all times. The technique described in this article aims to reduce financial and human resources as well as improve the capacity for self-directed e-learning in the field of electronics.

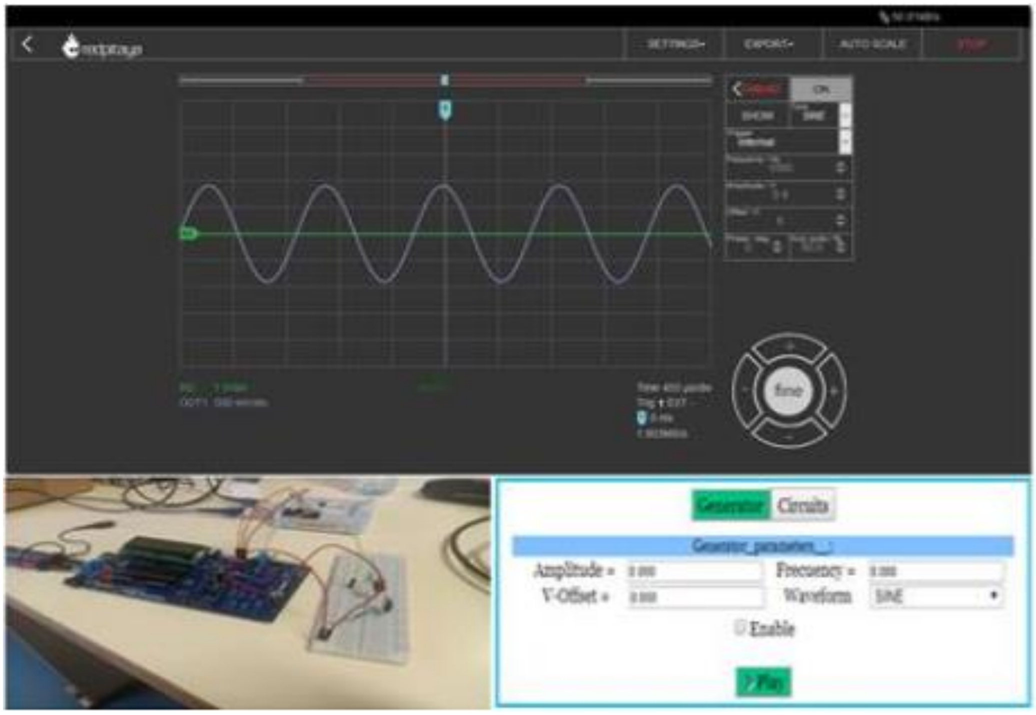


Figure 3.8 — The control interface of the IoT based remote lab

The generator and the oscilloscope are quite sophisticated and expensive in measuring devices are indispensable tools when performing electronics PWs [122]. The IoT system developed in this contribution is based on the Red Pitaya card which is an open-source project designed to replace many expensive laboratory measurement and control instruments, namely Generator and Oscilloscope. An interface web was developed for configuring the generator inside the Red Pitaya card also to see the circuit response on the oscilloscope on the same interface, EJsS (Easy JavaScript Simulation), which is a free authoring tool written in Java that allows the creation of interactive simulations in Java or Javascript, mainly for teaching and learning purposes, has been used to develop our interface [123].

The communication between the Red Pitaya card and the developed interface is based on the RIP protocol, which was designed at UNED for the remote operation of online laboratories [87]. It enables the use of Arduino, MATLAB, Red Pitaya (and many more) programs through the Internet as web services. The RIP protocol is used by the RIP client and RIP server to communicate both. The RIP server is implemented in the Red Pitaya, and the RIP client is implemented in the EJsS interface.

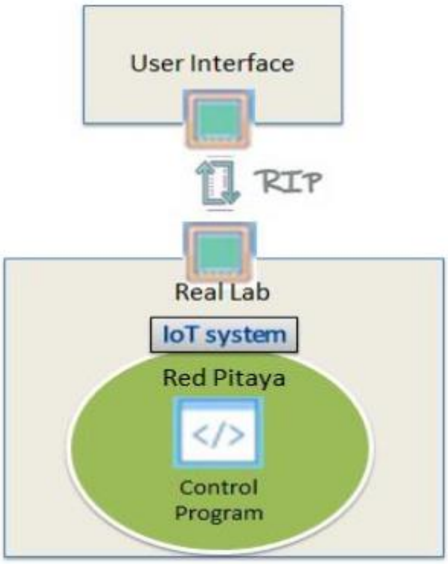


Figure 3.9 — Illustration of the communication between the GUI and the IoT system

The RIP Python server with a control program was implemented on the Red Pitaya card, the control program in charge of controlling the Red Pitaya generator.

3.3 Remote lab of electronics based on Arduino and Raspberry

3.3.1 Contribution purpose

Smart educational systems have been a success through the explosion of several kinds of technology in wireless sensors networks and networked control systems. A remote-controlled laboratory often uses very expensive propriety instruments and software. The purpose of this contribution is to present an operational low-cost architecture of remote experimentation in analog electronics, based on the cooperation of two embedded systems, Raspberry and Arduino. The students can access the PW via a web page developed with HTML/Javascript provided by the NodeJs server hosted in Raspberry. As the oscilloscope is one of the most important instruments when performing electronic PW. This work presents a software oscilloscope that has been developed with processing to be integrable in the GUI of remote command of the PW to visualize the measured signals from the practical work board.

3.3.2 Architecture of the remote lab

This section presents the general architecture based on the cooperation of Raspberry and Arduino to provide remote experimentations on analog electronics. The Raspberry plays the role of a low-cost server connected via Wifi. This last it is connected to the Arduino USB COM port, to ensure cooperation in the processing of the data generated as shown in Figure 3.10.

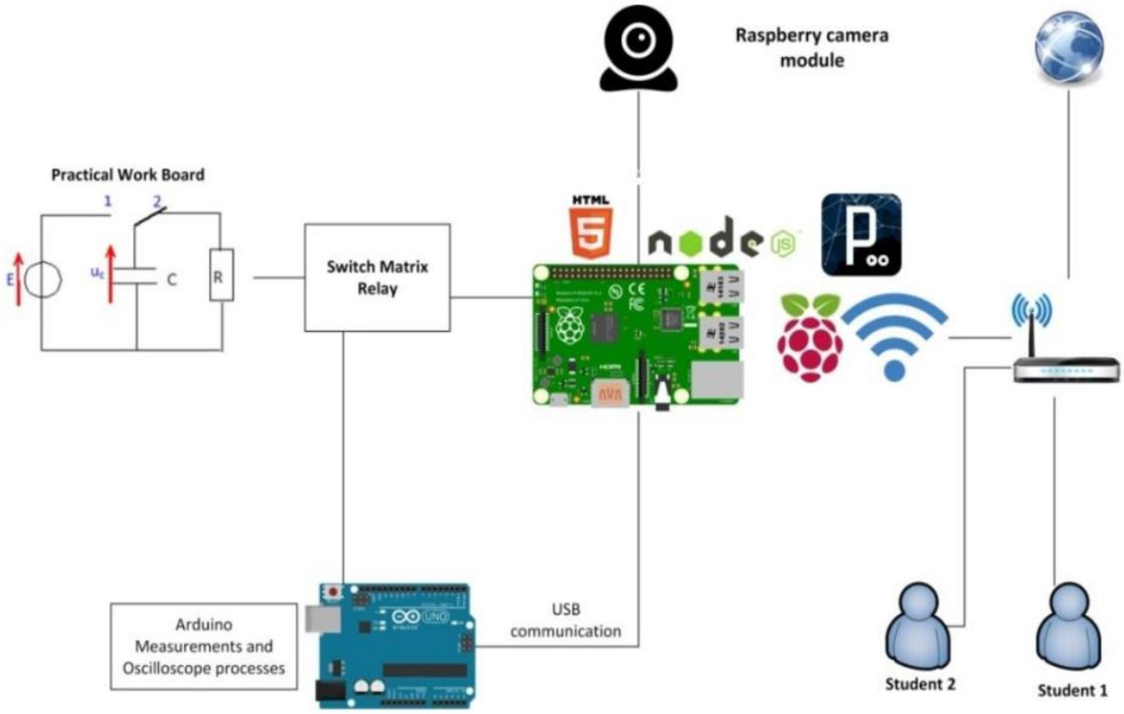


Figure 3.10 — General architecture of the remote lab

The generation of signals and the measurement of voltage are done with Arduino. The user can change the frequencies generated with the PWM via a web interface. The analog-to-digital converter (ADC) measures the voltages coming from the PW board, and then the data is sent via the USB port to the Raspberry for display in the oscilloscope. This proposition is based on a Raspberry Pi Which is used to control the PW card with the digital ports. Thanks to these different connection methods RJ45, Wifi, and Bluetooth, it plays the role of a low-cost server that provides a web page programmed with sockets technology NodeJs [124]. Moreover, we install an Arduino Uno that's plays two essential roles, acquiring data via its ADC and processing this data to send them to the oscilloscope software. Relay plays the role of a switch-matrix that connects the three parts of this architecture the Raspberry, Arduino, and PW card.

3.3.3 Description of the remote lab

The practical work module is designed to provide the student with several possibilities of combinations. The present example is a PW of charge/discharging of a capacitor. Figure 3.11 shows the different combinations of resistors (R) and capacitors (C). On the other hand, the software part of the architecture consists of two parts: Client-Server. The client part has been created with HTML and JavaScript to facilitate access to the users by any navigator also so that the solution is light for connections of low bandwidth. While the server-side is based on NodeJs language. This technology ensures the asynchronous aspect when handling in real-time.

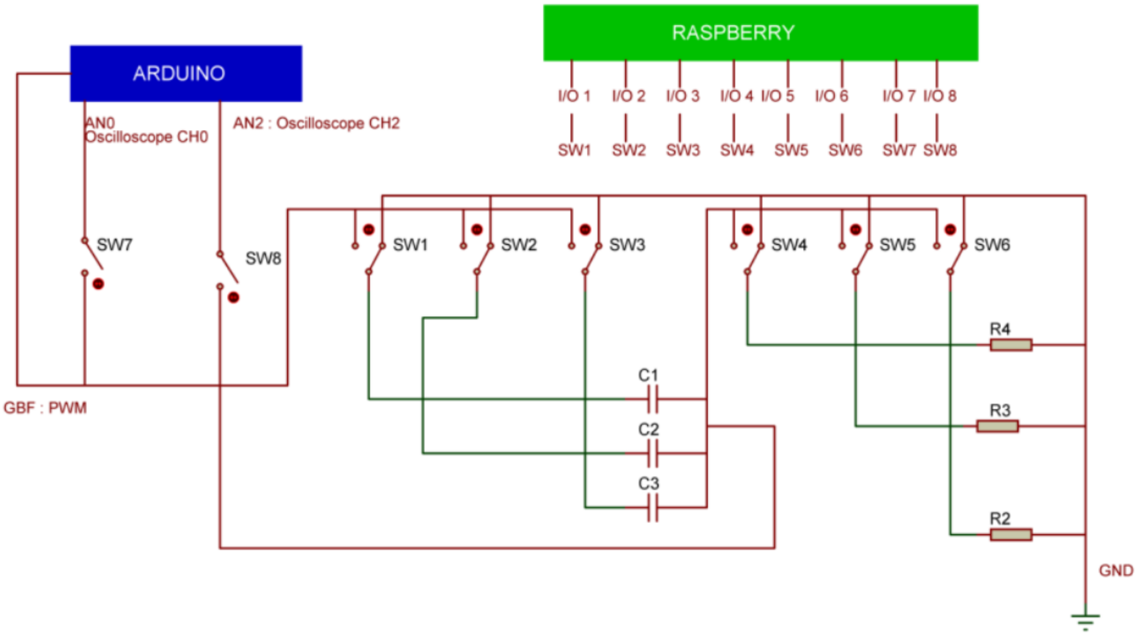


Figure 3.11 — Web practical work connection

Instead of using a very expensive physical oscilloscope, we have developed an open-source oscilloscope with Javaprocessing which provides several advantages (visualization of four signals at a time, modification of the frequency of the signal generated by Arduino, etc) as shown in Figure 3.12. Part of the application is hosted in the Raspberry to view the signals and another part is developed with Arduino that allows acquisition, processing, and sending data to the Raspberry via the COM port. Figure 3.11 shows the electronic diagram of our practical work. The relays are represented by switches (SW) which are controlled by the Raspberry via the outputs from I/O1 to I/O6, where the first 3 relays control 3 capacitors and the other 3 relays control the 3 resistors. This combination allows the student to test 9 combinations of R and C. SW7 allows to visualize the signal generated by the PWM of the Arduino and SW8 gives us the signal of the capacitor charge/discharge.

This page consists of three essential parts:

- An interactive diagram allows the student to change the status of the switches to control the relays and the practical work board. The relays control the possible combinations of R and C and also the oscilloscope channels.
- A dynamic oscilloscope that makes it easier for the student to visualize the charge/ discharge phenomena of a capacitor.
- The webcam gives the possibility to follow in real-time what is happening on the PW board.

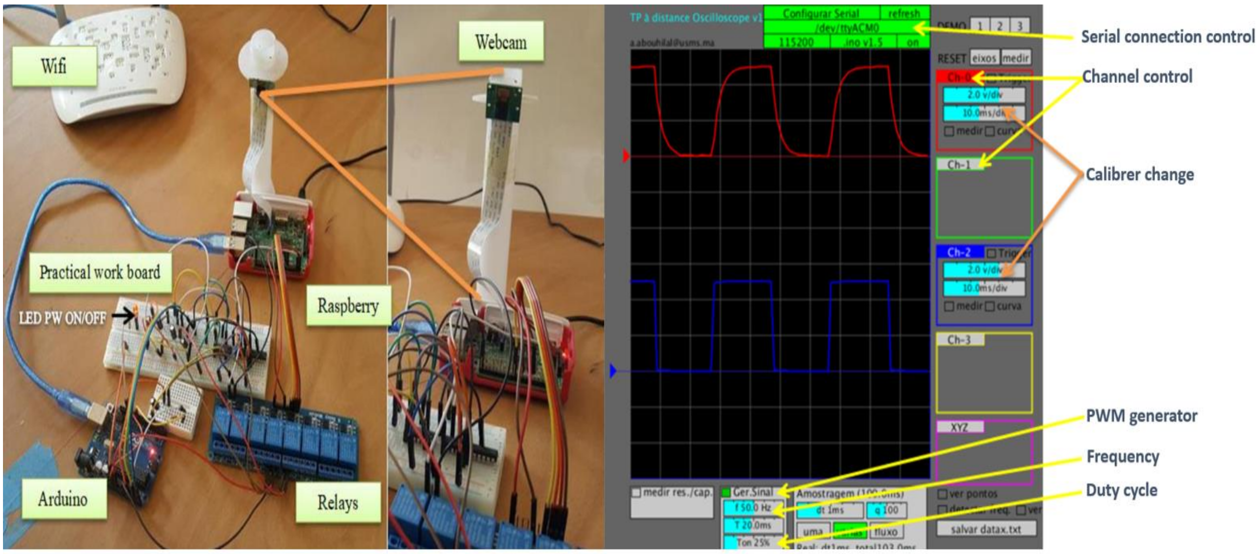


Figure 3.12 — The remote RC PW using the developed system

3.4 DC motor control in three PWs environments

3.4.1 Contribution purpose

The developments in technology and communication networks have enabled the possibility of establishing virtual and remote labs, providing new opportunities for students on campus and at a distance overcoming some of the limitations of hands-on labs. This study aims to validate students' perception of three environments of practical work, namely, hands-on, simulated, and online remote-controlled labs. A DC motor laboratory practice was designed and implemented in the three environments to conduct the comparative study. The following contribution report on the application of a methodology that takes into account the interaction between students and teachers at a different level of abstraction to evaluate the DC motor laboratory practice. The impact of each environment can be analyzed statistically by looking at specific skills or indicators respectively. This chapter describes the three environments of performing the PW. On the hand description of the methodology of evaluation as well as the results are reported in the next chapter.

3.4.2 Description of the PWs environments

This section focuses on the three practical work approaches selected for comparative study to conclude the perceptions of students in each type of environment. The technology adopted in each type of practical work environment, as well as the organization and the steps to follow for the accomplishment of the PW, are described in the following subsections. A DC motors laboratory practice was selected for this study because it is an attractive equipment in many industrial applications requiring variable speed and load characteristics due to its ease of control. Figure 3.13 illustrates a scheme of a controlled DC motor. It is a mechanism generally used to teach the basic concepts of control [125, 126].

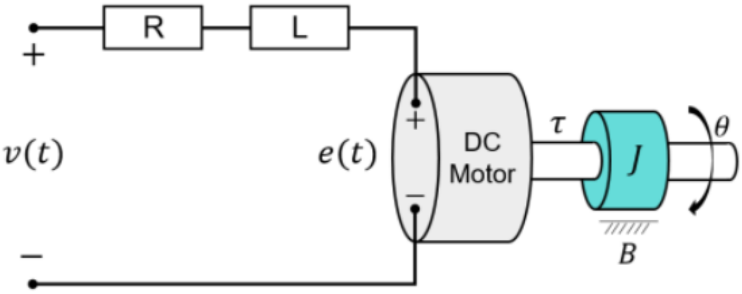


Figure 3.13 — Scheme of a controlled DC motor

A. Real online remote PW

The advent of Internet technologies and new methods of sharing information have enabled the emergence of a variety of e-learning scenarios. The best-known practical pillar of education is the creation of remote-controlled laboratories. In the remote laboratory, the same DC motor laboratory interaction between students and real devices takes place at a distance using an infrastructure based on a client-server architecture as shown in Figure 3.14.

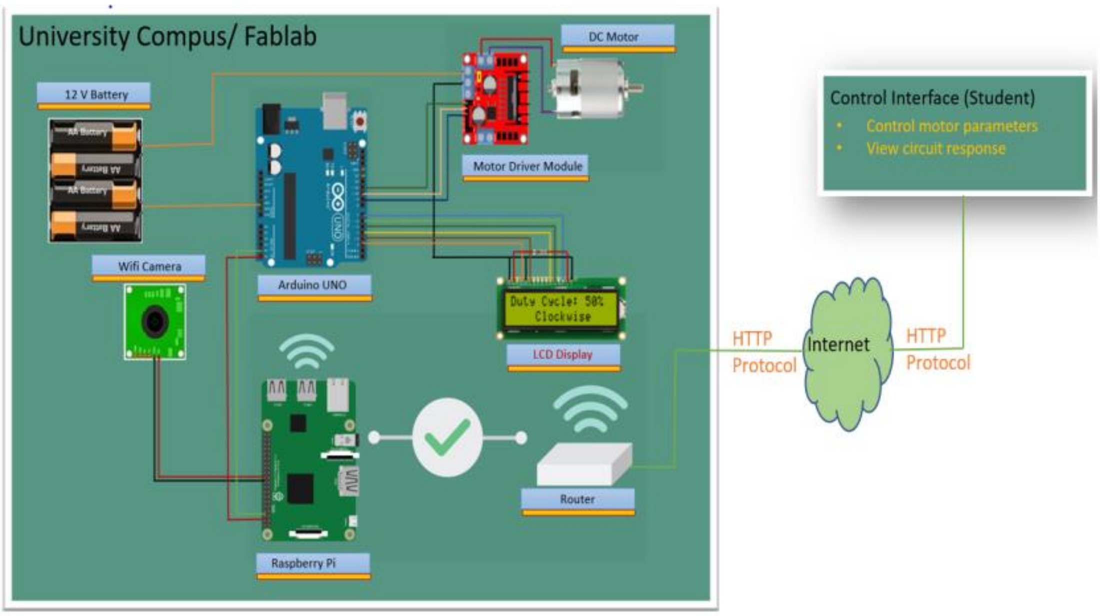


Figure 3.14 — The adapted architecture for the remote control of a DC motor

Information and guidelines for conducting the experiments using the experimental setup are provided to our students through our educational platform for distance learning FpVBm [127]. Usually, the experiment is done by employing online applications, designed with a user interface to replace known laboratory experiences. Since data transmission is the central issue in remote experimentation, the architecture, the protocol, and the format play the three main roles in this communication. The Client-Server architecture is defined by the central element, which provides all the information, data, and services which are offered online.

The purpose of the experience is to control two types of devices remotely:

- An engine has D.C current (Automating of DC engine)
- Command of an alternative power circuit with 220V

For this purpose, a Raspberry Pi running as a web server on the university's campus center and communicates locally with the Arduino microcontroller through the internet, which will allow a student using a computer/smartphone to access the command page deposited on the Raspberry. Students can type the IP address "172.16.223.5" that the authors have predefined in the browser of a Wi-Fi device either in the same network dedicated to the exploitation of practical work or outside the university campus using another network.

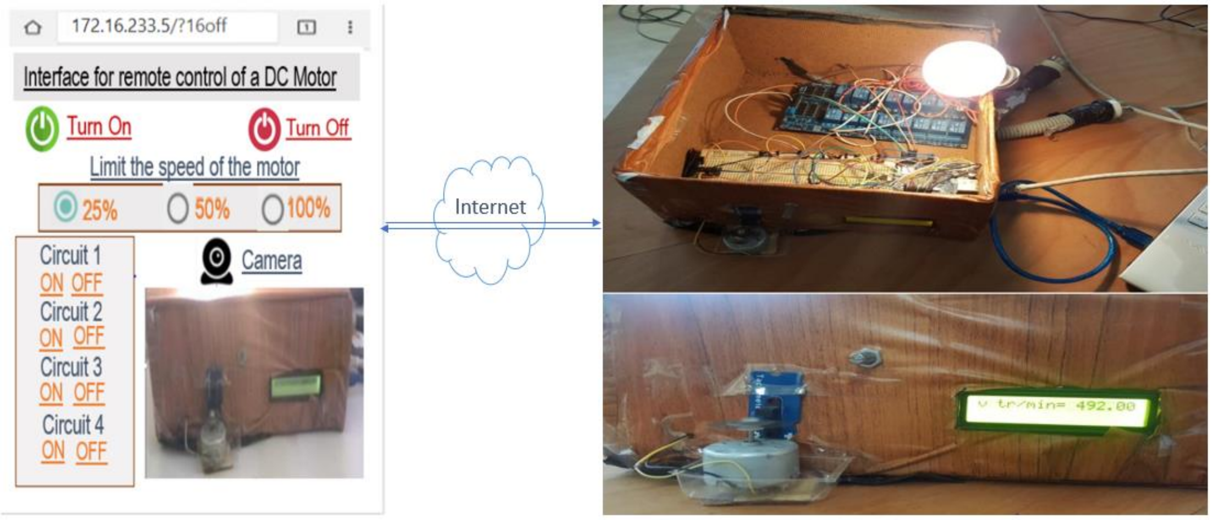


Figure 3.15 — The developed GUI and the real DC motor system

Figure 3.15 shows the GUI and the hardware experiment developed to control the DC motor. The GUI allows students to change and visualize the actual electrical states of the equipment. Through this web page, the student can command the DC motor and change the revolutions per second and the speed at which rotates. This last can command an alternative circuit remotely.

B. Simulated PW

The students perform the same practical work with a simulation tool. The Proteus ISIS software was chosen because it allows simulating the function of the Arduino and Raspberry [128, 129]. This software is mainly known to publish electric diagrams; besides, this last also makes it possible to simulate these diagrams, which makes it possible to detect certain errors at the stage of design. The software is used mainly by electronic design engineers and technicians to create schematics and electronic prints for manufacturing printed circuit boards. Thanks to this software that can be used in the most graphical aspect to control the DC motor experience selected for practical work in this work. In this lab experiment, students are asked to reproduce the same manipulation as explained in the online remote lab, to control a DC motor using Arduino. The students follow the teacher's instructions to perform the required measurements.

The assembly diagram is composed of the following elements:

- An Arduino
- A DC engine
- An integrated circuit to pilot the engine
- Short props pushrods
- Measuring instruments and a map of the relay

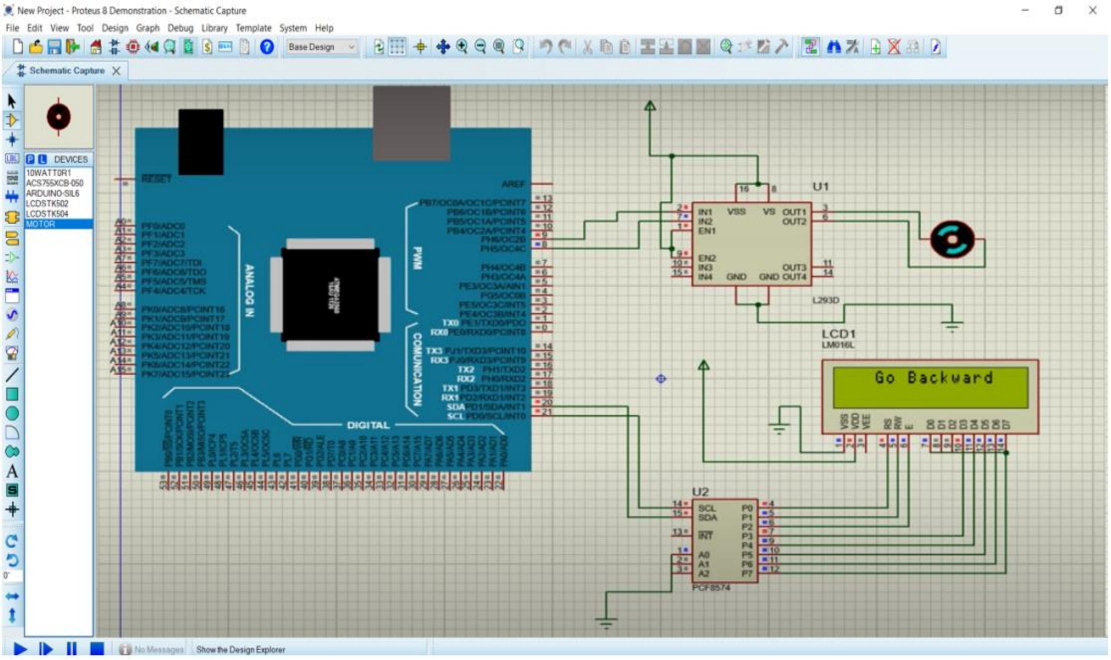


Figure 3.16 — The DC motor control on the Proteus simulator

C. Hands-on PW

In this part, the same students who performed the practical work by the first two methods carried out the same practical manipulations in a laboratory, which contains ten manipulations [130]. A group of 150 students was divided into three sessions, 50 students in each session so that every five students were distributed to manipulate one practical work. A handout with instructions, questions, and procedures for the practical work was distributed to the students beforehand. Each group had to set up the practical work according to the sheet given by the teacher. In the end, the group of students had to make a report by answering the questions related to the requested actions.

Part II: Event-based control labs contributions

Content

3.5 Context of the contribution

The following contribution was carried out within the framework of a research internship at the Department of Computer Science and Automatic Control of the Spanish Open University UNED, in Madrid [50]. The research group inside this Department has been working in the area of VRLs since the 1990s, to meet the nature of engineering teaching required by the UNED, which is an HEI dedicated to distance education. More precisely, the contribution made during this internship is part of the development carried out within the UNILabs (University Network of Interactive laboratories) platform that was created inside the same Department located at the «Higher Technical School of Computer Engineering, Madrid, Spain» [72]. The UNILabs is a network formed by a large number of universities that share their virtual and remote laboratories in form of online laboratories which cover several topics. The majority of the VRLS applications in the UNILabs were built and deployed using similar technologies. In this regard, all the online laboratories share three free and open-source applications: Moodle (the LMS that supports the web content of the open course in which the VRLs are), Easy Java/Javascripts Simulations (for building the VRLS applications), and a middleware software implemented (RIP, NodeJSONRPCElement, LabviewElement, etc) to synchronize the communication between the developed application and the hardware equipment in the case of RL or mathematical model in case of VL.

The following contribution focus on the communication process of building online labs. It proposes a new extension of the RIP protocol that allows more precise and sophisticated management of the communication in control systems. The introduction of recent ICTs in NCSs allows to obtain several advantages and has meant that sensors, actuators, and controllers are connected through a communication network. However, the deployment of a communication network implies new limitations and challenges. Accordingly, novel control strategies have appeared in the literature intending to improve performance by reducing the communication between the different elements of a controlled system. In this regard, the RIP protocol offers a simple and powerful communication tool that defines a standard method to communicate and control an online laboratory based on HTTP methods. Though RIP was originally focused on remote laboratories for control education, it is also suitable for other applications, not only for control engineering but more generally for other IoT environments.

3.6 Specification of the RIP protocol

3.6.1 RIP perspective

The implementation of VRLs is a technical process that necessarily requires the deployment of communication strategies between the different software and hardware tools that constitute the educational system. VRLs are naturally networked controlled systems, which implies that communication management is an important issue in the operational architectures of this type of system. Typically, the software application that interfaces with the mathematical model or hardware system is often separated from the software responsible for giving the student an interactive representation of the data received from the engineering system. The needs to ensure communication between these two elements are usually the same. Namely, handling the connection and user session control, handling the data transmission, handling the interaction with the final user, etc.

This section describes the RIP protocol which refers to a generic protocol conceived at the UNED to interoperate any kind of engineering software and especially to ensure the remote operation of OLs. RIP proposes to encapsulate all the communication issues into an interoperability API that can be implemented in many different systems. It is basically designed to provide a simple and powerful communication mechanism based on standard HTTP protocols handled by the majority of web browsers. One of the most advantages of the RIP protocol is that it can provide a convenient solution for ends users to obtain a set of important information about the input and output variables, as well as the corresponding methods programmed to act on variables defined in each PW experiment in the OL. This type of information allows the end-user to have a close look at the functionality supported and the way to interact with the engineering system presented as a virtual or remote-controlled lab activity.

3.6.2 RIP implementations

The online laboratories set up by universities usually include a combination of virtual and remote laboratories, where each experiment is defined as independent lab activity referenced by a unique «expId » in the platform of OLs. The communication process between the web client and the software implementation in the OL is generally based on the well-known Client-Server architecture. Accordingly, the implementation of communication-based of RIP protocol in this kind of architecture requires the incorporation of the RIP protocol on the client-side (RIP client) and on the server-side (RIP server). More precisely, the RIP client is implemented in a web browser application and the RIP server is implemented by the mathematical model of a virtual lab or the control program in the case of the remote-controlled lab.

Officially, there are two RIP server implementations created within UNEDLabs that are used in the development of different OL prototypes integrated into UNILabs, namely the RIP-LabVIEW-Server and the RIP-Python-Server. The two server implementation has been in production at the Department of Computer Science and Automatic Control for the last decade. As their name suggests, the first implementation is based on LabVIEW and the second is based on the Python programming language. In short, they are a middleware that enhances the LabVIEW and Python applications with the capabilities to be deployed as the remote lab. It enables the use of IoT programs through the Internet as web services. Technically speaking, there are three main functional subsystems in a server implementation based on the RIP protocol. Firstly the Web Server manages the requests received from the web client. It handles differently three types of requests: SSE (server to client data updates), GET(metadata), POST(client-to-server update). The second subsystem is the Command Interpreter that speaks the RIP and finally, the executor that supports the execution control of the simulation model or the control program in the online lab.

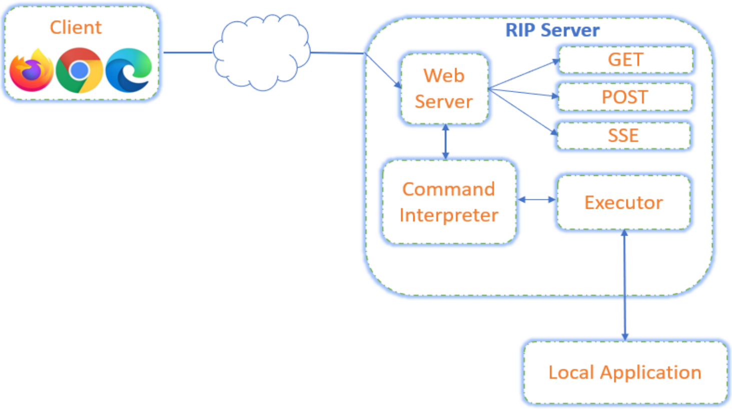


Figure 3.17 — Architectural view of the RIP server implementation

The majority of virtual and remote laboratory implementations created in the UNEDlabs adopt EJsS to develop the web client interface that implements the RIP protocol to communicate and control the experiences defined in the online laboratory. EjsS is an open-source tool developed in Java that assists non-expert programmers in the creation of dynamic simulations. The tool was originally designed to be used for learning purposes and relies on a model-controller-view architecture to ease the design process of the virtual or remote laboratories [123]. The motivation of this approach is to enlighten the creation process to teachers. Detailed descriptions of the RIP protocol are presented in the following research [131].

3.6.3 Incorporation of Server Sent Event

Web browsers are software tools used primarily to access and control RLs that are naturally considered NCSs. The congestion of the communication network is one of the main problems that can negatively affect the performance of this kind of engineering system. Basically, client web applications designed to control RL are basically based on the well-known HTTP protocol to communicate and control the hardware equipment placed generally close to the server-side. Students Access to RL application to control the hardware equipment and make frequent measures of the system variables. However, HTTP is not always the effective protocol to be adapted in several cases. This method work under a polling basis in which each request for new data is always initiated by the client, and it is not equally effective at enabling control strategies, especially if the usage scenarios are intended supports separate experiments or sampling strategies as event-triggering control of self-triggering control [132]. In fact, sometimes students need to receive remote measurements at high frequency, in the order of a millisecond. In this case, the delay in communication between the web client and the real system is not acceptable. In other cases, the transmission of a large request from the client to the server is not acceptable either, due to the congestion of the communication network as well as the client application or the server restriction [133].

The introduction of an asynchronous communication mechanism governed at the server-side is very important to address the communication challenges faced in the development of remote-controlled laboratories. The idea is based on the use of a communication protocol that allows the server to send information regarding defined variables on its own will, without the need of receiving a request from the client first which introduces unnecessary load and delays. The Server-Sent Events (SSEs) technology is the only pure HTTP protocol that allows such type of communication that decreases load and delays between the appearance of new data and its reception by the end-user. Several types of events can be defined according to different sampling strategies and the client can subscribe to one, some, or all events depending on their needs. For instance, a system could send data every time the error is bigger than a certain δ value. The system could send events when it is in a stable state, send data periodically, or when a certain perturbation is detected as explained by Luis de la Torre et al in [134]. The incorporation of Server-Sent Event in RLs provides students in distance learning and blended learning with the ability to work effectively with event-triggered and self-triggered control schemes [135].

3.6.4 Sampling strategies

Let us start with the basics. In a RL we have a set of signals that we want to study. At the very least, we have a scalar continuous signal y(t) that we can sample, or observe, in a discrete set of times $\{\tau_0, \tau_1, \tau_2 \ldots\ldots\}$ to obtain a discrete signal y[n] that coincides with the original signal at the sample times, $y[n] = y(\tau_n)$.

Periodic Sampling: It is common to assume periodic sampling, which means that the τi are equally spaced with a separation of T units of time so that $\tau_i = iT$ and therefore $y[n] = y(nT)$. And, at least until recent times, most digital control applications relied on that assumption.

Event-based Sampling: If we lose the equality-spaced constraint for the sampling times, we are talking about event-based sampling. In fact, many different terms in- including, but not limited to, aperiodic, event-triggered, or self-triggered, appear in literature with slightly different meanings. To be clear, from now on we will use the term event-based sampling to denote any sampling method that is not based on equally spaced times, i.e., the behavior is driven by the value of the signal, rather than the elapsed time. An example of event-based is send-on-delta (SoD) sampling, which is based on taking measures that are equally spaced in the value of the signal, rather than in time. Mathematically, we can characterize SoD as $y[n] = y(\tau_n)$, where $\tau_n = inf\{t \mid t > \tau_i -1 \wedge |y(t) - y(\tau_i - 1)| < \delta\}$.

A bit more general approach is to define an event as triggered by the zero crossing of a function $\zeta(y(t))$. Note that we are considering a simple case to not entangle the presentation. Actually, ζ could be a function of more than one variable or signal, as the integrated absolute error or any other thing we would want to compute.

Periodic Event-based Sampling: Another approach that has proven to be useful is kind of a hybrid of the two worlds, and is usually known as periodic event-based triggering. In this paradigm, the event function still determines whether the event is triggered or not, but it is only evaluated at times that are multiples of some period. A drawback of this approach is that in general there is a delay between the time the conditions of the event actually occur and the time where the event is triggered. However, this error can be minimized if the period is small enough. A good reason to use this approach is that, for practical applications based on digital systems, it is often difficult or even not possible to be purely event-based.

3.7 Extension of the RIP protocol

3.7.1 Contribution purpose

The SSEs technology appeared eventually as a perfect fit for the UNILabs research group to create remote laboratories where the communication is actually based on events rather than on time. RIP specification already considers the possibility of using a generic sampling mechanism and even defines a communication workflow to negotiate with the client. In fact, the RIP-

LabVIEW server implementation already offered periodic and periodic send-on-delta as two possibilities to notify updates of its client [136]. On the other hand, RIP Python server offered traditionally periodic sampling as the only possibility to notify updates to its client. The period between communication was set in the value ''sse-period'' of the global configuration. the two implementation version has been in production in the UNEDLab laboratories over the last decades, and can be downloaded respectively from [137, 138].

The following work focuses specifically on the RIP Python server version and aims to make improvements and new extensions to this implementation. The contribution made during this research are presented in two main steps:

- The first step aims to improve the server functionality by, (1) implementation of the send-on-delta sampling to allow the server to notify SSE updates to the end-users according to this strategy, (2) implementation of user session control that allows the server to handle concurrent user connection, (3) record, recover and resend lost events during unexpected communication interruption. This feature is extremely useful when performing critical operations in event-based control. These objectives have been described in the UNEDLab as some functionalities that need to be incorporated into the RIP-Python version in [139].
- The second step describes an extension of the RIP protocol to cope with generalized sampling (i.e combine different methods of sampling for a set of variables). We created a model of three levels of abstraction model that captures the relevant aspects of the sampling that appear in the online lab, then this work proposes an extension of RIP that supports the proposed abstract model.

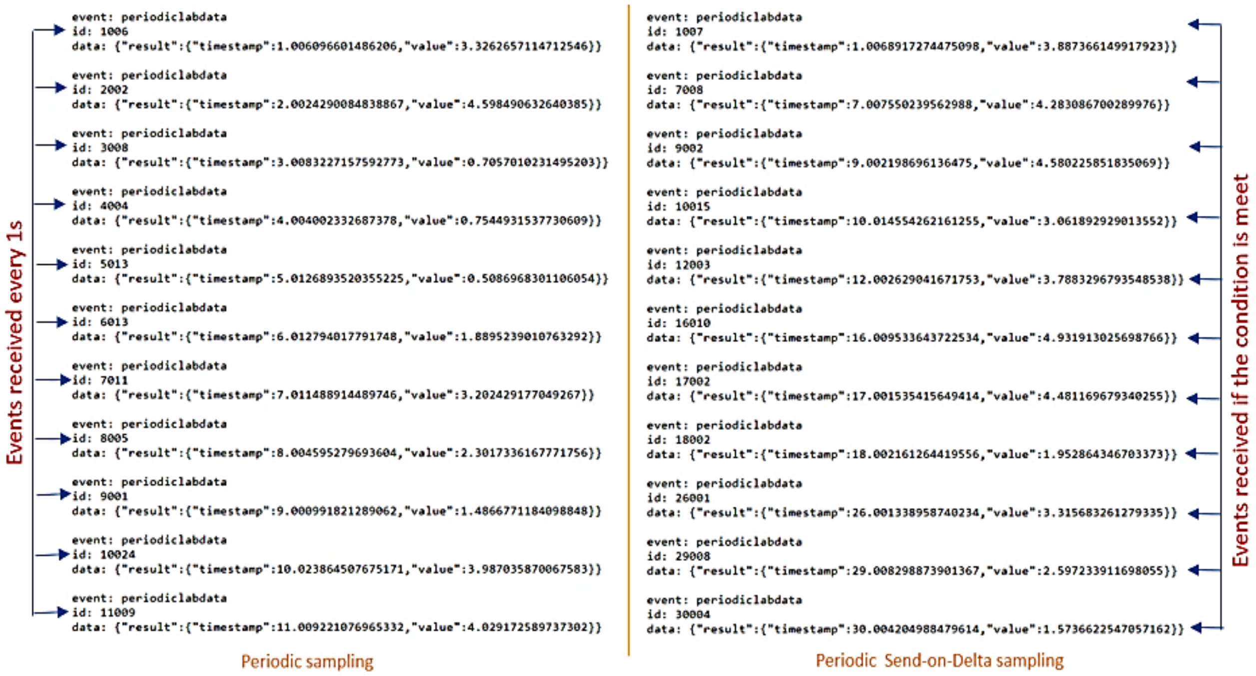
3.7.2 Improvement made to RIP Python server

This section describes the main feature integrated into the RIP-Python server implementation in order to enhance its capabilities. The RIP Python server refers to a middleware that enhances any Python application with the capabilities required to be deployed as a remote laboratory. It enables the use of Arduino, MATLAB, Red Pitaya (and many more) programs through the internet as web services. The new version of the RIP Python server that implements the new functionality is presented in [140].

A. Implementation of SOD sampling

The RIP protocol can include several predefined triggering strategies, these last can be used or ignored, depending on the choices of the client made on a configuration file in the software architecture of the implementation. Traditionally, RIP Python server offered periodic sampling as the only possibility to notify updates to its client. As explained before, send-on-delta is a sampling strategy based on firing events when the defined condition is met by the system variables. The concept is a sampling method depending on the signal sampled, where sampling is triggered if the signal deviates from the delta defined as the significant change in the variable value. In fact each time t milliseconds have passed since the client connected to the server, a program in the server checks the meeting of the conditions to decide whether to trigger the event or not.

The RIP Python server provided in the UNEDLabs portal presents a general architecture of the middleware (i.e the proposed architecture require the modification of certain parameters and function in different part in order to be deployed on a specified system), the send on delta sampling has been developed based on the Python Random package that generates a random value in each period. then a function has been defined with a condition that decides to send the event or not. Figure 3.18 illustrates the event received by the client where the server is configured to send data periodically and periodic SOD sampling.



```
event: periodiclabdata
id: 1006
data: {"result":{"timestamp":1.006096601486206,"value":3.3262657114712546}}

event: periodiclabdata
id: 2002
data: {"result":{"timestamp":2.0024290084838867,"value":4.598490632640385}}

event: periodiclabdata
id: 3008
data: {"result":{"timestamp":3.0083227157592773,"value":0.7057010231495203}}

event: periodiclabdata
id: 4004
data: {"result":{"timestamp":4.004002332687378,"value":0.7544931537730609}}

event: periodiclabdata
id: 5013
data: {"result":{"timestamp":5.0126893520355225,"value":0.5086968301106054}}

event: periodiclabdata
id: 6013
data: {"result":{"timestamp":6.012794017791748,"value":1.8895239010763292}}

event: periodiclabdata
id: 7011
data: {"result":{"timestamp":7.011488914489746,"value":3.202429177049267}}

event: periodiclabdata
id: 8005
data: {"result":{"timestamp":8.004595279693604,"value":2.3017336167771756}}

event: periodiclabdata
id: 9001
data: {"result":{"timestamp":9.000991821289062,"value":1.4866771184098848}}

event: periodiclabdata
id: 10024
data: {"result":{"timestamp":10.023864507675171,"value":3.987035870067583}}

event: periodiclabdata
id: 11009
data: {"result":{"timestamp":11.009221076965332,"value":4.029172589737302}}
```

```
event: periodiclabdata
id: 1007
data: {"result":{"timestamp":1.0068917274475098,"value":3.887366149917923}}

event: periodiclabdata
id: 7008
data: {"result":{"timestamp":7.007550239562988,"value":4.283086700289976}}

event: periodiclabdata
id: 9002
data: {"result":{"timestamp":9.002198696136475,"value":4.580225851835069}}

event: periodiclabdata
id: 10015
data: {"result":{"timestamp":10.01455426216125,"value":3.061892929013552}}

event: periodiclabdata
id: 12003
data: {"result":{"timestamp":12.002629041671753,"value":3.7883296793548538}}

event: periodiclabdata
id: 16010
data: {"result":{"timestamp":16.009533643722534,"value":4.931913025698766}}

event: periodiclabdata
id: 17002
data: {"result":{"timestamp":17.001535415649414,"value":4.481169679340255}}

event: periodiclabdata
id: 18002
data: {"result":{"timestamp":18.002161264419556,"value":1.952864346703373}}

event: periodiclabdata
id: 26001
data: {"result":{"timestamp":26.001338958740234,"value":3.315683261279335}}

event: periodiclabdata
id: 29008
data: {"result":{"timestamp":29.008298873901367,"value":2.597233911698055}}

event: periodiclabdata
id: 30004
data: {"result":{"timestamp":30.004204988479614,"value":1.5736622547057162}}
```

Figure 3.18 — Events stream according to periodic samling and SOD

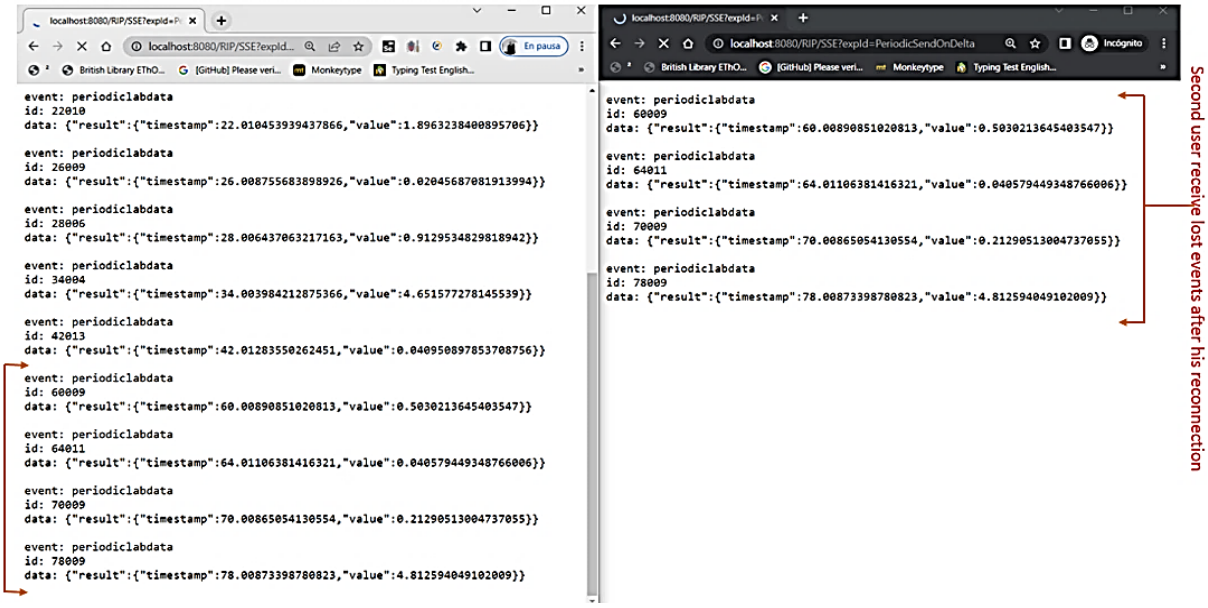
B.   User session control

A client/server session is a series of linked communications between a single client and a server that take place over a period of time. With an established session, the server can identify the client associated with each request and has the ability to remember, over many requests, a specific client. Without an established session, the communication between a client and a server can be renegotiated for each subsequent request. Session state information improves performance by eliminating the repeated closing and reopening of client/server sessions. This means that Web servers can be made very efficient and can serve large amounts of traffic very quickly.

The new architecture of the RIP Python server integrates a strategy to control the user session. It allows to provide and store an identifier for each new user. This parameter is very important to detect and collect a set of useful information when performing remote laboratory. For example, the time of connection, disconnection, reconnection, as well as the number of events received during the user's connection, etc. An overview of the user ID stored in the new architecture can be found at the following link.

C. Handling lost events

Dealing with disconnection issues while performing a remote laboratory is an important focus for developers and researchers. The disconnection can occur either because of the Internet connexion quality or due to technical problems with the electronic material used by the end-user in the majority of cases. Since the duration of the practical activities is often predefined for a well-determined period by the responsible teacher, which means that this kind of technical problem negatively affects the commitment of the students and the progress of the practical work sessions at a distance. This functionality address the challenge of the disconnection issue by detecting the disconnection time of each user, then generating the lost events saved during the disconnection time once the user manages to reconnect.



```
event: periodiclabdata
id: 22010
data: {"result":{"timestamp":22.010453939437866,"value":1.8963238400895706}}

event: periodiclabdata
id: 26009
data: {"result":{"timestamp":26.008755683898926,"value":0.020456870819139941}}

event: periodiclabdata
id: 28006
data: {"result":{"timestamp":28.006437063217163,"value":0.9129534829818942}}

event: periodiclabdata
id: 34004
data: {"result":{"timestamp":34.003984212875366,"value":4.651577278145539}}

event: periodiclabdata
id: 42013
data: {"result":{"timestamp":42.01283550262451,"value":0.040950897853708756}}

event: periodiclabdata
id: 60009
data: {"result":{"timestamp":60.00890851020813,"value":0.5030213645403547}}

event: periodiclabdata
id: 64011
data: {"result":{"timestamp":64.01106381416321,"value":0.040579449348766006}}

event: periodiclabdata
id: 70009
data: {"result":{"timestamp":70.00865054130554,"value":0.21290513004737055}}

event: periodiclabdata
id: 78009
data: {"result":{"timestamp":78.00873398780823,"value":4.812594049102009}}
```

```
event: periodiclabdata
id: 60009
data: {"result":{"timestamp":60.00890851020813,"value":0.5030213645403547}}

event: periodiclabdata
id: 64011
data: {"result":{"timestamp":64.01106381416321,"value":0.040579449348766006}}

event: periodiclabdata
id: 70009
data: {"result":{"timestamp":70.00865054130554,"value":0.21290513004737055}}

event: periodiclabdata
id: 78009
data: {"result":{"timestamp":78.00873398780823,"value":4.812594049102009}}
```

Figure 3.19 — Management of lost events

The event-based communication supported by SSE on the RIP- Python server allows the end-user to automatically reconnect when the communication has dropped and receive all data lost from the last received package or event as shown in Figure 3.19. This feature, in combination with automatic reconnection, is extremely useful when performing critical operations in event-based control.

3.7.3 Generalized sampling

As of version 0.361, RIP provides metadata of the laboratory server, which is very useful for the web clients to know the server capabilities and how to communicate with the server. According to RIP specification, the server metadata sends a list of readable with extended info about each variable: description, range, precision, etc. This information is useful for the client, for example, to validate user input or to build graphical user interfaces (GUI) automatically.

A web client can request information about the sampling methods by sending an HTTP POST, as defined by RIP, to *http://{Server IP/RIP/POST/* with a JSON payload that follows JSONRPC 2.0 standard. The server will send back with the following fields:

- ***Level***: An integer value 1, 2, or 3 that corresponds to the implementation level supported by the server.
- ***Methods***: A dictionary of predefined methods supported by the server, where the key is the unique identification of each method, and the value is another dictionary that contains the event id that is associated with the method, and the parameters that the method should require, such as the period for the periodic sampling.
- ***Languages***: A list of programming languages that the client is allowed to use to define the event function.

The metadata associated with each readable will contain an extra field named sampling indicating the sampling method associated with that variable and the parameters defined by the method. For instance, the following structure is acceptable:

```
{
   ‘name’: ‘y’,
   ‘description’: ’Output__variable’,
   ‘type’: ‘number’,
   ‘min’: ‘number’,
   ‘max’: ‘0’,
   ‘precision’: ‘0’,
   ‘sampling’: {
     ‘method’: ’delta’,
     ‘params’: { ‘delta’: 0.2}
   }
}
```

In general, the approach of RIP is to notify the web clients of the value of the outputs (readable, in RIP terminology) with events that are triggered by the server (or SSE). The information carried by these events is not only the values that are triggered by the server but also the event id that is sent with each communication and that is associated with the cause that triggered the event. The official implementation (LabVIEW and Python) implicitly assumed that the readables are sampled periodically with a unique and common sampling period. Therefore, each notification is tagget with ***periodiclabdata.***

The definition of a sampling scheme is structured in three levels, according to the simplicity of configuration vs. Flexibility.

A. Level 1: Periodic Sampling

This is the most basic configuration, however, it can cover a lot of use cases. The main benefit is its simplicity of configuration but could be inadequate for systems with more sophisticated communications. The RIP server generates periodically an event of type periodiclabdata that notifies the values of all the readables defined in the configuration of the experience. The only configuration option in this first level is the sampling time, which is defined globally for all the readables in the activity.

A level 1 server will provide the following metadata describing the sampling capabilities:

```
{
    ‘Level’: 1,
    ‘methods’: {
      ‘periodic’: {
        ‘event_id’: ‘periodiclabdata’,
        ‘period’: {‘description’:……….,}
      }
    },
}
```

B. Level 2: Expert-defined Sampling

This is a bit more flexible than the previous one. In this level, the sampling can be individually set for each readable. A level 2 RIP server provides a means to define, for each variable the triggering function that determines when to take a new sample. Note that this must be done locally by the expert (i.e. the person that is in charge of the configuration of the lab), for example through configuration files. Optionally, the server can provide a set of predefined methods that are ready to use and can be selected only by indicating the name of the method and any parameters that might be required.

In any case, each readable must declare the sampling method that it uses. The main benefit is that is much more flexible and only a bit more complex to configure.

```
{
    ‘Level’: 2,
    ‘methods’: {
      ‘periodic’: {
        ‘event_id’: ‘periodiclabdata’,
        ‘period’: {‘description’:……….,}
      },
      ‘send-on-delta’: {
        ‘event_id’: ‘delta’,
        ‘delta’: {‘description’: ‘……’, }
      }
    }
```

C. Level 3: User-defined Sampling

This is for the most demanding users. The server gives complete freedom to define what, where, and how must be notified. The main advantage is also the main drawback: with great power comes great responsibility. In addition to the functionality of level 2, the client provides a function that decides when to take a new sample in the negotiation phase, when the connection is established. Though in the server implementation the obvious way to define the event function is using the same programming language, and in level 2 it is reasonable too, in level 3 we must enforce compatibility between different implementations. For that reason, we choose Javascript as lingua franca, so that every level 3-enabled server must be able to accept and run the code provided in this language. Besides, the server optionally can accept any other programming language, in that case, it will inform the clients according to the protocol.

A typical example of metadata reported by a level 3 server is the following structure:

```
 {
     ‘Level’: 3,
     ‘methods’: {
        ‘periodic’: {
           ‘event_id’: ‘periodiclabdata’,
           ‘params’: {
             ‘period’: {‘description’:………,}
          }
       },
        ‘send-on-delta’: {
          ‘event_id’: ’delta’,
          ‘params’: {
          ‘delta’: {‘description’: ’……’,}
       }
     },
     ‘languages’: [‘Javascript’,’ Python’]
}
```

The function, that will be invoked by the server in a sandbox to check the event condition, must have the following arguments:

- Input: An object that contains a timestamp and the values of all the variable(s) that the server declares the RIPmetadata.
- Parameters: The parameters associated to the sampling method (for example, **delta** or **period**).
- State: This is a state that the server stores between successive invocations, but the information that is stored in it is completely managed by the triggering function.

Table1: Comparison of sampling methods

Level	Configuration	Responsible	Flexibility
1	Implicit	Server	low
2	Explicit	Server	medium
3	function	User	high

To illustrate with an example, a user could define the send-on-delta sampling in the following steps (interested readers can see the details in the RIP spec):

```
{
   ‘sampling’: {
     ‘name’: ‘user-send-on-delta’,
     ‘langauge’: ‘Javascript’,
     ‘code’:…………
   }
}
```

where the field code contains the event triggering function.

```
function trigger (input, parameters, state) {
  if (! State.y_prev != ) {
    let level = Math.floor(input.y / parameters.delt)
      return {
        ‘triggered’: true,
        ‘output’:  ,
        ‘state’: {
          ‘y’: parameter.delta
        }
      }
  }
  State.y_prev = ,
  return {
    ‘triggered’: true,
    ‘output’:  ,
    ‘state’:  modified_state
}
```

Part III: Blended learning contributions

Content

3.8 Hybrid educational system based on BigBlueButton

3.8.1 Contribution purpose

The ongoing changes in the educational system, especially in open access universities are forcing the teachers to consider and test the validity of other possible teaching scenarios according to well-designed studies. This work aims to evaluate the effectiveness of a distance learning system that provides theoretical and practical teaching, following a methodology that considers indicators at different levels of abstraction. The low-cost developed system consists of three subsystems that complement each other to provide remote training on solar energy. The first subsystem is a virtual classroom based on the open-source BigBlueButton videoconference system, while the second and third subsystems are respectively, a MATLAB graphical user interface that describes the behavior of solar panels under various climatic conditions, and a remote IoT-based system allowing students to measure the value of current and voltage needed for the operation of the graphical user interface. This chapter presents a detailed description of the subsystems involved in the operational architecture of the hybrid system. On the other hand. The next chapter presents the evaluation methodology followed as well as the result of several indicators that prove its effectiveness as an alternative to improve students' skills in the solar panel concepts.

3.8.2 Architecture of the proposed system

Providing an answer to the problem of overcrowding in open access universities, especially in technical sections, leads us to consider other possible educational scenarios [141]. The following section provides a detailed description of the organization of the proposed system, the technologies used for its development as well as the way the three subsystems complement each other to provide a distance learning system allowing theoretical and practical work on solar energy concepts. The adopted system is based on a client-server architecture that relies on a central station (Server) hosting the open-source web conferencing system called BigBlueButton, The minimum requirements for installing the latest release BigBlueButton are presented in [142]. This latter is acting as a focal point in our architecture presented in Figure 3.20.

Learning about the operation of photovoltaic devices requires that students to have a solid knowledge of mathematics and electronics, and to learn and interpret a variety of interrelated diagrams which are crucial to the analysis of solar system performance. Therefore, the proposed architecture integrates three subsystems that interact and complement each other to offer a distance learning experience combining theoretical teaching through a video conferencing system and practical works by a simulation prototype and a remote measurement that are presented together to students of technical universities.

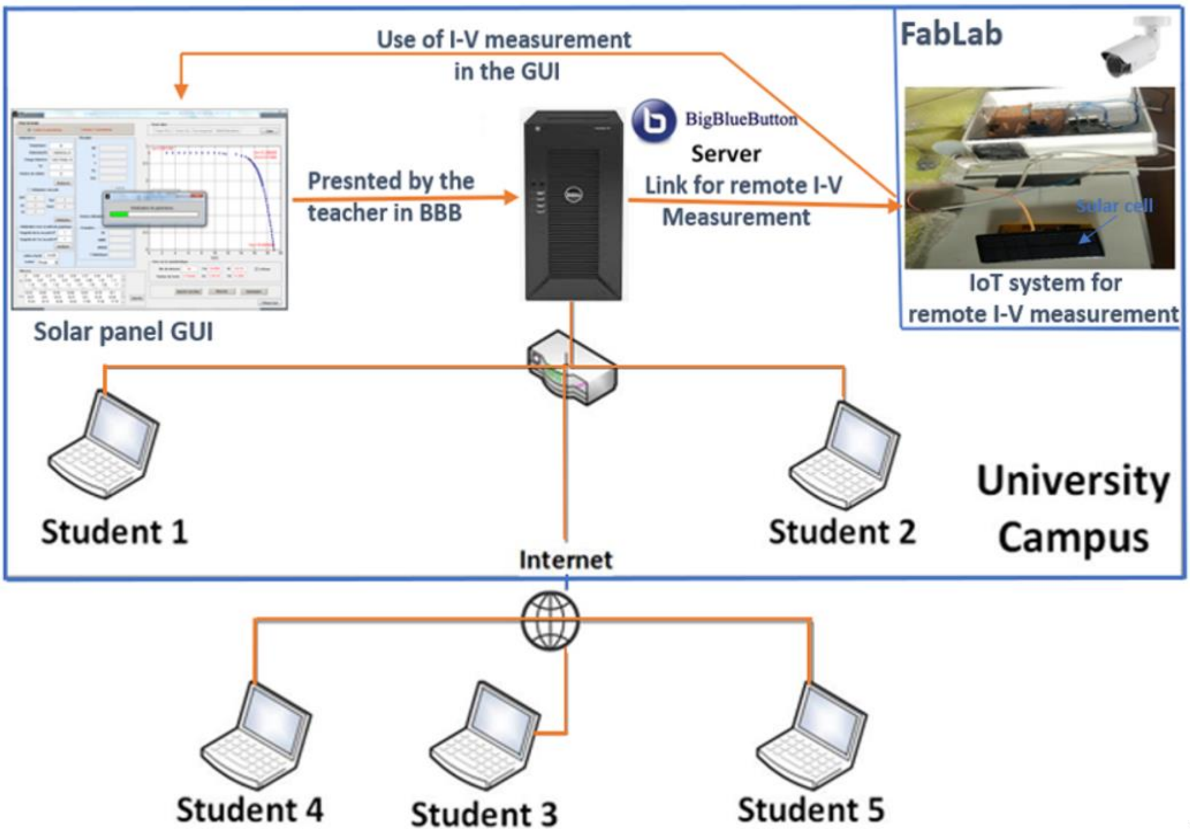


Figure 3.20 — The architecture of the low-cost remote educational system

The first and central subsystem of the architecture shown in Figure 3.20 is the BigBlueButton videoconferencing system that aims to enable teachers to engage remote students in a high-quality online learning experience [143]. In recent years, videoconferencing has become reliable, accessible, and affordable, Especially with the coining of Covid'19, the education sector has had to transform its learning methods for all students who have to stay homebound. Indeed, in this study, BigBlueButton allows students to access a virtual classroom by sending an HTTP request to the server, i.e. by opening a hyperlink or an IP address via the browser to have lunch at the BigBlueButton videoconference session organized by the teacher.

The second subsystem is a graphical user interface distributed for our students as an interactive simulation tool. It is an electrical characterization interface that describes the behavior of a solar cell/panel under various climatic conditions developed using MATLAB. An executable file has been created to distribute this interface to students for use on their computers without the need for any special kind of program installed. The operation of the interface necessarily requires the import of a set of current and voltage measurements in order to simulate the characteristics of the photovoltaic device under study. Therefore, the third subsystem is a remote-controlled plant based on IoT systems permitted to measure the Current-Voltage values necessary for the operation of the solar panel graphical user interface.

3.8.3 Materials and methods

The following section describes in detail the elements involved in the development of the distance education system and the guide of its use by the students to convey the concepts necessary for our solar energy course. As the technological advances applied in the field of education require well-designed studies that validate the effectiveness of the tools as well as the methods suitable for their use, this section presents the methodology adopted to examine the indicators of learning and competencies to statically analyze the impact of the developed system on the learning process.

A. Solar panel graphical user interface

In recent years, the production of electricity by photovoltaic panels holds an important place both of its relative simplicity of implementation and its strong societal impact. The World solar plan is seen as an important step on the path of countries toward a secure and sustainable energy supply. Consequently, this solar plan has forced the creation of renewable energy sections in several public and private establishments [144]. Accordingly, higher education institutions should be able to train young people to replay to challenges linked to climate change and the energy transition in their technological, economic, and regulatory dimensions with particular attention to digital tools [145].

Solar cells are generally associated in series and parallel, then encapsulated under glass to obtain a photovoltaic panel. The operation of solar cells/panels is generally described by the characteristics I = f(V) which provide information about the internal electrical transport mechanisms and the imperfection of the technological stages of manufacturing. The characteristics of I-V are obtained through a set of experimental measurements of the Current (I) and Voltage (V) taken from a photovoltaic panel. This last depends on several electrical parameters, namely the photocurrent Iph, the series resistance Rs, the parallel resistance Rsh, the saturation current Is, and the ideality factor η, which are part of the characteristic equation of the current generated by a photovoltaic device in the equation 1 and the well known equivalent circuit of Figure 3.21.

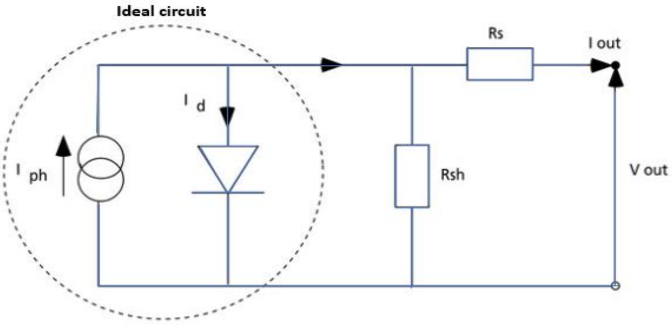
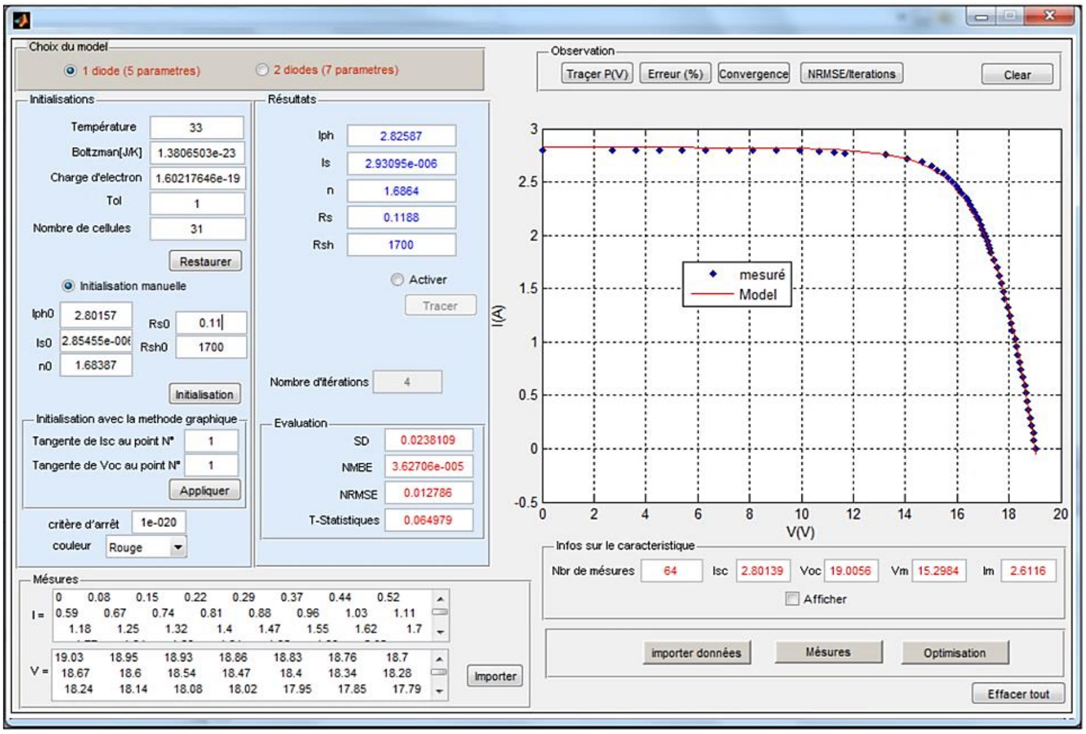


Figure 3.21 — Equivalent diagram of a photovoltaic cell

$$I = I_{ph} - I_s.[exp(\frac{\text{V} + \text{I}R_S}{\eta\text{KT}}) - 1] - \frac{\text{V} + \text{I}R_S}{R_{sh}} \qquad (1)$$

In this work, the authors performed a case study and scenarios to transform the pedagogical requirements into a computer solution that will allow students not only to plot the current-voltage and power-voltage characteristics of the panel, but also to study the influence of intrinsic parameters, lighting, temperature, and many other indicators on the energy production of the solar device by implementing a numerical algorithm making it possible to extract the value of the intrinsic parameters presented in Equation (1). Therefore, a graphical user interface for the electrical characterization of a solar panel has been developed under the MATLAB environment which is shown in Figure 3.22.



Choix du model
● 1 diode (5 parametres)
○ 2 diodes (7 parametres)

Initialisations
Température 33
Boltzman[J/K] 1.3806503e-23
Charge d'electron 1.60217646e-19
Tol 1
Nombre de cellules 31

● Initialisation manuelle
Iph0 2.80157
Is0 2.85455e-006
n0 1.68387
Rs0 0.11
Rsh0 1700

Initialisation avec la methode graphique
Tangente de Isc au point N° 1
Tangente de Voc au point N° 1

critère d'arrêt 1e-020
couleur Rouge

Résultats
Iph 2.82587
Is 2.93095e-006
n 1.6864
Rs 0.1188
Rsh 1700
○ Activer
Nombre d'itérations 4

Evaluation
SD 0.0238109
NMBE 3.62706e-005
NRMSE 0.012786
T-Statistiques 0.064979

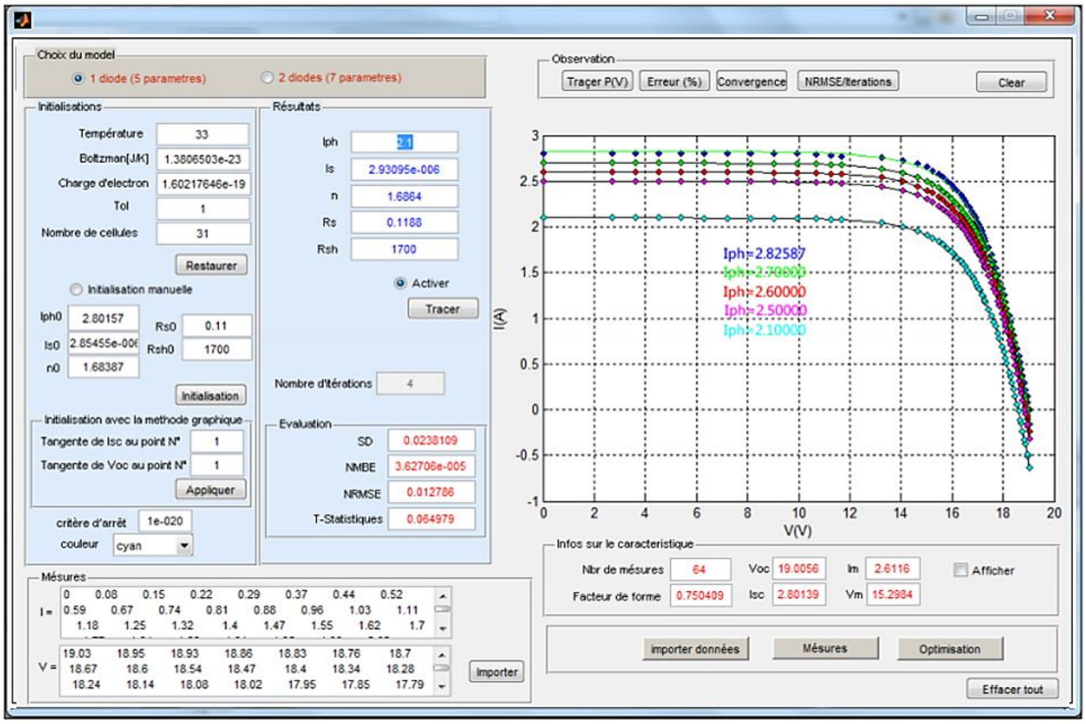
Mésures
I = 0 0.08 0.15 0.22 0.29 0.37 0.44 0.52
0.59 0.67 0.74 0.81 0.88 0.96 1.03 1.11
1.18 1.25 1.32 1.4 1.47 1.55 1.62 1.7
V = 19.03 18.95 18.93 18.86 18.83 18.76 18.7
18.67 18.6 18.54 18.47 18.4 18.34 18.28
18.24 18.14 18.08 18.02 17.95 17.85 17.79

Infos sur le caracteristique
Nbr de mésures 64
Isc 2.80139
Voc 19.0056
Vm 15.2984
Im 2.6116
☐ Afficher

Figure 3.22 — The solar panel graphical user interface

Equation (1) is a nonlinear equation that involves the overall output current produced by the solar cell on both sides of the equation, therefore the characteristic equation has not an explicit analytical solution. In the literature, different numerical methods are often used to solve nonlinear equations, in order to know about the value of the intrinsic parameters of the photovoltaic studied. This approach allows the simulation of the behavior of photovoltaic devices which helps students and manufacturers to design and produce devices meeting well-defined specifications, in terms of reliability and efficiency consumption.

The graphical user interface was distributed to our students as an executable file that was configured to run on student computers without the need for additional software. When opening the interface for the first time, some buttons will be disabled because the full operation of the interface requires the import of I-V measurements from the panel studied. The interface offers students the possibility of directly entering I-V measurements or browsing the desired measurement file via a window, the extension to import must be .txt or .dat. After this step, students can plot these measurements in the form of a graph to get an idea of the performance of the device being studied. The next step consists in launching the algorithm implemented by the graphical interface to extract the intrinsic parameters, these allow to polt the calculated characteristic in order to allow the students to compare the measured graph and that calculated as shown in Figure 3.23.


Choix du model
● 1 diode (5 parametres) ○ 2 diodes (7 parametres)

Initialisations
Température 33
Boltzman[J/K] 1.3806503e-23
Charge d'electron 1.60217646e-19
Tol 1
Nombre de cellules 31
○ Initialisation manuelle
Iph0 2.80157
Is0 2.85455e-006
n0 1.68387
Rs0 0.11
Rsh0 1700
Initialisation avec la methode graphique
Tangente de Isc au point N° 1
Tangente de Voc au point N° 1
critère d'arrêt 1e-020
couleur cyan

Résultats
Iph 2.1
Is 2.93095e-006
n 1.6864
Rs 0.1188
Rsh 1700
● Activer
Nombre d'itérations 4
Evaluation
SD 0.0238109
NMBE 3.62706e-005
NRMSE 0.012786
T-Statistiques 0.064979

Mésures
I = 0 0.08 0.15 0.22 0.29 0.37 0.44 0.52
0.59 0.67 0.74 0.81 0.88 0.96 1.03 1.11
1.18 1.25 1.32 1.4 1.47 1.55 1.62 1.7
V = 19.03 18.95 18.93 18.86 18.83 18.76 18.7
18.67 18.6 18.54 18.47 18.4 18.34 18.28
18.24 18.14 18.08 18.02 17.95 17.85 17.79

Infos sur le caracteristique
Nbr de mésures 64
Facteur de forme 0.750409
Voc 19.0056
Isc 2.80139
Im 2.6116
Vm 15.2984
☐ Afficher

Figure 3.23 — The influence of the Iph parameter on the performance of the studied panel

In general, these parameters are not measurable or included in the actual manufacturing data and must be determined from an I-V equation system at various operating points, or through the experimental data based on numerical methods [146]. Once these parameters are extracted, the student can change the value of any parameters and trace the characteristics again to detect the influence of this one on the curve.

B. IoT based solar energy measurement system

The proposed architecture of the low-cost educational system designed in this work includes the design of a remote-controlled laboratory through the implementation of a remote-controlled solar energy measurements system. The IoT system presented in this section was developed to give the students a sense of control over the actual equipment in the lab and allow them to get remotely a set of values of the Current and Voltage needed for the operation of the graphical user interface presented in the previous section. From a pedagogical point of view, monitoring solar energy parameters is necessary for a student to learn if the solar panel meet the performance expected.

Remote laboratories open up opportunities for distance learning, especially in open-access institutions in developing countries, where first and second-year engineering sections suffer more from increasing student numbers and limited teaching resources in practical work sessions. During the development of the remote IoT measurement system, hardware and software design were adressed. The hardware involves the development of the power unit, the control unit, and the sensor unit by using Raspberry and electronic components as presented in Figure 3.24.

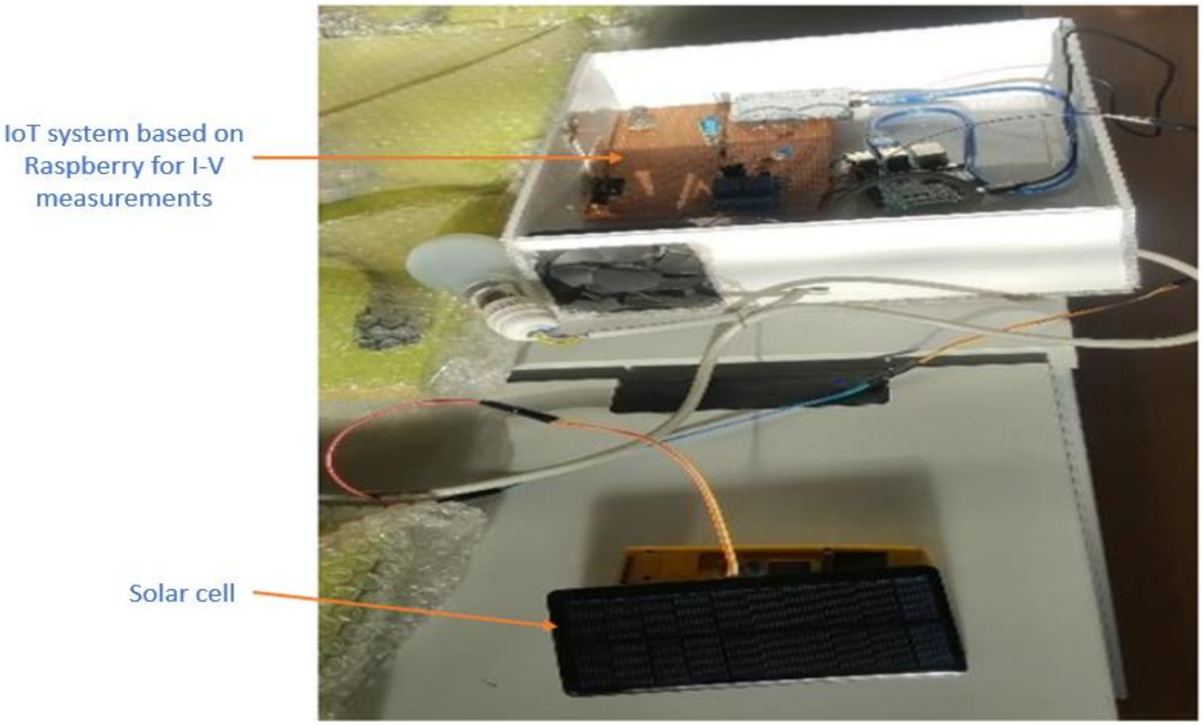
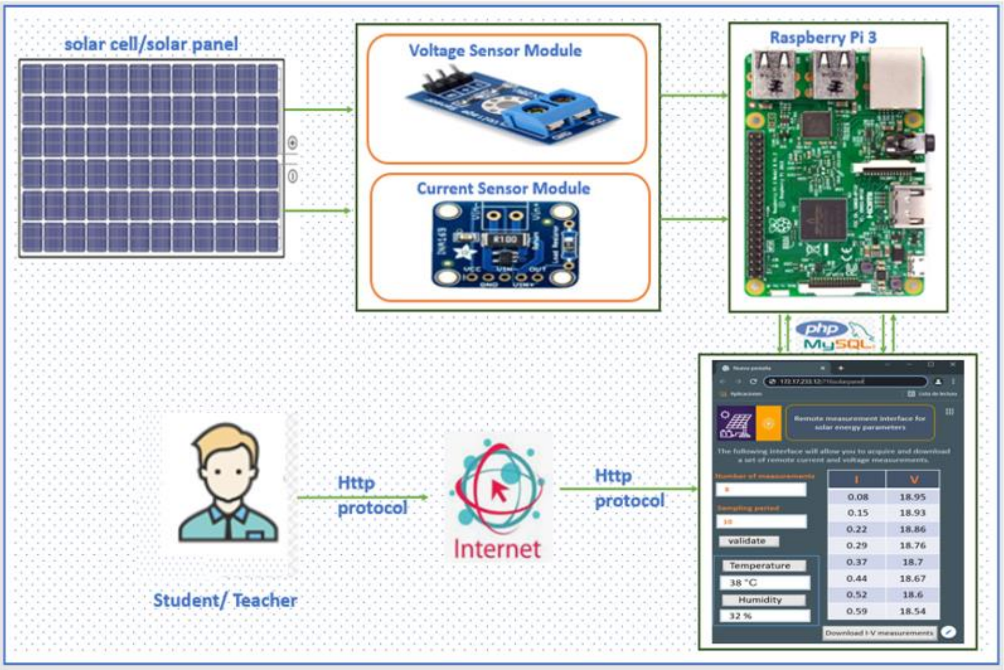


Figure 3.24 — The hardware part of the IoT based measurement system

The solar energy parameters are sensed using sensors for each parameter. The current was measured using the current sensor module which can sense the current generated by the solar cell/panel. On the other hand, a voltage divider is used to measure the voltage because the value generated by a solar panel is unbearable for the Raspberry. Temperature and light intensity was measured using a temperature sensor and a light-dependent resistance sensor, respectively. Software design involves the development of an interface using web technologies namely PHP, HTML, and CSS to enable the Raspberry pi to function and perform as desired.

In the literature, many works and architectures have been proposed for the implementation of a solar energy measurement system where the majority of the proposed architectures are based on a microcontroller to provide the control part [147]. As long as, the solar energy parameters should be taken remotely by the students in this study, the control part of the architecture of the IoT measurement system is based on a Raspberry. This card plays the role of a mini-server allowing it to host the command interface developed as the software part of the IoT system, it also allows conversion of the analog inputs to digital inputs and displays them on the command interface. The basic input of the system is the sensor units, they sense the required variables and their values are displayed in the developed web interface. Thanks to the HTTP protocol which allows to transmission of student commands to the equipment set up in the lab and receives parameters value on the other side [148].



The following interface will allow you to acquire and download a set of remote current and voltage measurements.

Temperature: 38 °C

Humidity: 32 %

I	V
0.08	18.95
0.15	18.93
0.22	18.86
0.29	18.76
0.37	18.7
0.44	18.67
0.52	18.6
0.59	18.54

Figure 3.25 — Technological architecture to measure solar panel parameters

C. Learning experience using BigBlueButton

The technological architecture of the low-cost system presented in this work is based on the BigBlueButton video conference system to provide a theoretical and practical learning experiences during a course on solar energy. In fact, research that has adapted BigBlueButton as a video conferencing tool in their studies have increased dramatically in 2020, where web conferencing software becomes an part of teaching activities at all educational levels due to the global COVID-19 pandemic [149, 150].

In this study, the BigBlueButton is used to facilitate the students' contact with the teachers in our experiment. It was used as a virtual classroom allowing for a discussion environment during the realization of the remote practical work. In this system, the teacher can upload any presentation type which can explains the theory of the photovoltaic devices as well as the steps to perform the practical work using the graphical user interface and the IoT measurement system. The teacher can share his/her desktop and keep students in synchronization with their current page, where he can open the solar panel graphical user interface to show how to perform the first tasks of the practical work through some examples.

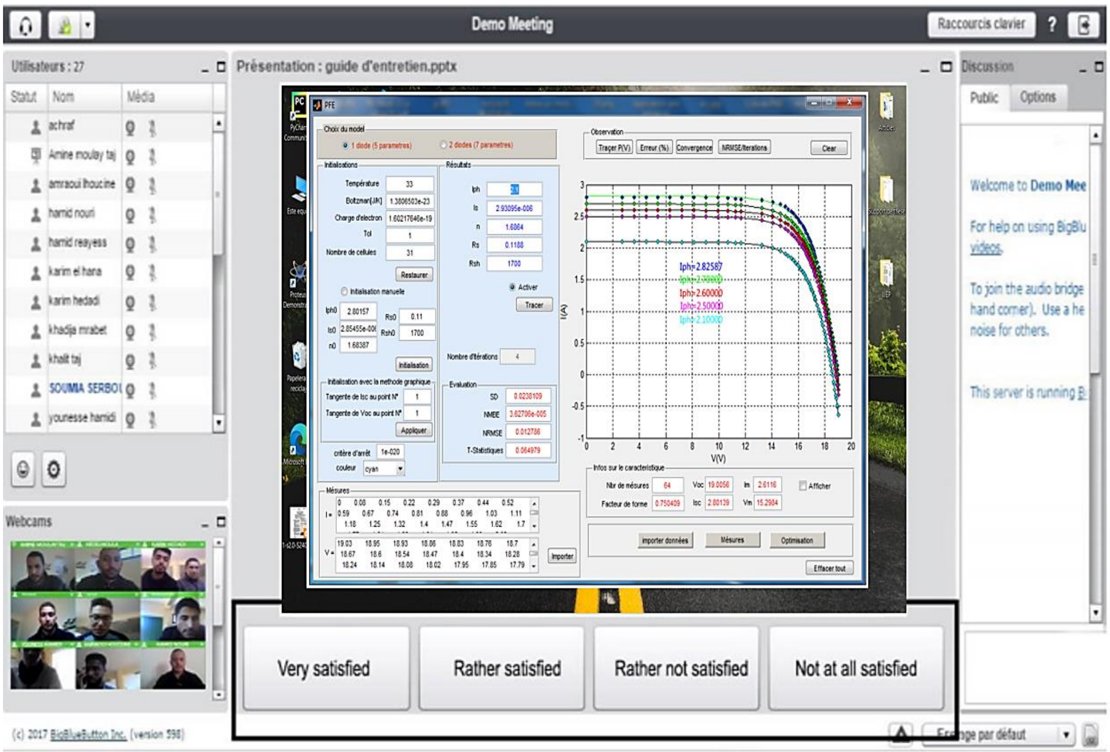


Figure 3.26 — The learning experience of the PW using BigBlueButton

On the other hand, the teacher can allows to a specific student to share his desktop interface and to perform some practical work tasks while all the students participate remotely by sharing their webcams at the same time and giving their feedback. review the task through some comments as shown in figure 3.26.

A special server was prepared to host the BigBlueButton in our University, where we installed an Ubuntu 20.04 server, with 8GB RAM which is sufficient for the latest stable version of BigBlueButton. Control and analysis tests were carried out before the experiment period and the results prove that the implemented BigBlueButton server in our university can control 200 participants simultaneously. During the sessions of practical work the students are generally divided into small groups in order to have the performance of the BigBlueButton largely sufficient for the normal conduct of our study.

3.9 Classroom response system using Raspberry

3.9.1 Contribution purpose

Educational innovations have challenged pedagogical practices in traditional lectures especially because the lectures at universities do not produce the learning goal that is presumed to achieve. Therefore the need for increased interactivity has been emphasized, and technology and several methodologies grouped under the name of interactive engagement were developed since 1990. This contribution presents a low-cost operational architecture of a techno-pedagogical IoT-based instrument, which aims to optimize the process of interaction and interactivity during the learning and teaching process. The IoT system uses a Raspberry card that integrates a classroom response system (CRS) software application which has been developed to allow the teacher to interview students using multiple-choice questions, in order to test their understanding of a concept discussed in the classroom. As part of this study, a mobile-based CRS has been developed using web-based technologies that make the system very easy to use in educational environments, the results of a question are displayed in real-time on the mobile of the teacher. We named the technical tool RaspCRS, this tool has a strategic character because it allows improving the image of our university, pursuing the paths of smart cities. This solution takes into account the didactic and pedagogical constraints that hinder the process of questioning, in order to create favorable conditions for investment and cognitive engagement of students.

3.9.2 Architecture of the system

The architecture of the operation of the developed solution contains three main and typical parts that describe the main actors involved in the operation of RaspCRS as shown in Figure 3.27.

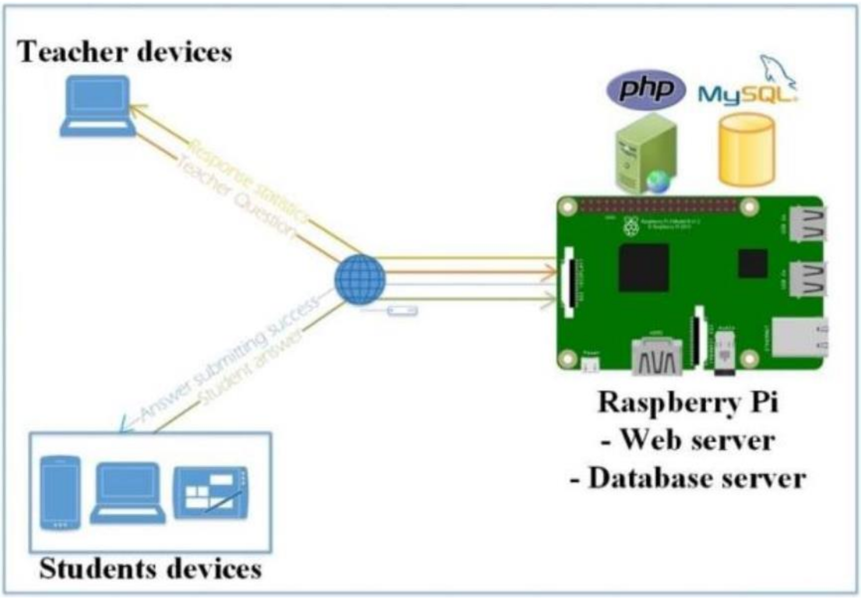


Figure 3.27 — Architecture proposed for mobile-based CRS

The RaspCRS system contains two main modules, one dedicated to the student and the other for the teacher. On the teacher side, a dashboard in the form of a web page is accessible for the teacher through its preferred heterologous terminal, this interface allows the teacher to ask questions to students enrolled in a specific module. In the same way on the student side, a web interface is accessible for the students after the inscription in the RaspCRS system, this interface allows students to answer questions asked by the teacher through their preferred device. The server part of the proposed architecture plays the role of intermediary between the students and the constructor. This hardware part is based on the use of a Raspberry Pi 3, which is a single-board computer with wireless LAN and Bluetooth connectivity, it is the first 64-bit Raspberry Pi with a quad-core 64-bit processor clocked at 1.2GHz and 1GB RAM. It allows the execution of several variants of operating systems and compatible servers.

To host the developed CRS solution, we have installed the Apache webserver on the Raspberry, this term refers to the software that allows this card to analyze the HTTP requests of the users and return the file corresponding to the request [151]. In order to be able to store the information of the classroom response system, a database management system SGBD namely MySQL was set up. In this way, the proposed architecture allows collecting the answers of the students and dissemination of the results to the teacher in a Client-Server architecture, based on the Wi-Fi connection to enable the networked devices in the classroom because of theoretically the extended Wi-Fi and important Bluetooth connection.

3.9.3 Description of the system

RaspCRS was made using the current web technologies that allow having a great ease of use of the system in an educational environment. We used in terms of developing the programming language PHP, realizing interactive and accessible interfaces based on the HTML markup language, as well as CSS and Javascript technologies [152]. These technologies produce applications executable on any device by following the optics of applications considered responsive that present the ability to adapt to any platform. In terms of interface, we took into consideration user profiles, and questions are submitted to teachers and students to collect their expectations. Particularly, we took into consideration the context of a particular use of the teacher, indeed the authentication part of the application allows to redirect each type of user to his dedicated web page. The readability at first sight of the information on the teacher's dashboard was highlighted, particularly the parts that allow him to ask questions and receive comments. Other features are presented to the constructor namely, the addition of a new module/course that has just been taught, which automatically assigns students enrolled in a path to the new module. In this way, when the constructor adds a question to the form, he must select the group/module concerned by this question as shown in Figure 3.28.

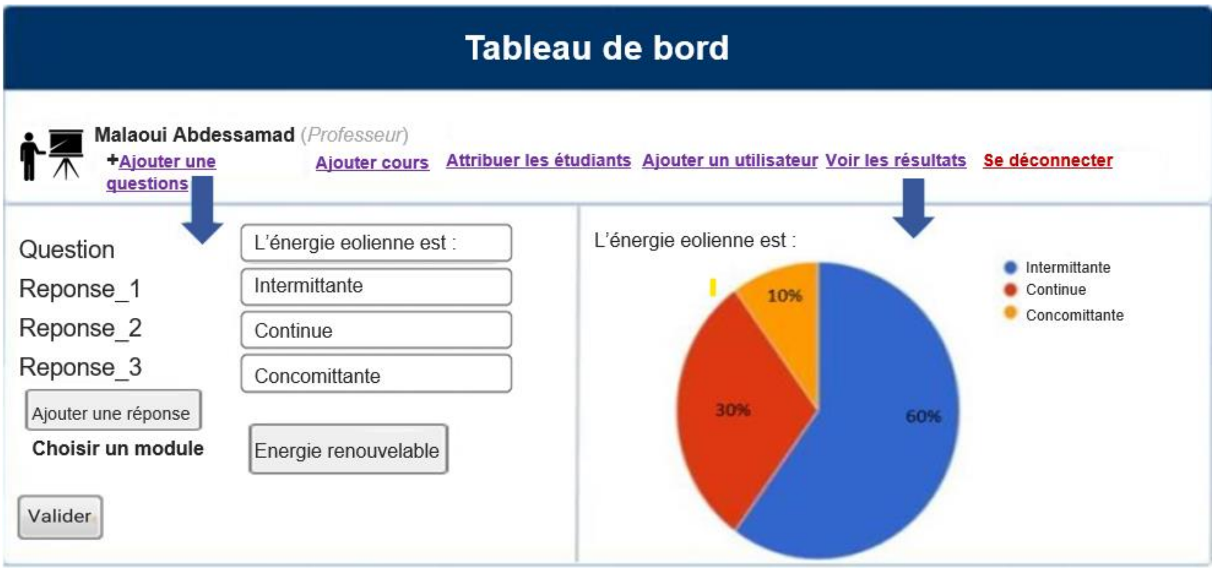


Tableau de bord

Malaoui Abdessamad (Professeur)

Question: L'énergie eolienne est :

Reponse_1: Intermittante

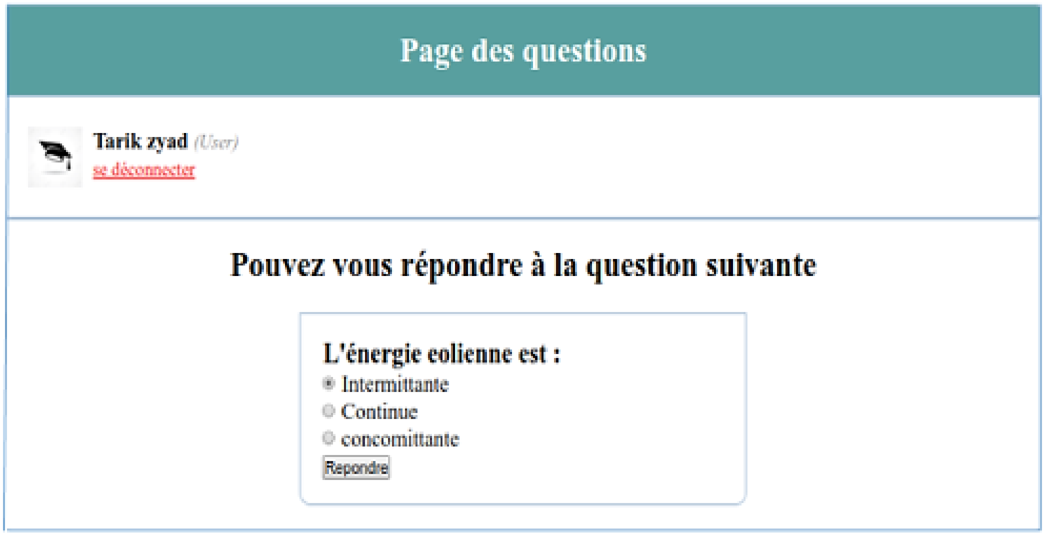
Reponse_2: Continue

Reponse_3: Concomittante

Choisir un module: Energie renouvelable

Figure 3.28 — Teacher side on RaspCRS

Students must connect to the same Wi-Fi network as the teacher, the latter distributes the URL allowing students to access the login page of the RaspCRS. If the student is not yet registered, he can click on a registration button allowing him to enter this information on a form and to choose a login and a password for access to the RaspCRS application. After identification with a username and password, a page web is displayed to the student containing the set of the module in which he is enrolled, the student must choose the current module, during the court session once the teacher asks a multiple-choice question, it's displayed in real-time on its device as shown in the following.



Page des questions

Tarik zyad (User)

Pouvez vous répondre à la question suivante

L'énergie eolienne est :

● Intermittante

○ Continue

○ concomittante

Figure 3.29 — The student side on RaspCRS

The Raspberry and a Wi-Fi router were set up in the classroom as shown in Figure 3.30, they aim to establish communication between the teacher and the students by dealing with HTTP requests from these two actors. The main functions for each actor are described in Figure 3.31 which illustrates the use case diagram.

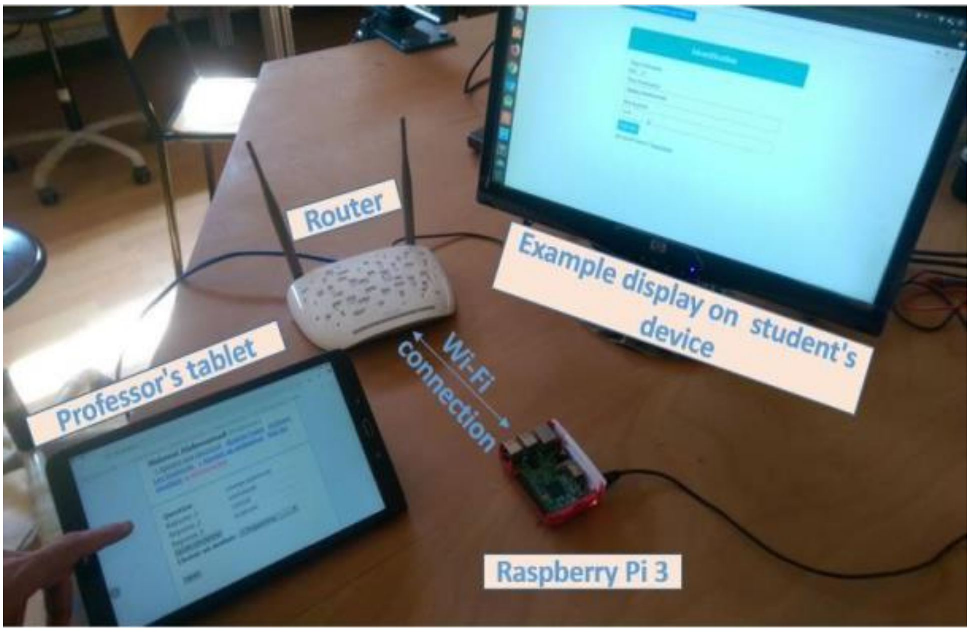


Figure 3.30 — The real implementation of the proposed architecture

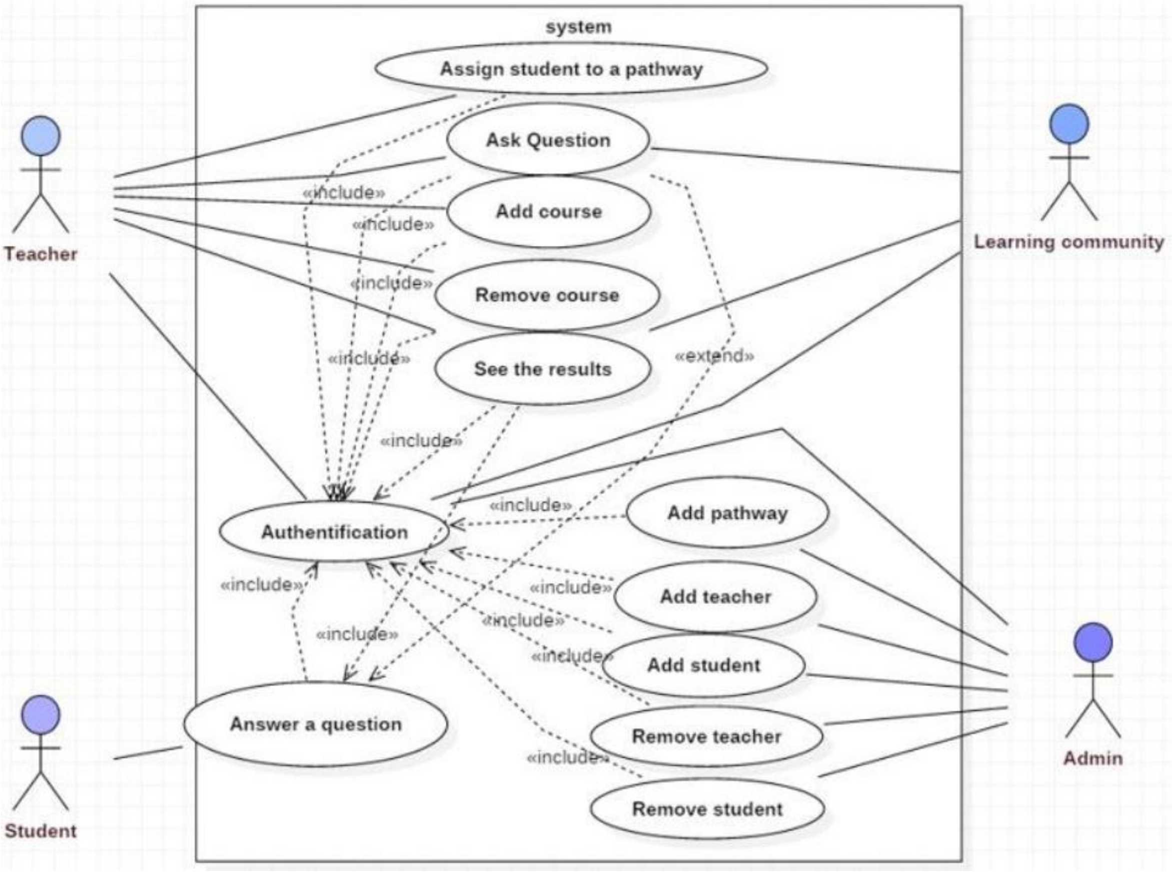


Figure 3.31 — The use case diagram

3.10 Conclusion

This chapter presented the set of low-cost IoT-based technical contributions that have been developed and implemented during the research period of this thesis. The main technical contributions aim to provide other possible teaching and learning scenarios to address certain problems related to practical work activities and interaction processes between teachers and students in different contexts.

The chapter has been divided into three main parts. The first part refers to the low-cost remote IoT-based laboratories prototypes that have been developed at the Polydiscipliary Faculty of Beni Mellal, Morocco, especially to meet challenges related to performing practical work in the field of Electronics and to fill the lack of equipment and equipped rooms of performing this kind of important activities.

The second part presents contributions in the field of automatic control realized within the UNILabs network located at the UNED, Madrid, Spain. It highlights the communication process in the field of remote-controlled laboratories which are basically network-controlled systems and presents an open-source software tool that implements SSEs as an effective communication protocol to enable the use of event-triggered and self-triggered control techniques. This contribution aims to effectively use the communication resources of the systems and transmit only the necessary information to satisfy the control objectives at not-prefixed instants of time.

The third part of this chapter presents blended contributions that combine online educational materials opportunities for interaction online with traditional place-based classrooms methods in order to enhance students-teachers interactions at the Ploydisciplinary Faculty of Beni Mellal, Morocco. It presents an IoT-based classroom response system allowing the teacher to test the understanding of students using their mobile by real-time multiple-choice questions, and a technical system providing theoretical and practical distance learning experience based on an open-source videoconference system named BigBlueButton.

Chapter 4

Contributions tests

Content

4.1 Introduction

The expansion of connectivity and interoperability devices has paved the way for the development of IoT technology, which is an upcoming concept that is contributing to offensive quality improvement in education. IoT is expected to impact many facets of education, but it has not been widely reported and validated [153]. Therefore, several intrinsic benefits of implementing an IoT system in the educational environment are not yet well-referred to and studied in the literature. The digital divide, which refers to differences in financial incomes and education levels between developed and developing countries is one of the important factors that affect the acceptance and diffusion of IoT technology. Therefore, developers and researchers need to consider this difference in order to provide a low-cost technical solution for higher education institutions in several developing countries to address their challenges and reduce inequality as well as the potential rejection of IoT implementation. The following chapter presents the tests of the different technical contributions presented in the previous chapter. Contributions tests are divided into three main parts, each one of them present the evaluation methodology, the technical and pedagogical results as well as the benefits and limitation of each contribution described previously in this thesis.

Part I: Tests of the remote IoT-based labs

Content

4.2 Test of the remote lab based on Red Pitaya

4.2.1 Methodology

The IoT-based system presented in this study has been designed and implemented to allow the realization of some remote practical works in analog electronics. The solution is based on the incorporation and development of low-cost IoT cards to provide a technical solution allowing students to perform PWs remotely. The proposed architecture of the RL is based on the Red Pitaya STEMLab card, especially for communication and control in order to allow remote measurement and data acquisition through another IoT card that has been developed during this study for allowing an intelligent selection between the different integrated PWs as well as other manipulations carried out outside as extensions according to the professor's needs.

Capturing students' perceptions about the learning experience and use of a new technology tool is very important to highlight the benefits, limitations, and engagement degree of the students with the system developed. Among the PW manipulations proposed by the IoT-based remote lab, the RC charge and discharge have been selected to conduct a comparative study between the PW performed traditionally in a hands-on laboratory and the same practical work performed using the remote lab. Figure 4.1, illustrates the remote manipulation of the RC circuit (charging and discharging of the capacitor) using the IoT-based remote lab.

The primary objectives that students should achieve during the laboratory activity selected for the comparative study are described below:

1. Describe the variation of charge during both charging and discharging of the capacitor.
2. Derive the relationship between the charge stored in a capacitor and the voltage across its plates.
3. Calculate the capacitance from the measured voltage and the time calculated at the half-time voltage.

Amplitude = 0,9
Frecuency = 1000
V-Offset = 0
Waveform SQUARE

Figure 4.1 — Remote manipulation of an RC circuit using the IoT-based system

The evaluation of the IoT system was conducted with 24 students enrolled in the 3rd year of the "Electronics program" at the Sultan Moulay Slimane University of Beni Mellal, Morocco. Students were divided into two groups, the first one perform the PW locally in the campus laboratory, and the second group use the remote IoT system to perform the PW. The evaluation process adopt the same questionnaire and factor methodology applied at the same university in 2017, to validate a strategy of online practical work on power electronics for embedded systems [24]. A K factor is calculated using both Equations 1 and 2, where S is the average of the student responses for each question and K is the percentage of S by the number of choices in each question. In our case N = 12 represents the number of students in each group, M = 4 is the number of answers for each question and The "Rj" is the response of student j for each question. The questionnaire contains four closed questions (Q1, Q2, Q3, and Q4) and two open questions (Q5 and Q6).

$$S = \frac{1}{N} + \sum_j R_j \qquad (1)$$

$$\mathrm{K} = \frac{S}{M} * 100\% \qquad (2)$$

4.2.2 Research findings

This section presents the results of the comparative study. Table 2 presents closed and open questions adopted to measure students' opinions in each practical work environment as well as the value of the K factor related to each closed question.

***Table 2**: Evaluation results of closed and open questions*

Closed questions				
Factor	***Questions***	***Response***	***Hands-on PW (%)***	***Remote PW (%)***
K1	Q1: How is difficult to have access to all the different PW elements?	1-Very difficult 2- Quite difficult 3- Minor difficulties 4- No problem	98.5	84.3
K2	Q2: Are the PW documents clear enough about what you have to do?	1-Very clear 2- Quite clear 3- Not very clear 4- Not clear at all	90.75	89.7
K3	Q3: How difficult is it to handle all the practical work's elements?	1-Very difficult 2- Quite difficult 3- Minor difficulties 4- No problem	90.15	80.2
K4	Q4: According to you, does this practical work match the theoretical concepts?	1-Yes, totally 2-Yes, partially 3- Not so much 4- Not at all	95.5	89.1

Open questions			
Questions		***Time Hands-on Pw***	***Time Remote PW***
-	Q5: How long did you take for this practical work (Min)?	60 min	40 min
-	Q6: How long did you take to process the results and write this practical work report (Min)?	104 min	75 min

Analysis of the responses in Table 2 shows some important remarks about the students' learning experience. According to the results of the closed questions, we noticed that the majority of the students' answers were favorable, varying between the first and second choice answers for each question in the two practical work environments. The results of the K-factor in the practical laboratory are always higher than the remote laboratory factor, which highlights two conclusions: On one hand, the hands-on laboratory activities are still the practical work environment preferred by the students due to the direct interaction with real equipment, on the other hand, the minor difference between the K factor value in the hands-on lab and the remote laboratory proves that the IoT based system succeeded in transmitting the essential knowledge for the understanding of the lab activity at distance. It proves also that the remote technological architecture proposed in this work can be adapted perfectly to provide remote electronic experimentation in unexpected eventual cases such as COVID-19, to provide some alternatives scenarios for performing practical learning. Answers to the two open questions (Q5 and Q6) presented in Table 2 show the average time required to perform the lab activity as well as the time required to write the practical work report in the proposed environment. Based on the student's answer, it is clair that performing lab activity remotely using the IoT-based system allows saving students time.

4.2.3 Benefits and limitations of the contribution

The IoT-based architecture presented in this work proposes a low-cost technical solution for conducting remote PWs in analog electronics. The purpose of the solution was to replace the essential equipment when carrying out practical electronic work, such as signal generators and the oscilloscope, by incorporating the Red Pitaya and a developed board that integrates several PWs in a small space to allow an intelligent selection between them. In fact, the developed board incorporates two digital potentiometers that are controlled via the SPI protocol to continuously monitor the resistances value in different electronics circuits [154]. It is worth mentioning that the proposed IoT system is not designed and implemented to replace the hands-on PWs but to be a compliment or an alternative scenario in some critical situations.

Regarding the limitations of the contributions, we can mention that the solution integrates six PW on the developed board and it gives more freedom to the students to change the value of the resistance via digital potentiometers. On the other hand, the extension outside the board requires additional work from the teacher to design other practical work outside the developed board to be controlled. The participation of students in the evaluation process was voluntary, 24 students were enrolled in this process, which does not allow us to recover solid facts and more generalized perception about the developed system, but in the first stage of the implementation of the educational system, it allows us to identify some aspects that need to be improved in the future. We are treating as future work to develop a more complete platform using the EjsS tool to study the issue of accessibility and load increase with more students. We are also looking to incorporate a window of conversation with the teacher in order to accompany the experiments.

4.3 Test of the remote lab based on Arduino and Raspberry

4.3.1 Methodology

A low-cost operational architecture for conducting remote PWs in analog electronics has been presented in this study. The hardware part of the proposed architecture is based mainly on the cooperation of Raspberry and Arduino. On the other hand, the software part has been developed using HTML and Javascript, the developed interface integrates a software Oscilloscope developed with processing. A sample of 20 students in the electronic program tested the proposed prototype at the Sultan Moulay Slimane University of Beni Mellal, Morocco. They were divided into two groups, the first group of students performed the manipulations locally in the dedicated physical laboratory, while the second group used the remote technology architecture to perform the remote laboratory activities. At the end of the manipulations, both groups of students were asked to complete a 4 question questionnaire as shown in Table 3 . A K factor is calculated using both questions 1 and 2 (See page 85) presented in the previous sections, where S is the average of the student's responses for each question and K is the percentage of S by the number of choices in each question. In this study, N= 10 represents the number of students in each group and M=4 is the number of answers to each question.

4.3.1 Research findings

This section presents the results of the questionnaire adopted to collect the students' opinions on their learning experience using the technological system designed to carry out electronic practical work. Table 3 shows the questions adopted for the evaluation and the value of the K-factor calculated based on the students' responses to the multiple-choice questions.

***Table 3**: Evaluation results of the questionnaire*

Factor	*Questions*	*Response*	*Hands-on PW (%)*	*Remote PW (%)*
K1	Q1: Was the oscilloscope easy to understand and use?	1-Yes, totally 2-Yes, partially 3- Not so much 4- Not at all	80	80
K2	Q2: Does the PW reinforce your theoretical concepts?	1-Very clear 2- Quite clear 3- Not very clear 4- Not clear at all	75	72.5
K3	Q3: Was the time enough to handle the PW?	1-Very difficult 2- Quite difficult 3- Minor difficulties 4- No problem	82.5	95
K4	Q4: Were you able to understand how to manipulate the PW without the presence of the teacher?	1-Yes, totally 2-Yes, partially 3- Not so much 4- Not at all	85	82.5

Analysis of the responses in Table 3 shows several important facts. Students in both groups are satisfied with the ease of understanding and using the software Oscilloscope to the same degree. On the other hand, the students feel that they have enough time to do the remote PWs but some of them need the teacher's guidance during the remote activities. According to Figure 4.2, several students chose the answer "Yes partially" for the remote laboratory, which shows major satisfaction. Comparing the results with those in Figure 4.3, we find a great similarity. and this is proven in Figure 4.3, which presents the correlation between the variables of the students' responses for the remote labs with the classic labs.

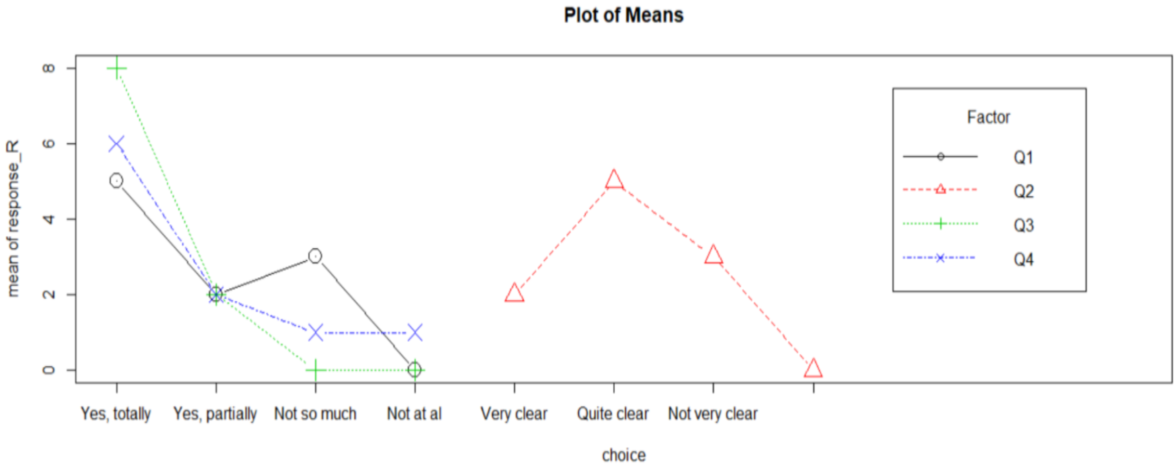


Figure 4.2 — Means of the responses using the remote PW architecture

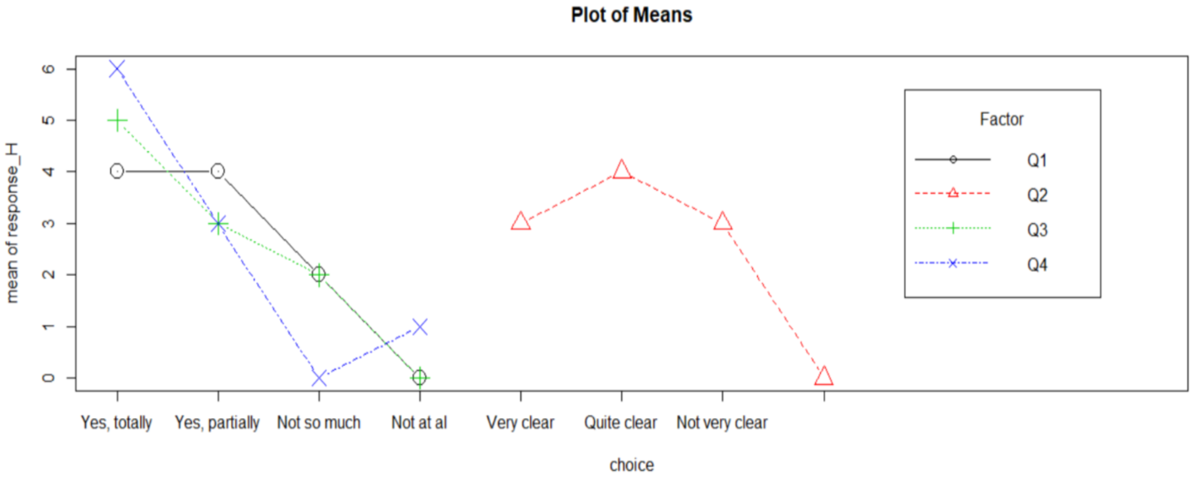


Figure 4.3 — Means of the response in hands-on PW

4.3.1 Benefits and limitations of the contribution

The technical system is based on a modular architecture, as each part of the system can be independently developed and improved, which allows using this system for other practical work easily by changing the PW board and web schema. Moreover, in terms of cost, the developed system is cheaper than those using measuring instruments and low-frequency generators. We replaced these with an embedded system controlled by a web page. Indeed, the cost of our system is around 80 euros. The developed oscilloscope/GBF provides several advantages, it is accessible via the web and plays two essential roles, the visualization of the signals by 4 channels, generated by PWM. The student can change the frequency, and duty cycle. This software oscilloscope facilitates the duplication of prototypes of practical work without misguided cost or development time. But this oscilloscope has some disadvantages and limitations because its performance (maximum frequency, max. voltage, number of channels, conversion time, processing speed, etc.) depends directly on the on-board system used.

At the level of the embedded system, cooperation between Arduino and Raspberry makes it possible to lighten the operations executed by the server in such a way, the latter takes care of web communications, control of digital outputs, and serial communication via USB, where the Arduino takes care of the conversion of analog signals and they process them to provide the final result to the server. The client/server communication is ensured thanks to the NodeJs socket. A delay was noticed between the web click and activation on relays with an average of 0.85 s, including 0.3 s between the web page and the server. One of the concerns being improved is the real-time synchronization of the webcam, which has a delay of 1.5 s due to the use of the transfer of a set of images captured via sockets. During the evaluation process, 20 students tested the developed system in order to verify, as a first step, the ability of the system to be adopted to perform remote practical work and to detect its advantages and limitations. In the future, we plan to duplicate the remote lab to allow access to a large number of students to collect students' perceptions through statistical studies that analyze the results of open and closed questions as well as students' final exam scores using the proposed technological architecture.

4.4 Test of the DC motor control in three PWs environments

4.4.1 Methodology

Capturing student perceptions of their learning experiences on different dimensions is an important issue in the evaluation process of any kind of practical work. The impact of innovations on students' performance can be analyzed statistically either globally or locally by looking at specific skills or indicators. In this work, the authors adopt a methodology that takes into account the interaction between students, teachers, and the practical work environment at different levels of abstraction to evaluate a DC motor laboratory practice and measure the satisfaction of our students with the three practical work methods.

We have defined that the student's attitude towards a specific practical work method depends on its usefulness, usability, motivation, and quality of comprehension, these parameters have been measured utilizing a questionnaire that considers the relationship between the student, the teacher, and the practical work environment during each laboratory session.

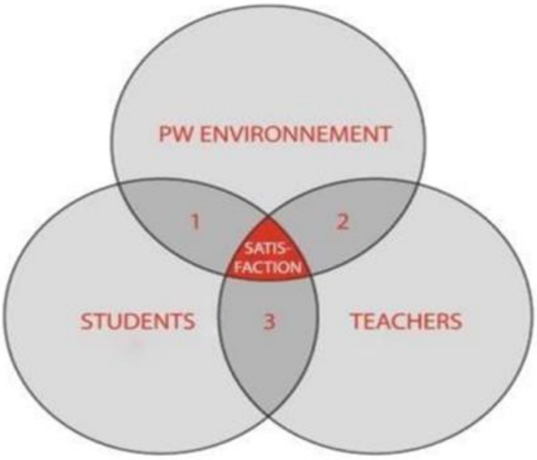


Figure 4.4 — Student-Teacher-PW environment relationship

The evaluation was carried out with 150 students enrolled in the physics degree program at the Polydisciplinary Faculty of Beni Mellal. Students were required to answer a questionnaire at the last of each laboratory session. The authors prepared questions for the survey based on key factors that were identified from the literature reviews in order to gather information on our students' perceptions when using each practice method [155, 156].

The adopted questionnaire in this study consists of two parts:

- The first part focuses on the relationship between the three actors involved in the realization of the practical work, namely, students, teachers, and the working environment, in the three experiences as shown in Figure 6.
- The second part consists of measuring student satisfaction toward four indicators namely, usefulness, usability, student motivation, and quality of understanding in each experiment.

A. First part of the questionnaire

Students' and teachers' reactions and perceptions of their interaction with each practical work environment are obtained by completing a questionnaire with closed-ended questions. Students were limited to answering Yes or No to the following questions presented in Table 1.

***Table 4:** Questionnaire on the interaction of the different actors in the PWs*

Interaction Students-PW environment	
Q1	The practical work environment is good for your learning?
Q2	Is this practical work environment collaborative?
Q3	Does the practical work environment save you time?
Q4	Does the practical work environment provide you with a good understanding?
Q5	Do you have more time flexibility in this practical work environment?
Interaction Teacher-PW environment	
Q6	Does the practical work environment improve teaching transmission?
Q7	Does the practical work environment ensure traceability?
Q8	The practical work environment facilities the framing of the students?
Q9	Is the practical work environment secure?
Q10	Effective time utilization in the practical work environment?
Interaction Teacher-Student	
Q11	Are students more independent in this practical work environment?
Q12	Stronger group work in this practical work environment?
Q13	Do students make mistakes in this practical work environment?
Q14	Are Students motivated in this practical work environment?

A. Second part of the questionnaire

This part aims to measure the students' attitude towards each specific practical work method, which in this work depends on its usefulness, usability, motivation, and quality of understanding. These indicators are obtained by filling in a questionnaire with closed-ended questions. Responses are rated on a four-point Likert scale.

The authors define these indicators as follows:

- ***Usefulness*** of these methods refers to the level at which someone thinks using the new technology will improve its effectiveness.
- ***Usability*** refers to the effort that someone considers necessary to use the technology and do the job required.
- ***Motivational dynamics*** of the students originate in the first place with the value that it grants to practical activities. As well as his perception of his competence with accomplishments and his feeling of control over their progress.
- ***Quality of understanding*** refers to the retention of concepts physical, the profit of information, and the level of the experiment.

The evaluation of these indicators in the three methods of practical work was carried out in total among 150 students. They were divided into three groups, with 50 students in each group. The first group was in charge of the manipulation in the laboratory, while the second group of students used the simulation method and finally the last 50 students performed the practical work using the real online laboratory remotely. The authors adopt the same factor applied at the same university to validate a new online practical work strategy on power electronics for embedded systems in 2017, to measure each indicator presented in Table 5 [24].

A K factor is calculated using both equations 1 and 2 (Page: 86), where S is the average of the student responses for each question and K is the percentage of S by the number of choices in each question. In our case N = 50 represents the number of students in each group, M = 4 is the number of answers for each question and the "Rj" is the response of student j for each question.

Each indicator was assessed by three questions, therefore, students' responses to these questions gave an overall picture of this indicator in each type of practical work. The average of the three factors for each indicator is calculated according to equation 3 and the results for the four indicators are presented in Table 7.

$$A = \frac{1}{n} * \sum_{i=1}^{n} K_i \qquad (3)$$

Table 5: Questionnaire on students' satisfaction according to the four indicators

Factors	Usefulness Questions	Response level
K1	Q1: Was the PW environment useful?	1- Yes, Totally 2- Yes, Partially 3- Not so much 4- Not at all
K2	Q2: Were you able to understand how to control the system in this PW environment?	
K3	Q3: Were the capabilities of the laboratory adequate?	
Factors	**Usability Questions**	**Response level**
K4	Q4: Was the system in the PW environment easy to understand and use?	1- Yes, Totally 2- Yes, Partially 3- Not so much 4- Not at all
K5	Q5: Were you able to use fully the PW environment by following the instructions provided?	
K6	Q6: The ideas and concepts incorporated in the the laboratory was easy to follow?	
Factors	**Motivation Questions**	**Response level**
K7	Q7: The value of the experience is interesting?	1- Yes, Totally 2- Yes, Partially 3- Not so much 4- Not at all
K8	Q8: The perception of your skill is high?	
K9	Q9: Is your perseverance high?	
Factors	**The quality of understanding Questions**	**Response level**
K10	Q10: Did the PW environment help you to learn the concept Faster?	1- Yes, Totally 2- Yes, Partially 3- Not so much 4- Not at all
K11	Q11: Was the level of the experiments adequate?	

4.4.1 Research findings

This section deals with the results and analysis of the data collected from the case study presented in the methodology section, where a well-structured questionnaire is used because they generate the response frequencies to compare student opinions.

The results of the questionnaire are presented in two parts:

- The first main part results of this study are summarized in Table 3, which refers to the students and tutor answers about their relationships in each environment of practical. These questions are presented in the first part of the adopted questionnaire in Table1, and the average of the actor's responses to each question is presented in Table 3.
- The second main part results of this study are summarized in Table 4. In this part, students answered 12 questions aimed at measuring indicators, namely, utility, usability, motivation, and quality of comprehension. These questions are presented in Table 2. and the average of student responses to each question are presented in Table 3, according to the statistical method presented in the methodology section using equations 1, 2, and 3.

***Table 6**: Results of the interaction of the different actors in the PWs methods*

Interaction	Question	Agree (Remote labs) %	Agree (Simulation) %	Agree (Hands-on) %
Students-Environment	**1**	80	75	95
	2	75	80	90
	3	95	80	75
	4	80	75	95
	5	90	70	60
Teacher-Environment	**6**	80	80	90
	7	85	80	90
	8	70	80	95
	9	100	100	75
	10	100	90	75
Teacher-Student	**11**	60	70	90
	12	50	60	80
	13	80	60	80
	14	80	60	80

Based on their responses, students believe that the three types of practical work environments presented in this study are generally valuable. The results presented in the first part of the questionnaire prove the flexibility of students in using information and communication technologies, mentioning that most of the students did not manipulate an experiment remotely before. The results indicate also that the student's interaction with the three practical work environments was high.

This assessment aimed to compare actors' attitudes with traditional, simulated, and real remote labs. The results of the first five questions in Table 3, which measures student perceptions of the three types of labs, showed that the majority of the students preferred the traditional laboratory to do technical experiments which also dominates in terms of collaboration.

Although the simulation and the remote-controlled lab have almost similar values, the authors can conclude that the students found that remote handling saves them time and gives them more flexibility. Results also suggest that remote labs are comparable in effectiveness to hands-on labs, at least in teaching basic applications.

Open-ended questions are a complement to closed questions that invite honest and personal comments from students. They are especially useful when the number of respondents is reduced The students were asked to provide the most common positive and negative aspects at the end of the questionnaire. The most common positive feedback from students on the hands-on experiment was their handling of equipment. On the other hand, students find that the time for reflection with the equipment is insufficient because of the number of students in the laboratory.

For the simulation, the most common positive comment was that the software environment allows them to establish the reality of the studied phenomenon or to measure electrical parameters. However, the students have a lack contact with the real material. On remote manipulation, the most common positive comment was the connection to real experiments from any place at any time. However, Students suggested that the live experiment should be available over an extended period to gain full benefit from the experience.

The perception of the five teachers who followed the three experiments also guarantees that when carrying out the distance work that they save in terms of time and safety, however, the subject is complex when the authors add to this the warnings of the professor on the use of the equipment, the fear of working with high voltages. But face-to-face work remains essential when it is the first time that the students are in a laboratory where not only must understand and assemble the circuits, but also understand and see how the equipment works with the change of each component in the practical work. On the other hand, the results of the satisfaction questionnaire which refers to the second main part results of this study are summarized in Table 7, the authors presented the average satisfaction of the three factors K dedicated to measuring each indicator calculated with equation 3.

Table 7*: Indicators satisfaction results*

Parameters	Agree (Remote labs) %	Agree (Simulation) %	Agree (Hands-on) %
Usefulness	95,75	95,25	97,75
Usability	95,25	97,5	98,5
Motivation	97,5	85,25	90,15
Understanding	95,15	90,5	90,5

From the results cited in table 7, the authors can note that the hands-on usefulness is adequate to other methods. Furthermore, usability using a remote lab is best than others with a minor difference. we can also remark that hands-on motivation and quality of understanding are very close to the simulation and remote lab. But in a general way, it proves that it can be adopted in the current educational system taking into account the critical points.

4.4.1 Benefits and limitations of the contributions

The introduction of computer simulations, virtual instruments, and remote laboratories in addition to hands-on lab sessions are powerful solutions to increase the efficiency of the engineering and technology education process. In this work, we have adopted a method that takes into account the relationship between student teachers and the environments of practical work in order to compare the satisfaction of our students by measuring some indicators. This information is fundamental to progress toward the best methods of teaching electronics in open-access universities. The results indicate that student satisfaction with the three practical work environments is high, demonstrating the flexibility of students in the use of information and communication technologies, noting that most students had never manipulated a remote experiment before. The usage of labs in electronic education is a key element, and it gains more importance in the distance education paradigm due to the difficulties involved.

In fact, each type of laboratory has advantages and disadvantages. One can distinguish the fact that students prefer to combine the types of laboratories: simulated, hands-on, and remote lab, but also combine approaches to use classical instrumentation, virtual instrumentation, and modern dedicated instrumentation. Remote laboratories have the advantages of access, programming, and repeatability. As these laboratories are accessible at any time, they allow students to repeat the laboratories leading to a better understanding of the phenomena studied. We are treating as future work the development of more complex experiments in electronics that will allow us to compare the results of the practical work obtained in class and at distance with a large number of students, we also seek to take advantage of the automatic assessment paradigm to collect indicators in a fast and effective way, thus reducing the effort required in this process.

Part II: Tests of the event-based control labs contributions

Content

4.5 Methodology

This section presents the test of an extension of the RIP protocol that allows more precise and sophisticated management of the communication process in control systems. In fact, RIP-LabVIEW and RIP-Python are the two server implementations created within the UNEDLab research group and used in the development of various OL prototypes integrated into the UNILabs network [79]. Traditionally, RIP-LabVIEW offered periodic sampling as the only possibility to notify updates to its clients. The period between communications was set in the value *sse-period* of the global configuration. Recently, the RIP-LabVIEW server was leveled-up to support send-on-delta sampling. The contribution presented in this thesis aimed to level up the RIP-Python server to integrate the same functionalities as the RIP-Labview server.

The test of the contribution was done in two main steps. The first step consists of validating each integrated functionality separately using unit testing Python programs. On the other hand, integration of the new version of the RIP-Python server on a real laboratory activity has been presented by deploying an AirLevitation system. The new version of the RIP-Python server is available on GitHub [140].

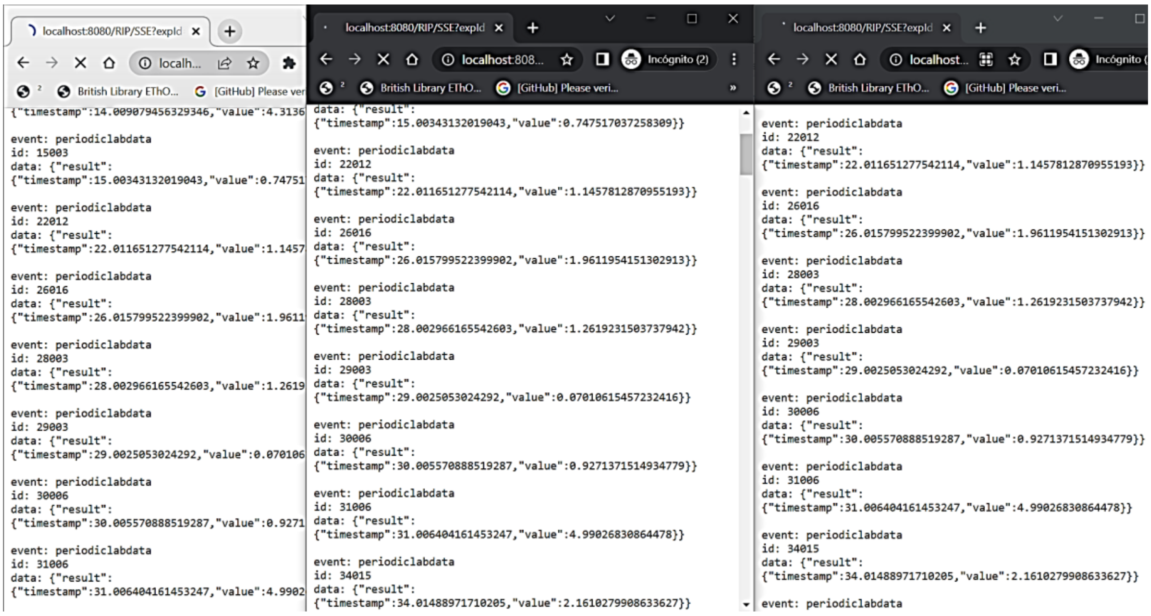
4.6 Unit testing of the RIP extension

Unit tests are a way to verify that a piece of code is working properly. It is one of the procedures implemented as part of an agile work methodology. In other words, unit testing is a method of software testing in which individual units of code, such as functions, methods, and classes, are tested to determine whether they are fit for purpose. Intuitively, a unit can be thought of as the smallest testable part of an application. Unit tests are short code fragments created by programmers during the development process. They form the basis for component testing. In this section, we performed unit tests to verify the proper functioning of various features built into the previous version of the RIP-Python server.

As a unit test programming framework, we have adopted the PyUnit module based on the Unittest package for testing new features built into the server. PyUnit (Unittest) is a unit testing framework for Python that was inspired by JUnit. It is the default Python testing framework that comes out of the box with the Python package, and thus the one that most developers start their tests with [157]. We have limited the tests to 3 users connecting to the server simultaneously, the following sections will present the source code links for each test and some figures that illustrate the response of the server depending on the test executed.

4.6.1 Server access tests

This section provides links to the Unittest source code that verifies that users can access the server and receive events as previously configured on the server-side. Since we have limited the test to three users, there are several scenarios for testing user access to the server. For example, Figure 4.6 illustrates the result of a test that checks if the server can handle the access of three users at different times and verify that each user receives the same events after the connection.



```
{"timestamp":14.009079456329346,"value":4.3136

event: periodiclabdata
id: 15003
data: {"result":
{"timestamp":15.00343132019043,"value":0.74751

event: periodiclabdata
id: 22012
data: {"result":
{"timestamp":22.011651277542114,"value":1.1457

event: periodiclabdata
id: 26016
data: {"result":
{"timestamp":26.015799522399902,"value":1.9611

event: periodiclabdata
id: 28003
data: {"result":
{"timestamp":28.002966165542603,"value":1.2619

event: periodiclabdata
id: 29003
data: {"result":
{"timestamp":29.0025053024292,"value":0.070106

event: periodiclabdata
id: 30006
data: {"result":
{"timestamp":30.005570888519287,"value":0.9271

event: periodiclabdata
id: 31006
data: {"result":
{"timestamp":31.006404161453247,"value":4.9902
```

```
data: {"result":
{"timestamp":15.00343132019043,"value":0.747517037258309}}

event: periodiclabdata
id: 22012
data: {"result":
{"timestamp":22.011651277542114,"value":1.1457812870955193}}

event: periodiclabdata
id: 26016
data: {"result":
{"timestamp":26.015799522399902,"value":1.961195415130291З}}

event: periodiclabdata
id: 28003
data: {"result":
{"timestamp":28.002966165542603,"value":1.2619231503737942}}

event: periodiclabdata
id: 29003
data: {"result":
{"timestamp":29.0025053024292,"value":0.07010615457232416}}

event: periodiclabdata
id: 30006
data: {"result":
{"timestamp":30.005570888519287,"value":0.9271371514934779}}

event: periodiclabdata
id: 31006
data: {"result":
{"timestamp":31.006404161453247,"value":4.99026830864478}}

event: periodiclabdata
id: 34015
data: {"result":
{"timestamp":34.01488971710205,"value":2.1610279908633627}}
```

```
event: periodiclabdata
id: 22012
data: {"result":
{"timestamp":22.011651277542114,"value":1.1457812870955193}}

event: periodiclabdata
id: 26016
data: {"result":
{"timestamp":26.015799522399902,"value":1.9611954151302913}}

event: periodiclabdata
id: 28003
data: {"result":
{"timestamp":28.002966165542603,"value":1.2619231503737942}}

event: periodiclabdata
id: 29003
data: {"result":
{"timestamp":29.0025053024292,"value":0.07010615457232416}}

event: periodiclabdata
id: 30006
data: {"result":
{"timestamp":30.005570888519287,"value":0.9271371514934779}}

event: periodiclabdata
id: 31006
data: {"result":
{"timestamp":31.006404161453247,"value":4.990268308644 78}}

event: periodiclabdata
id: 34015
data: {"result":
{"timestamp":34.01488971710205,"value":2.1610279908633627}}

event: periodiclabdata
```

Figure 4.5— results of test access of three users to the server at different times

The following lines show the code source developed to check the server access according to other different scenarios :

- One user test access to the server [158].
- Two user test access at the same time [159].
- Two users test access at different times [160].
- Three users test access at the same time [161].
- Three users test access at different times [162].

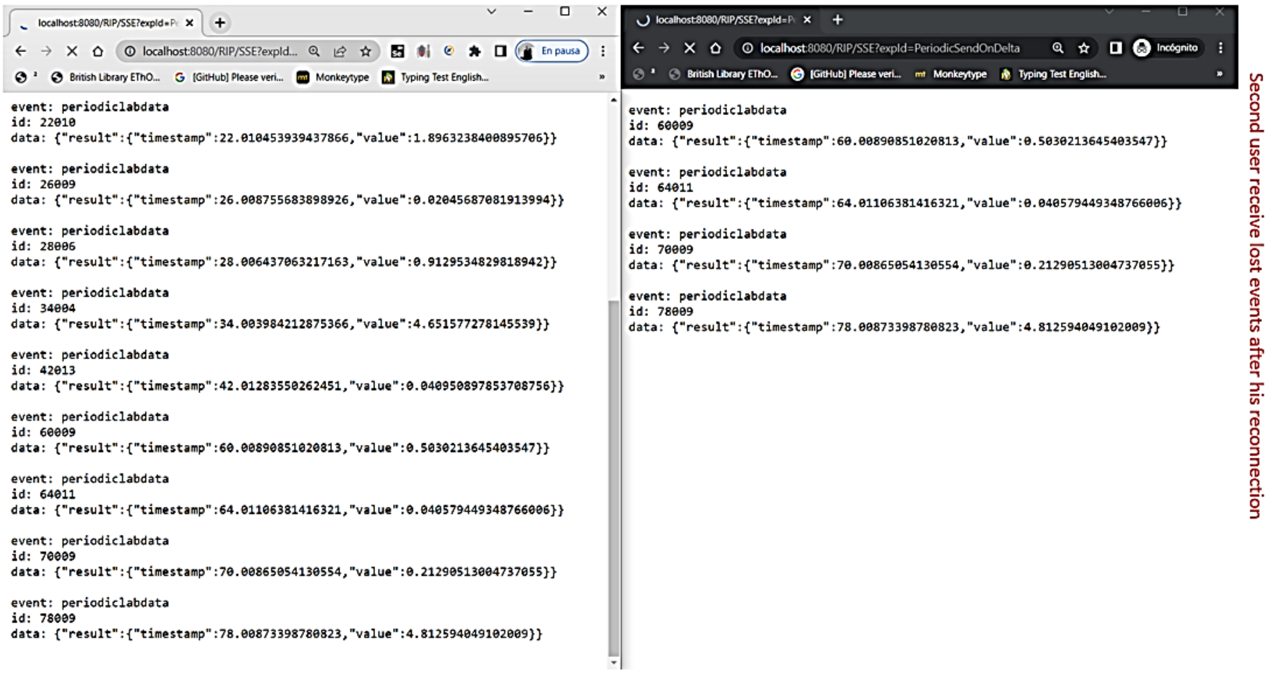
4.6.1 Test of reconnection and management of lost events

The test aims to verify a very important feature which consists of programming the server to record events when a user is disconnected and to return these events if the user manages to reconnect before the session is terminated. In fact, the expiration time of a user's session is configured on the server-side. Normally, if the user manages to reconnect to the server before the configured session expires, the user should receive all the lost events when he reconnects to the server. On the other hand, if the user reconnects after the session has expired, the server considers him as a new user and he receives the last events.

The Unittest codes that verify a set of scenarios to test the handling of lost events are presented in the following links:

- Two users
    - Reconnection before the session expires [163].
    - Reconnection after session expires [164].
- Three users
    - Reconnection before the session expires [165].
    - Reconnection after session expires [166].

Figure 4.7, illustrates the result of the test which consists in verifying that two users can access the server without a problem, the event is configured to be sent periodically (sse-period=2s).



```
event: periodiclabdata
id: 22010
data: {"result":{"timestamp":22.010453939437866,"value":1.8963238400895706}}

event: periodiclabdata
id: 26009
data: {"result":{"timestamp":26.008755683898926,"value":0.02045687081913994}}

event: periodiclabdata
id: 28006
data: {"result":{"timestamp":28.006437063217163,"value":0.9129534829818942}}

event: periodiclabdata
id: 34004
data: {"result":{"timestamp":34.003984212875366,"value":4.651577278145539}}

event: periodiclabdata
id: 42013
data: {"result":{"timestamp":42.01283550262451,"value":0.040950897853708756}}

event: periodiclabdata
id: 60009
data: {"result":{"timestamp":60.00890851020813,"value":0.5030213645403547}}

event: periodiclabdata
id: 64011
data: {"result":{"timestamp":64.01106381416321,"value":0.040579449348766006}}

event: periodiclabdata
id: 70009
data: {"result":{"timestamp":70.00865054130554,"value":0.21290513004737055}}

event: periodiclabdata
id: 78009
data: {"result":{"timestamp":78.00873398780823,"value":4.812594049102009}}
```

```
event: periodiclabdata
id: 60009
data: {"result":{"timestamp":60.00890851020813,"value":0.5030213645403547}}

event: periodiclabdata
id: 64011
data: {"result":{"timestamp":64.01106381416321,"value":0.040579449348766006}}

event: periodiclabdata
id: 70009
data: {"result":{"timestamp":70.00865054130554,"value":0.21290513004737055}}

event: periodiclabdata
id: 78009
data: {"result":{"timestamp":78.00873398780823,"value":4.812594049102009}}
```

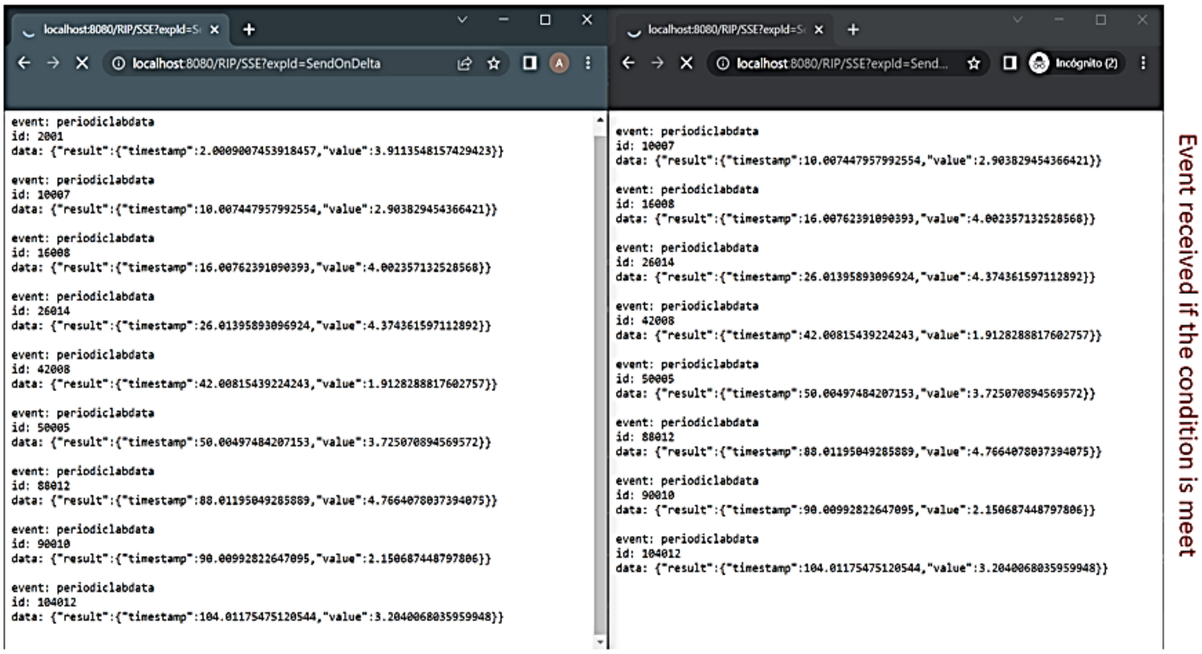
Second user receive lost events after his reconnection

Figure 4.6 — Resent of the lost events test result

The second user disconnect for 16 s and arrives at a logout, the user receives the lost events and continues to receive the next events as the first user. The session expiration time has been configured to 2 min and the sampler has been configured on a periodic sampling of events with a period of 2s.

4.6.1 SOD sampling tests

This part presents the Unittest code source to verify the ability of the server to update the event to the client based on periodic send-on-delta sampling. Figure 4.8, Illustrate two users connected to the server and receive events based on send-delta sampling where the condition is checked every 2 seconds. The Unittest code to check that two users receive the same event according to send on delta sampling.



```
event: periodiclabdata
id: 2001
data: {"result":{"timestamp":2.0009007453918457,"value":3.9113548157429423}}

event: periodiclabdata
id: 10007
data: {"result":{"timestamp":10.007447957992554,"value":2.903829454366421}}

event: periodiclabdata
id: 16008
data: {"result":{"timestamp":16.00762391090393,"value":4.002357132528568}}

event: periodiclabdata
id: 26014
data: {"result":{"timestamp":26.01395893096924,"value":4.374361597112892}}

event: periodiclabdata
id: 42008
data: {"result":{"timestamp":42.00815439224243,"value":1.9128288817602757}}

event: periodiclabdata
id: 50005
data: {"result":{"timestamp":50.00497484207153,"value":3.725070894569572}}

event: periodiclabdata
id: 88012
data: {"result":{"timestamp":88.01195049285889,"value":4.7664078037394075}}

event: periodiclabdata
id: 90010
data: {"result":{"timestamp":90.00992822647095,"value":2.150687448797806}}

event: periodiclabdata
id: 104012
data: {"result":{"timestamp":104.01175475120544,"value":3.2040068035959948}}
```

```
event: periodiclabdata
id: 10007
data: {"result":{"timestamp":10.007447957992554,"value":2.903829454366421}}

event: periodiclabdata
id: 16008
data: {"result":{"timestamp":16.00762391090393,"value":4.002357132528568}}

event: periodiclabdata
id: 26014
data: {"result":{"timestamp":26.01395893096924,"value":4.374361597112892}}

event: periodiclabdata
id: 42008
data: {"result":{"timestamp":42.00815439224243,"value":1.9128288817602757}}

event: periodiclabdata
id: 50005
data: {"result":{"timestamp":50.00497484207153,"value":3.725070894569572}}

event: periodiclabdata
id: 88012
data: {"result":{"timestamp":88.01195049285889,"value":4.7664078037394075}}

event: periodiclabdata
id: 90010
data: {"result":{"timestamp":90.00992822647095,"value":2.150687448797806}}

event: periodiclabdata
id: 104012
data: {"result":{"timestamp":104.01175475120544,"value":3.2040068035959948}}
```

Figure 4.7 — Send-on-delta sampling tests

4.7 Application on the Air Levitation system

The Air Levitation System Chacon et al. (2017) [167] is a low-cost experimental system for teaching control engineering. It is composed of a tube with a fan coupled to an end that generates an airflow that can lift a small object (a ball). The position of the ball is measured with a distance sensor that is mounted at the base of the tube. The ALS allows to carry out experiences of different levels of complexity, such as sensor calibration, model identification, controller tuning, or design.

Originally, the ALS was configured to use the standard version of RIP, thus being based on periodic sampling. In this section, we will update the server to incorporate the RIP extension for sampling methods, and then we configure it to use send-on-delta sampling. The experience provides two inputs (setpoint, servo), and two outputs (time, y).

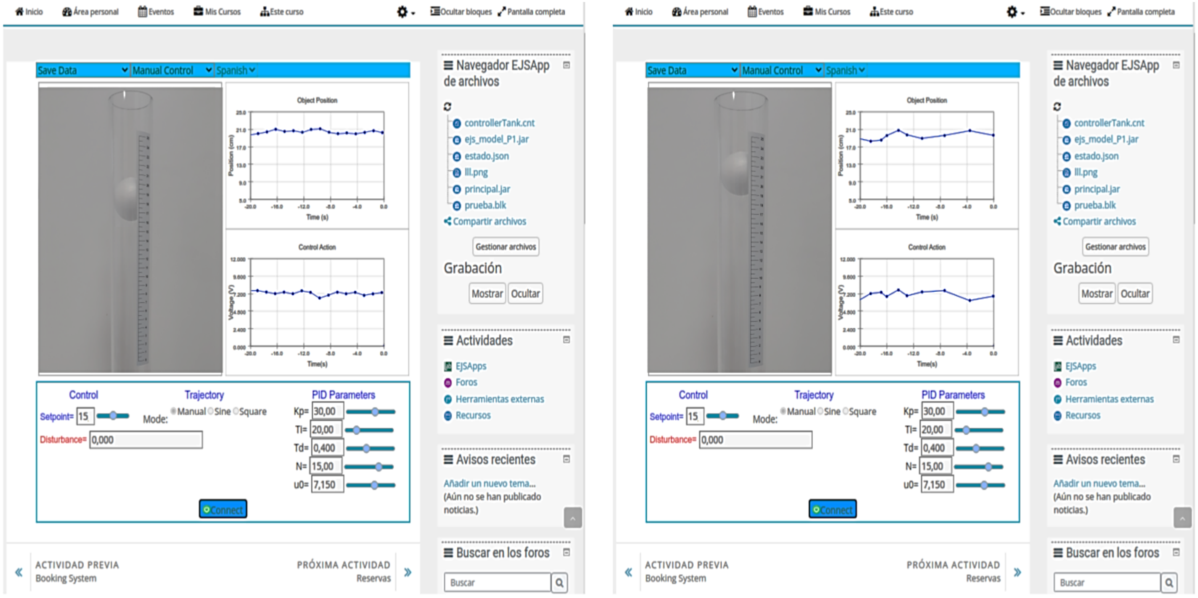
```
‘writables’: [{
   ’name ’: ’setpoint ’,
   ’description’: ’Set␣Point␣of␣the␣controller’,
   ’type ’: ’double ’,
   ’min ’: ’10’,
   ’max ’: ’30 ’,
   ’precision ’: ’0.5’
}, {
   ’name ’: ’servo ’,
   ’description ’: ’Disturbs␣the␣inputs␣airflow’,
   ’type ’: ’int ’,
   ’min ’: ’0 ’,
   ’max ’: ’180 ’,
  ’precision ’: ’1 ’
}],
’readables ’: [{
  ’name’: ’time ’,
  ’description’: ’Server␣time␣in␣seconds’,
  ’type ’: ’float ’,
  ’min ’: ’0 ’,
  ’max ’: ’Inf’,
  ’precision ’: ’0’
}, {
  ’name’: ’y’,
  ’description’: ’Output␣variables’,
  ’type’: ’array’,
  ’min’: ’0 ’,
  ’max ’: ’0 ’,
  ’precision’: ’0’
}],
```

Since the variables do not declare explicitly the sampling, that means that the server is using Level 1 Sampling. In this case, it is configured to send a sample every 100 ms. Since we have implemented the support for level 2 of the RIP extension, we can configure the server to use a different sampling method, in particular, we choose a send-on-delta sampling with $\delta = 0.5$ for the variable y that yields the position of the ball.

```
’readables ’: [
  ...
  {
  ’name’: ’y’,
  ...
  ’sampling’: {
     ’method’: ’delta’,
     ’params’: {’delta’: 0.5 },
```

```
    },
}],
```

Now, every time a new sample is taken, the web client will receive an SSE event with id delta and as payload the values of the last known state of the system. Figure 9 shows the interface of the remote laboratory. The plots show, respectively, the ball position (output) and the fan voltage (input). Since the OL on the left is configured to use a periodic sampling, the state of the server is notified to the web client every second. However, for the OL on the right (note that the web client is the same in both cases) a send-on-delta strategy is used to generate.



Setpoint= 15
Disturbance= 0,000
Kp= 30,00
Ti= 20,00
Td= 0,400
N= 15,00
u0= 7,150

Figure 4.8 — Remote laboratory of the Air Levitation System embedded in a course hosted in Moodle LMS. On the left, the OL is configured to use periodic sampling. On the right, the send-on-delta strategy is used to notify the ball position.

Part III: Tests of the blended learning contributions

Content

4.8 Test of the hybrid system based on BigBlueButton

4.8.1 Methodology

This contribution aims to evaluate the effectiveness of a distance learning system that provides theoretical and practical teaching, following a methodology that considers indicators at different levels of abstraction. The low-cost developed system consists of three subsystems that complement each other to provide remote training on solar energy. In this study, the analysis of the highest levels of indicators offers a panoramic view of the system performance. On the other hand, the low-level indicators make it possible to accurately identify the effect of the designed system on the learning process. The integration of new technological tools into engineering education should be supported by empirical evidence through clearly designed studies that validate the methods and tools that work best. In fact, it is currently difficult to measure the true effectiveness of these technological tools, especially in open-access universities and in crisis or upheaval times [168, 169].

In the pilot study, the evaluation was conducted on two groups of 50 students each one at the Sultane Moulay Slimane University, in Morocco. The first group learns the theory of photovoltaic devices in the classroom and performs the lab session by measuring directly the current and voltage from the studied photovoltaic device, then they use the solar panel graphical user interface as a simulation tool to study the parameters influencing the performance of this device. On the Other hand, the second group performed all the learning processes remotely using the technological architecture proposed in this work.

***Table 8**: Course contents on which the technological system was evaluated*

Competency	**Check compliance with quality and safety standards**	
Learning outcome	**Indicators**	**Low-level Indicators**
The students must be able to set up and operate an energy installation and verify its compliance with quality standards.	The students analyze the electric measurements of the Current (I) and Tension (V) from the studied device under different conditions.	***M-ES:*** Students determine the properties of I-V measurements under electric light and solar light
		M-C: Students determine the properties of I-V measurements under clouds.
		M-PS: Students determine the properties of I-V measurements under partial shading.
	The students recognize that mathematical models are simplifications that do not always mimic hardware's behavior adequately.	**P-DC:** Students plot the I-V characteristic and describe the performance of the solar panel being studied.
		E-IP: Students estimate the values of the different intrinsic parameters using the algorithm implemented by the solar panel GUI.
		C-MC: Students compare the actual measurements and the model predictions by quantifying the differences between the two with mathematical criteria.
	The students identify and interpret the main factors limiting the efficiency of photovoltaic conversion.	**I-Icc:** Students interpret the value of short circuit currents Icc.
		I-Vo: Students interpret the open circuit voltage value Vco.
		I-FF: Students interpret the form factor FF.
		I-IP: Students determine the influence of intrinsic parameters namely, Iph, Is, η, Rs, Rsh.

A Serie of open and closed questions to have students' opinion about the usability and usefulness of the two methods of providing the energy renewable course has en elaborated. The students' good comprehension was measured by a final test containing the questions based on the indicators cited in Table 8 to show how well they learned the objective of the course.

In previous courses, students have performed poorly in this content, especially when it comes to analyzing and discussing the effects of internal parameters on the performance of solar panels. Consequently, the instructors decided to integrate a system allowing to enrich this concept in presential, through the graphical user interface of the solar panel as a simulation prototype and remotely by combining the graphical interface with the IoT measurement system and the BigBlueButton system to boost their understanding remotely.

The adopted methodology of evaluation in this study enables instructors to analyze information at different abstraction levels in our learning experience. In fact, the data are organized hierarchically in a competency-based model, where the higher levels provide a panoramic view of the results, and the fine-grained analysis help to identify the innovation's effect accurately. This methodology was presented in the following work [170] and recommended as a methodology that guides researchers and practitioners to perform evaluations for collecting evidence about the strengths and shortcomings of technological tools.

4.8.2 Research findings

The results of the evaluation of the learning experience of the two groups are presented in this section. Indeed, the evaluation methodology adopted in this study is carried out in two stages of analysis. Firstly, a qualitative analysis was carried out with open and closed questions to gather information on the effectiveness of the two teaching methodologies adopted in this study. On the other hand, a quantitative analysis was carried out by analyzing the students' scores according to the competency structure presented in Table 8. Particularly we targeted the following research questions:

- ***RQ1: Educational value of the proposed technological architecture***. Is the hybrid BigBlueButton-based architecture useful for improving solar transformation analysis and interpretation skills remotely? In previous course editions, students have performed poorly in this content especially when it comes to analyzing and discussing the effect of internal parameters on the performance of solar panels. This concept was explained traditionally durant the course session because these parameters are not measurable or included in the actual manufacturing data and must be determined from an I-V equation system at various operating points or through the experimental data based on numerical methods.
- ***RQ2: The hybrid BigBlueButton-based architecture melioration***. What are the issues faced when using the BigBlueButton-based architecture and what improvement do students demand. We intend to support and improve the tools that have been developed by our team, namely, the graphical user interface and the remote IoT measurement system to provide a complete technical solution for our students in the future. Our assessments and tests could help developer teams by examining student experience on the BigBlueButton video conferencing platform and detecting new features that should be improved and incorporated.

A. Qualitative analysis

During our investigation of satisfaction toward the two teaching methods, namely The Remote Teaching method (RTM) based on (the BigBlueButton videoconference system for delivering theoretical teaching and the graphical user interface, the remote IoT measurement system for providing a remote practical learning experience) and the traditional or the Presential Teaching Method method (PTM) providing theoretical learning in the classroom and practical session in laboratories. In the PTM method, the description of the desktop interface has been issued traditionally in direct contact with the teacher who describes during the session the various steps necessary for the desktop interface operation. Students were equipped with their laptop, the interface, and a folder containing all the I-V experimental measurements issued from the PW.

Students were asked to fill out a straightforward questionnaire at the end of each learning experience. The presented questionnaire contains two closed questions to gather students' opinions on the effective usability of the two methods and two open-ended questions giving deeper and new insight by prompting students to answer with formulated sentences to center their responses.

- Closed questions

This section presents the obtained frequencies for two closed questions that inquire students about the effective use of the technical architecture of the RTM proposed in this study. Responses are rated on a five-point Likert scale as shown in Figure 4.10. The authors prepared questions for the surveys based on key factors that were identified from the literature review to gather information on the learning experiences studies in this work.

A K factor is calculated using both equations (1) and (2), where S is the average of the student responses for each question and K is the percentage of S by the number of choices in each question. In our case N = 50 represents the number of students in each group, M = 5 is the number of answers for each question and The "Rj" is the response of student j for each question.

Figure 4.10 Summarizes the questions adopted for measuring the effectiveness of the BigBlueButton based technological architecture presented as a remote teaching method in this study RTM, the Likert scale, the obtained frequencies as well as the K factors associated with the questions in the two teaching methods during this study.

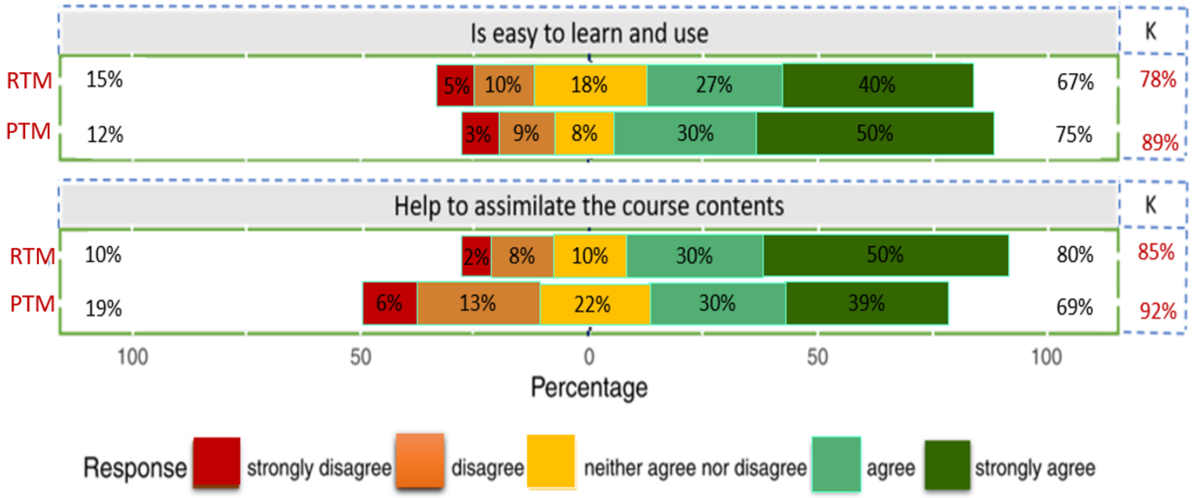


Figure 4.9 — Students' response frequencies to the close questions

According to the closed questions, the learning method based on the remote educational system proposed in this study is appropriate in transmitting the theoretical and practical knowledge needed remotely but its less useable in comparison with the traditional/presential educational method of teaching and learning in the students' point of view in our introductory course on solar energy. The satisfaction of the students who have experienced the technological and the traditional methods of learning never reaches 100 % but is greater than 78 % according to the measure of the K factor of each question. On the other hand, it is notable that the measured values of the K factor relative to the RTM method approach to those of the PTM.

- Open questions

The survey study adopted in this work includes open-ended questions to encourage students to express honest and personal opinions on the strengths and weaknesses of the technical architecture of the remote education method. The open-ended questions were formulated as sentence completion items to focus the students' responses.

Please complete the following sentense in your own words:

1) RES strengths to learn the analysis of solar energy transformation are…
2) RES weakneses and my suggestions to improve it are…

Table 9 summarizes the responses of the group that used the BigBlueButton-based technological architecture. The right column indicates the percentage of students who agree with the answer in the left column. Table 9 summarizes the opinions supported by at least three students.

Table 9. Students' responses to the open-ended questions

strengths of the proposed system	
The ability to provide a theoretical and practical learning experience by the use of the technological architecture proposed.	78.19%
A good illustration of the several parameters' effect on the performance of the photovoltaic device studied.	70%
High interactivity	43.90 %
The ability to own the learning and have the choice to choose the best place to learn.	75.13%
Weaknesses and suggested improvements	
Documentation should be improved and a video tutorial with examples of how to use each element of the technological architecture should be provided.	40.2 %
The graphical interfaces of the technological tools in the distance education system are rigid, therefore more simplified versions should be available.	19 %
Technical difficulties related to Internet connexion problems when using the BBB video conferencing system and the remote IoT measurement system.	75%

The open-ended questions concerning the remote technological architecture reinforce that the proposed system is appropriate as a remote learning system mixing theoretical and practical teaching on solar energy. However, students think that the proposed system needs to be polished in various aspects that affect its learnability and usability.

B. Quantitative analysis

The qualitative study presented in this work was carried out in two stages. The first aims to analyze the results of the global final examination carried out during the solar energy course by the two groups presented in this study. The second part consists in analyzing the low-level indicators presented in Table 8. It is worth noting that all students undertook the same global exam consisting of a set of questions to measure the indicators presented in Table 8.

✶ Global exam

This section aims to compare the results of the final global exam passed after the course period. The total scores considering the global exam are presented in Figure 4.11 and Table 3. It is worth noting that in the Morrocan education system, students are graded from 0 to 20. Accordingly, a score of a teen is the threshold to pass the exam. The black line in Figure 4.11 indicates the passing score for the exam.

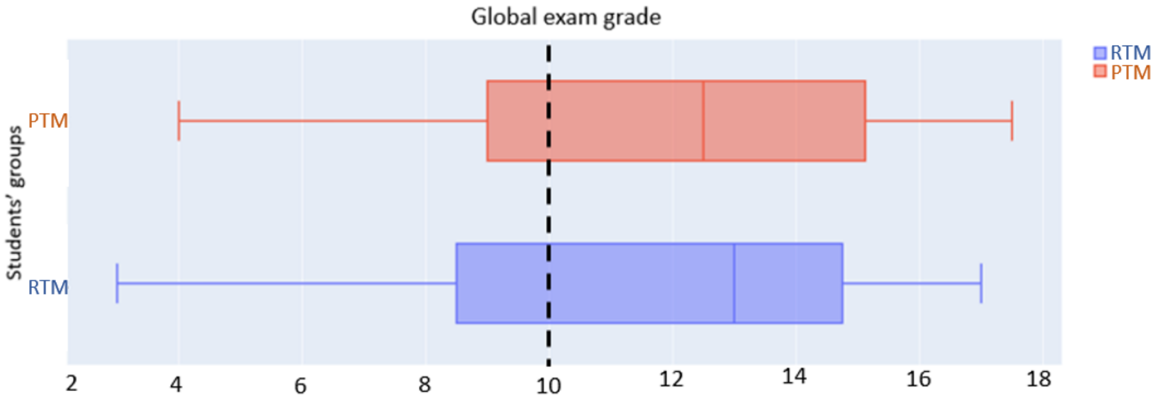


Figure 4.10 — PTM and RTM groups' global grades

The box plot presented in Figure 4.11, helps in examining the key statistical properties of the global exam. According to the box-plot graph, the distribution of students' marks is almost similar in the two groups. The lowest score “3” was recorded in the group that conducted the remote study against “4” in the group which is carried out the course through the traditional method. On the other hand, the success rate is slightly higher in the presential method compared to the remote method. We can note that the majority of students who have succeeded in exceeding the threshold are part of the group which attended the course, on the other hand, the difference is not too remarkable between the two groups as shown in Table 10.

Table 10. Descriptive statistics of the global exam grades

Data Summary								
Groups	**N**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
PTM	45	4	9	12.5	15	17.5	11.944	3.674
RTM	48	3	8.75	13	14.62	17	11.557	4.112

According to Table 10, We can conclude that the distance teaching method based on the technological architecture presented in this study was able to achieve comparable results to those of the traditional method which is proved by the mean of students' marks in the two groups. The traditional method remains the most appropriate for our students and the one which gives more performance. On the other hand, this study was able to conclude certain points of improvement to approach the two teaching methods in our course on solar energy transformation.

✶ Low-level indicators

In this study, we were particularly interested in whether the low-cost distance education system helps students achieve the learning outcomes on solar energy transformation concepts. Accordingly, this section focuses on the analysis of the fine-grained indicators presented in Table 8. These indicators were measured through 10 questions in the global exam presented to the two groups in this study. The final exam was scored from 0 to 20 and each question is scored from 0 to 2. Table 11 summarizes and visualize key statistical measure such as median, mean, and quartiles (Q1, Q3) of the exam scores for these specific indicators. For example M-ES (The students' ability to determine the properties of the current and tension measurement under "Electric light" and "Solar light"), M-C refers to (the students' ability to determine the properties of the current and tension under "Clouds").

Table 11. Descriptive statistics of the exam indicators

		Mean	Q1	Median	Q3	SD
M-ES	PTM	1.197	0.500	1.000	2.000	0.707
	RTM	1.142	0.500	0.900	1.500	0.696
M-C	PTM	1.213	0.500	1.000	2.000	0.751
	RTM	1.195	0.550	1.000	1.550	0.698
M-PS	PTM	1.192	0.400	0.800	2.000	0.711
	RTM	1.224	0.490	1.000	1.800	0.652
P-DC	PTM	1.134	1.000	1.000	1.750	0.639
	RTM	1.139	1.000	1.000	1.750	0.659
E-IP	PTM	1.201	0.500	1.000	2.000	0.784
	RTM	1.279	0.500	0.700	1.900	0.701
C-MC	PTM	1.153	0.450	1.000	1.760	0. 712
	RTM	1.214	0.200	1.000	2.000	0.721
I-Icc	PTM	0,958	0.300	1.000	1,400	0.654
	RTM	0,494	0.000	0.000	0.600	0.698
I-Vo	PTM	1.130	0.400	1.200	2.000	0.710
	RTM	1.204	0.800	1.000	1.600	0.550
I-FF	PTM	0.954	0.600	0.600	1.200	0.500
	RTM	0.614	0.000	0.000	1.200	0.748
I-IP	PTM	1.153	0.490	1.000	1.760	0. 712
	RTM	1.214	0.400	1.000	2.000	0.785

The first three indicators (M-ES, M-C, M-PS) aimed to assess the students' ability to analyze the electrical measurement of the current (I) and the voltage (V) of the photovoltaic device studied under different conditions. The first group of students carries out this measurement in the laboratory in direct contact with the professor and the photovoltaic device. On the other hand, the second group carried out the measurement remotely via the IoT measurement system as well as the contact with the professor was carried out through the BigBlueButton videoconference system. According to the results, the mean of answer success to the three questions is slightly high in the laboratory-based method compared to the measurement and analysis carried out at distance. The results agree with previous research opinions on the effectiveness of practical work carried out in laboratories compared to those carried out by remote-controlled laboratories and also prove that remote methods are a good option to perform distance practical work in some cases.

The following indicators (P-DC, E-IP, C-MC) aimed to evaluate the students' ability to estimate the value of the different intrinsic parameters using the algorithm implemented by the solar panel graphical interface and to recognize that mathematical models are a simplification do not always mimic hardware's behavior adequately. From the students' scores on these questions, it can be concluded that the graphical user interface was useful and allowed students in both groups to summarize and understand the characteristic nature of the photovoltaic device studied. On the other hand, the average marks of the students who carry out the experience of distance teaching are higher than those in face-to-face. We believe that remote use of the graphical user interface deepens students' knowledge by following the demonstration presented by BigBlueButton as they have a lot more time to practice and they feel more relaxed when asking questions.

The last four indicators (I-Icc, I-Vo, I-FF, I-IP) aimed to evaluate the students' ability to identify and interpret the main factors limiting the efficiency of the photovoltaic conversion. This last part of the exam is related to the issues analyzed in the last two paragraphs, namely (the measurement of current and voltage and then the use of these measurements for the operation of the graphical interface) to analyze the influence of different parameters on the performance of the photovoltaic device studied. Through the results, the students who were able to overstate the two previous stages of the exam were able in a similar way in the two groups to interpret the values and the influence of the different parameters on the I-V characteristic of the photovoltaic device.

4.8.1 Benefits and limitations of the contribution

The proposed contribution in this work provides a low-cost hybrid technical system that provides theoretical and practical teaching on solar energy transformation. The hybrid system allows for the transmission of solid fundamental knowledge of solar energy. The architecture of the proposed system contains three subsystems that complement the technologies needed to implement distance learning capable of describing the behavior of solar panels under various climatic conditions. The educational system is based on the BigBlueButton open-source video conferencing software used as an online classroom. On the other hand, the second subsystem is a MATLAB graphical user interface that extracts the intrinsic parameters of solar panels to study their effects on the performance of photovoltaic devices. While the third subsystem is remote controlled plant based on IoT systems allowing students to measure remotely the value of the current and tension needed for the operation of the graphical user interface. The indicator results prove that the proposed systems can be used as an alternative to improve the student's skills in the solar panel concepts of our renewable energy courses. On the limitation side, some connection problems were mentioned by some students due to technical issues related to the performance of their computer or the Internet connection. On the other hand, some delay was noticed in the connection to the remote PW work for current and voltage measurement. As a result, we plan as our next work to reduce the architecture from three subsystems to only two by developing the solar measurement system on the graphical user interface using MATLAB to optimally reduce the conduction time of the remote experiment.

4.9 Test of the classroom response system based on Raspberry

4.9.1 Methodology

The technical contribution of this study presents a low-cost architecture based on the Raspberry embedded system to host and run a classroom response system. The software solution was developed using web-based technologies, which makes the system easy to use in an educational system. The evaluation of the educational system was conducted in two main stages. The first one aims at testing the technical performance of the system and its ability to broadcast questions and collect answers from students by powering up the system and measuring its performance using the Linux Sysbench software. On the other hand, the student's opinion on the integration of the response system in the classroom was measured using a questionnaire.

Indeed, during the course, questions or series of questions were asked depending on the nature and progress of the course. Students were invited to log on to RaspCRS and answer the teacher's questions. After a short period, usually less than 5 minutes, students are allowed to answer the question. Afterward, students are allowed to discuss with their classmates and try to convince them of the correct answer. In the end, the teacher explains the reasoning behind the correct answer.

We prepared questions for our survey based on the main factors that were identified from literature reviews, to help us collect about the use of the classroom response system [171, 172]. The questionnaire focus on the interaction of students with the CRS through three preliminary questions and four questions that measures the satisfaction of these students with these technology tools.

Students' feedback is obtained by filling in a questionnaire sent to the email section that included questions on the following:

Preliminary questions:

1. Did you attempt to answer the teacher’s questions?
2. Did you discuss answers with a classmate(s)?
3. Did you bring an internet-enabled device?

Satisfaction questions:

4. The use of CRS and discussion improved your understanding of the unit content?
5. The use of CRS and discussion increased your interaction with the lecturer?
6. The use of CRS and discussion increased your interaction with other students?
7. Do you recommend the use of CRS to test the understanding of students?

4.9.2 Research findings

This part deals with the results of the study. Technical and pedagogical tests to check the validity of the proposed architecture were conducted with 40 students enrolled in a renewable energy program at the Polydisciplinary Faculty of Beni Mellal, Morrocco.

Functionally the results were satisfactory, with a bandwidth greater than 54 Mbit/s the flexibility of the system reaches a flexible level, the student obtains the questions and transmits their answers to the teacher, with an average transaction time equal to 10 seconds. Point out that the Wi-Fi implemented on the Raspberry Pi 3 allows obtaining rates from 7 Mbit/s to 70 Mbit/s. Access to the Classroom response system has been tested taking into account the different browsers installed on users' devices as shown in Table 12.

Table 12. Access test according to different browsers

Navigator	Version	Functional
M.FireFox	55.0	Yes
I. Explorer	11.0.11	Yes
G.Chrome	64.0	Yes
Safari	5.1.7	Yes

Through the test results presented in Table 12, these browsers have allocated access to the CRS application. It is strongly recommended to install the latest version of the browsers because it allows avoiding problems access to the server. Several good reasons to configure Raspberry pi 3 as a server offering educational services, teachers' point of view, the size of this card makes it useful as a portable device. Another alternative is to host the classroom response system on a local server in the teacher's computer, comparing this solution with our architecture, the Raspberry Pi 3 can be turned on for a long time. As this card has low energy and economic footprint, this makes it a good choice under a low charge.

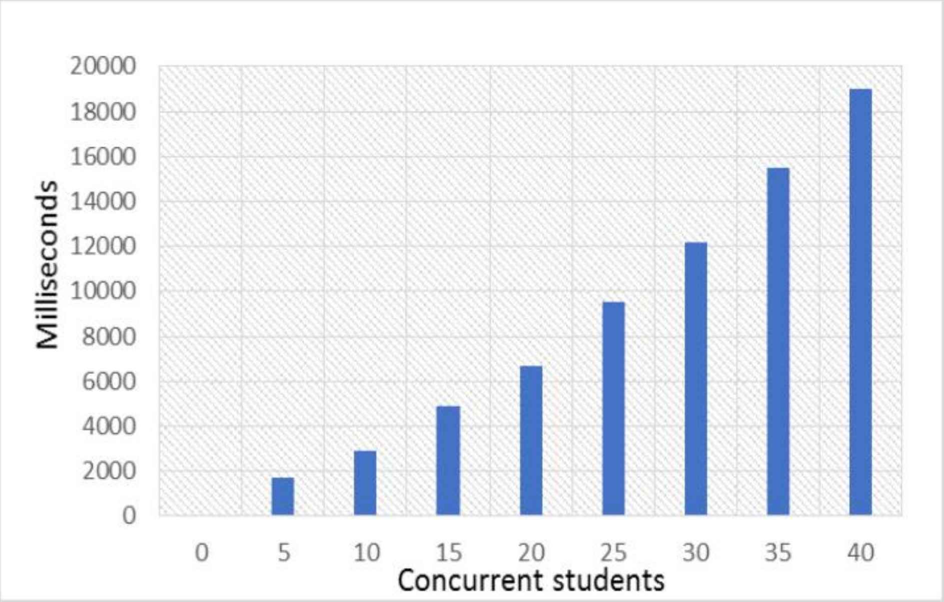


Figure 4.11 — The average transaction time of student's response on RaspCRS

To better discuss the weakness of this new pedagogy of learning especially when the number of students increases or decreases by less than 30 students, we tested the system with 10 more students using the Sysbench software for Linux which is a benchmark and stress test method often used to gauge the performance of desktop application and server. These tests are also useful in finding hardware problems and system anomalies that are observed only when a system is under a heavy load. The results are shown in Figure 4.12.

According to the graph, The response time increases by 3300 milliseconds for 35 students, and 6810 milliseconds for 40 students. It can be noticed that the difficulties increase as the load increases, which is a remarkable disadvantage as regards the performances.

Pedagogically speaking, 80% of students reported that the interaction between them and the teacher had been improved, students claimed that this methodology helped them to get their attention, with 90% of participants giving positive feedback on this system. Answers to questions anonymously through RaspCRS made the students feel better, giving their opinions reliably and freely presenting their true understanding of the concept developed during the lessons. This methodology allowed the teacher to open a channel of communication when the rate of bad answers is high; we noticed that on average this discussion allows spreading the duration of the session by 15%.

The statistics of student responses to the three preliminary questions are presented in Figure 3.10. 35 students usually try to answer the teacher's question, while 8 students sometimes answer and 2 do not use their laptops to participate in this activity. In response to the second question, it is clear that the methodology followed increased interaction between students. The result has been favorable and falls in the way of the objectives of a system that improves privacy and interactivity. The third question focuses on the essential material used by students to respond to teacher questions, according to statistics, more than 80% ensure that they have brought their internet-enabled device to the course.

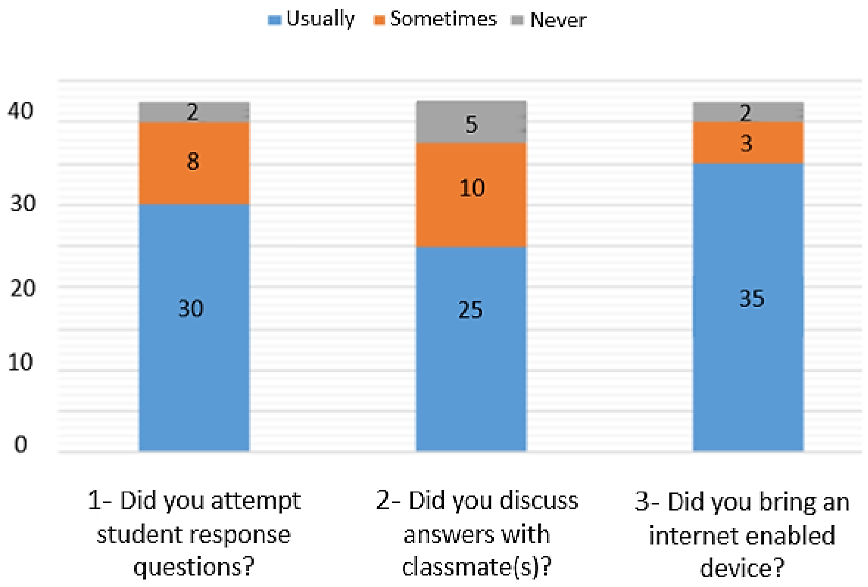


Figure 4.12 —Response to preliminary questions

4.9.3 Benefits and limitations of the contribution

Educational innovation has challenged the pedagogical practice in traditional courses because the lectures do not produce the learning goal that is presumed to achieve. A classroom response system proposed in the market of education is generally a project that proposes expensive hardware and software architectures. This contribution proposed a low-cost technical architecture for the operation of a classroom response system developed using web technology. Several good reasons to configure Raspberry pi 3 as a server offering educational services. The size of this card makes it useful as a portable device. Another alternative is to host the classroom response system on a local server in the teacher's computer, comparing this solution with our architecture, the Raspberry Pi 3 can be turned on for a long time. As this card has low energy and economic footprint, this makes it a good choice under a low charge. The proposed solution was tested during a course on renewable energy with 40 students. The interaction between the students and the teacher is more complex in the amphitheater lecture with a larger number of students. We have noticed a delay in interaction with the Raspberry-based system when the number of students connecting to the system exceeds 35 students simultaneously. Accordingly, the implementation of the solution in the amphitheater lecture requires the hosting of the software solution in a powerful server in order to improve the interaction of the teacher with a large number of students.

4.10 Conclusion

The mainstreaming of digital learning technologies into the educational process has been highlighted as a main key factor in reducing the digital divide. Despite the considerable growth in the number of technologies acquired by HEIs in developing countries in recent years and the sacrifices made to fund them, there has been little assessment of their assessment. Academic staff of HEIs must be able to analyze the needs of their students, propose and design the necessary technological solution, and set the directives for their efficient and effective use by conducting well-designed studies to highlight the advantage and weaknesses of the educational system designed.

This chapter has presented the contributions tests of the different technical contributions made during this thesis research. These contributions have been described in detail in chapter 3 and were divided into three main parts: (1) remote IoT-based labs contributions, (2) Event-based control laboratory practice, (3) Blended learning contributions. Accordingly, this chapter has presented the contributions tests of the three main parts of the contributions respectively, where for each contribution the methodology, results in findings, as well as benefits and limitations of the research, are presented. The learning evaluation of the remote IoT-based lab's prototypes conducted at the Polydisciplinary Faculty of Beni Mellal, Morocco, have a positive impact on teaching and learning where factors and variables received from users' experience are systematically collected and analyzed through well-designed questionnaires. The second part focus on the evaluation of a new extension of the RIP protocol that allows more precise and sophisticated management of the communication process in control systems. The tests of the contribution was done in two steps. The first one consists to validate the new integrated functionalities using unit testing Python programs to determine that they are fit for purpose. On the other hand, the new version of the RIP-Python server has been integrated into an Air Levitation system which refers to an online laboratory for control engineering deployed in the UNILabs platform. The third part presents the learning evaluation of two blended learning contributions according to a detailed methodology, the student's perception of the user of these technologies was protective and proves that it can be adopted as alternative teaching and learning technological scenarios to support the educational process within the ongoing changes in the educational system, especially in open access universities.

These kinds of surveys make an influential contribution by offering evidence of students' and academic staff's experience about the integration of different types of technologies. The effects of technology on the teaching and learning process are most often obtained by examining teachers' and students' perceptions of the usefulness of the proposed technology during the teaching and learning process, assessing their level of technology integration, determining the motivational factors that drive them, and identifying the challenges that inhibit.

Chapter 5

Conclusion and Future Studies

Content

This thesis is a contribution to the challenges faced by HEIs, that propose low-cost IoT-based architecture to face some problems related to putting online engineering PWs and propose a solution to the decrease of interaction between teachers and students in mass context, with a particular application to electronics, automatic control, and renewable energy disciplines. The following chapter presents a summary of the motivation that conducted the study and the research question on which the study has been focused. This is followed by presenting the technical contributions made and test methodology followed to answer the research questions. The chapter presents the benefits and limitations of each contribution as well as a proposal for further studies in the three main contexts of the contributions.

5.1 Conclusion

The challenges faced by HEIs and the ongoing change in the educational system are forcing developers and education providers around the world to involve in the creation of innovative resources and consider cost-effective educational scenarios. HEIs are inevitably experiencing a rapid increase in student enrollment which has occurred without an accompanying increase in financial, physical, and human resources. Unfortunately, this situation has a direct and perceptible impact on the quality of the teaching and learning process, especially in developing countries where the scale of the magnitude of challenges is greater. HEIs are turning to the next generation of innovative technologies and cost-effective systems to respond to the growing global pressures to maintain strong outcomes and improve performance levels while meeting expectations and respecting shrinking budgets.

The expansion of connectivity and interoperability devices has paved the way for the development of IoT technology, which is an upcoming concept that is contributing to offensive quality improvement in education. IoT is expected to impact many facets of education, but it has not been widely reported and validated. Therefore, several intrinsic benefits of implementing IoT systems in the educational environment are not yet studied and referred in the literature. The digital divide, which refers to differences in financial incomes and education levels between developed and developing countries is one of the important factors that affect the acceptance and diffusion of IoT technology. The severity of the challenges faced by HEIs and the integration degree of technologies to address these challenges vary considerably between developed and developing countries. The majority of the technological solutions proposed come from active companies in the field of education or were born within the framework of well-supported projects in well-recognized universities. Accordingly, several platforms allowing for the enhancement of theoretical and practical teaching are proposed in the market of higher education. However, the price of these solutions is not affordable for all universities in developing countries, especially RLs platforms that seek to provide an answer to the problems of Practical Works (PWs) in STEM courses. Therefore, developers and researchers need to consider this difference in order to provide a low-cost technical solution for HEIs in several developing countries to address their challenges and reduce inequality as well as the potential rejection of IoT implementation.

5.1.1 Research questions-revisited

The main motivating factors that led to the development and evaluation of the technical contribution made during this thesis are the challenges faced by HEIs in most developing countries, regarding:

1. Provision of meaningful remote laboratory experiences based on low-cost IoT systems, given the typically high costs of the traditional engineering laboratory, the large class sizes as well as the high costs of PWs online platforms.

2. Provision of an API solution that allows for more accurate and sophisticated communication management in the remote-controlled system. Management of the communication process is an important issue that developers and educations providers meet when creating OLs. Accordingly, a communication solution that reduces the exchange load between client and server, handles multiple user access to the hardware, manages the lost information during users' disconnections problems, and provides more configuration possible for the networked control systems is needed.

3. Provision of meaningful and low-cost architecture for IoT-based educational systems to enhance engagement and interaction between teachers and students during classrooms lectures in a mass context.

Based on the motivations cited above and taking into account the need to reform the teaching methods in HEIs to cope with congestion and several challenges. This thesis attempted to address some of the difficulties by developing and implementing low-cost IoT systems to improve the teaching and learning process by developing RLs and blended learning educational systems. Indeed, the research questions were divided according to the context of contributions, namely in the remote electronic lab, in control laboratory practice, and in blended learning. Particularly, we targeted the following research questions:

A. Remote IoT-based labs questions

- ***RQ1: Educational value and effectiveness of the low-cost IoT-based architectures proposed for remote PWs.*** Are the IoT systems proposed in each contribution able to succeed in transmitting the same knowledge as in a hands-on lab? What are students´ perceptions/opinions about the remote lab's activities based on the proposed architectures?

- ***RQ2: The low-cost IoT-based architectures melioration.*** What are the issues faced when conducting remote PWs activities based on the low-cost IoT-based architectures? What are the limitations of these technical contributions and how can they be maintained and improved to meet the technical and pedagogical challenges?

B. Event-based labs control questions

- ***RQ3: Educational value and effectiveness of the RIP Python server extension.*** Are the new features implemented on the RIP python server work properly? What is the added value of the generalized sampling proposed for OL? Are the new architecture of the RIP Python server able to run properly on an OL prototype?

- ***RQ4: The RIP Python server melioration.*** What are the issue and limits of the new architectures? Are the Unit testing programs validate the proper working of the integrated features in the RIP Python server extension? What are the issue and limitations when running the new extension on an OL (Air Levitation system) prototype?

C. Blended learning systems questions

- ***RQ5: Educational value and effectiveness of the blended learning systems developed.*** Are the technological architectures developed useful for improving teacher-student interaction during presential and distance lectures? How effective are these educational systems in improving the learning process? What are students´ perceptions/opinions about the blended system proposed?

- ***RQ6: The low-cost blended learning systems melioration.*** What are the issues faced when using the classroom response system and the BigBlueButton based architecture and what improvement do students demand in the two technological architectures proposed?

5.1.2 Technical contributions and tests

The main focus of this thesis was the development, implementation, and test of open source software and low-cost IoT-based technical system to deal with certain challenges of engineering education in HEIs. The technical contributions made during this thesis has been validated according to designed studies in order to highlight the advantage and limitations of the developed systems as well as to investigate how the integration of the low-cost IoT-based educational systems supports the engagement of students and how they can influence the way they collaborate and communicate in a HEIs. These types of studies make a very important contribution to the literature by providing low-cost architectures for educational systems, as well as evidence of student and academic staff experience using IoT technology through well-designed studies to provide clear pathways for instructional use and technical improvements.

A. Remote IoT-based labs contributions

- ***First contribution:*** It presents the design and the implementation of an IoT system allowing several remote manipulations in the field of analog electronics. This solution is mainly based on the Red Pitaya STEMLab board, in particular for communication and remote control for measurements and data acquisition through different protocols. The low-cost system provides an intelligent selection between the different practical works (PWs) integrated on a developed board, as well as other ones carried out externally as extensions according to the professor's needs.
    - ***test methodology:*** An RC charge and discharge PW has been selected to conduct a comparative study between the hands-on PW and the same PW performed using the IoT-based RL. The evaluation of the developed system has been conducted with 24 students enrolled in the 3rd year of the «Electronic Program» at the Sultan Moulay Slimane University of Beni Mellal, Morocco. The evaluation adopts a questionnaire that includes open and closed questions to capture students' perceptions of the proposed system.
        - ✦ ***Research Findings:*** The analysis of the student's responses shows generally a favorable perception about the IoT-based RL. On one hand, the hands-on lab activities are still the PW environment preferred by students. On the other hand, the minor differences between students' perceptions of the two PW environments prove that the developed architectures can be adopted as a complement or alternative for performing Electronic PWs.
- ***Second contribution:*** It aims to present an operational low-cost architecture of remote experimentation in analog electronics based on the cooperation of two embedded systems, Raspberry and Arduino. The student accesses the practical work via a web page developed with HTML/Javascript provided by the NodeJs server hosted in Raspberry. In this contribution, a software oscilloscope has been developed with processing integrable in the web page to visualize the measured signals from the practical work board.

    - ***Test methodology:*** A sample of 20 students in the electronic program tested the proposed prototype at the Sultan Moulay Slimane University of Beni Mellal, Morocco. They were divided into two groups, the first one performed the manipulations locally in the physical laboratory, while the second group used the remote architecture to perform the PWs. At the end of the manipulations, both groups of students were asked to complete a 4 questions questionnaire.

        - ✦ ***Research findings:*** Students in both groups are satisfied with the ease of use and understanding of the software oscilloscope in the same way. Students feel that they have enough time to do the remote PWs. Some of them need the teacher's guidance during remote activities. There is a clear correlation between the variables of students' responses in remote lab and hands-on lab which proves students' satisfaction.

- ▪ ***Third contribution:*** A DC motor laboratory practice was designed in three PWs environments to conduct a comparative study. The contributions aim to capture students' perception of the three PWs environments, namely, hands-on, simulated, and online remote-controlled lab.

    - ***Test methodology:*** The following contribution report on the application of a methodology that takes into account the interaction between students and teachers at a different level of abstraction to evaluate the DC motor laboratory practice. The impact of each environment can be analyzed statistically by looking at specific skills or indicators respectively. The evaluation was carried out with 150 students enrolled in the Physics degree program at the Polydisciplinary Faculty of Beni Mellal. The adopted questionnaire consisted of two main parts. The first one focus on the relationship between students, teachers, and the PW environments. The second part consists of measuring student satisfaction toward usefulness, usability, student motivation, and quality of understanding.

        - ✦ ***Research findings:*** Based on the student's responses, students believe that the three types of PW environments presented in this study are generally valuable. The results prove the flexibility of students in using the ICTs. The majority of students prefer hands-on labs to perform PW which also dominates in terms of collaboration. On the other hand, students found that remote lab give them more flexibility and save their time. Results also suggest that remote labs are comparable in effectiveness to hands-on labs, at least in teaching basic applications according to four parameters measured in the second part of the questionnaire.

B. Event-based labs control contributions

- This contribution falls within the field of automatic control and focuses on the communication process of building VRLs. It presents a new extension of the RIP Protocol that allows more precise and sophisticated management of the communication in the control system. novel control strategies have appeared in the literature intending to improve performance by reducing the communication between the different elements of a controlled system. In this regard, the RIP protocol developed by the UNEDLabs offers a simple and powerful communication tool that defines a standard method to communicate and control an online laboratory based on HTTP methods. The enhanced version of the RIP Python server implementation solution implements Server-Sent-event as an effective communication protocol to enable the use of event-triggered and self-triggered control techniques in educational RLs based on web applications that run on a web browser without any additional requirements. The new extension of the RIP Python server handles multiple user access, automatically reconnects, and resents lost event streams for the disconnected users, as well as the extension, proposes an architecture to implement generalized sampling in online Laboratories.

    - *Test Methodology:* The new extension of the RIP Python server presented in this thesis has been validated in two main steps. The first step consists of validating each integrated functionality separately using unit testing Python programs. On the other hand, An integration of the new version of the RIP-Python server on a real laboratory activity has been considered by deploying an AirLevitation system.

        - *Research findings:* The Unit testing program and the integration of the new RIP extension on the Air Levitation system prove the good operation of the new version of the RIP Python server.

C. Blended learning contributions

- *First blended contribution:* Present a low-cost hybrid educational system based on three subsystems that complement each other to provide remote training on solar energy. The first subsystem is a virtual classroom based on the open-source BigBlueButton videoconference system, while the second and third subsystems are respectively, a MATLAB graphical user interface that describes the behavior of solar panels under varied climatic conditions, and a remote lab based on an IoT system to allow students to measure remotely the value of the current and tension needed for the operation of the graphical user interface.

    - *Evaluation methodology:* The following study adopts an evaluation methodology that considers indicators at different levels of abstraction. The analysis of the highest levels of indicators offers a panoramic view of the system's performance. On the other hand, the low-level indicators make it possible to accurately identify the effect of the designed system on the learning process. The evaluation was conducted on two groups of students each one at the Sultan Moulay Slimane University, in Morocco. The evaluation has been carried out in two stages of analysis. Firstly, a qualitative analysis was carried out with open and closed questions to gather information on the effectiveness of the two teaching methodologies adopted in this study. On the other hand, a quantitative analysis was carried out by analyzing the students' scores.

  - ✦ ***Research findings:*** According to the closed questions, the learning method based on the remote educational system proposed in this study is appropriate in transmitting the theoretical and practical knowledge needed remotely but its less useable in comparison with the traditional/presential educational method of teaching and learning in the students’ point of view in our introductory course on solar energy. The open-ended questions concerning the remote technological architecture reinforce that the proposed system is appropriate as a remote learning system mixing theoretical and practical teaching on solar energy. However, students think that the proposed system needs to be polished in various aspects that affect its learnability and usability.

- ***Second blended contribution:*** aims to propose a low-cost architecture based on Raspberry for the operation of a Classroom Response System. It allows the teacher to interview students using multiple-choice questions, to test their understanding of a concept discussed in class. This solution takes into account the didactic and pedagogical constraints that hinder the process of questioning, to create favorable conditions for investment and cognitive engagement of students.

  - ***Evaluation methodology:*** The evaluation of the educational system was conducted in two main stages. The first one aims at testing the technical performance of the system and its ability to broadcast questions and collect answers from students by powering up the system and measuring its performance using the Linux Sysbench software. On the other hand, the student's opinion on the integration of the response system in the classroom was measured using a questionnaire. The evaluation was conducted with 40 students enrolled in a renewable energy program at the Polydisciplinary Faculty of Beni Mellal, Morocco.

    - ✦ ***Research findings:*** The response time increases by 3300 milliseconds for 35 students, and 6810 milliseconds for 40 students. It can be noticed that the difficulties increase as the load increases, which is a remarkable disadvantage as regards the performances. Pedagogically speaking, 80% of students reported that the interaction between them and the teacher had been improved, students claimed that this methodology helped them to get their attention, with 90% of participants giving positive feedback on this system.

5.1.3 Benefits and limitations of the contributions

First IoT-based RL contribution: The proposed architecture was able to replace essential expansive instruments needed when performing electronic practical work, such as generator and oscilloscope, and propose a developed board that minimizes the teacher effort when putting the PW online in order to be performed remotely, The cost of the developed system is around 500 euros. Regrading the limitations of the contribution, we can mention that the solution integrates Six electronic PW only on the developed board and it gives large options to change the value of the resistance only in the PWs. The participation of students in the evaluation process was voluntary, 24 students were enrolled in this process, which does not allow us to recover solid facts and more generalized perception about the developed system, but in the first stage of the implementation of the educational system, it allows us to identify some aspects that need to be improved in the future.

Second IoT-based RL contribution: The proposed system integrates a software oscilloscope and it is based on a modular architecture, which means that each part of the system can be independently developed and improved, which allow which allows using this system for other practical work easily by changing the PW board and web schema. Moreover, in terms of cost, the developed system is cheaper than those using measuring instruments and low-frequency generators. We replaced these with an embedded system controlled by a web page. Indeed, the cost of our system is around 80 euros. Regarding the limitation of the proposed system, a delay was noticed between the web click and activation on relays with an average of 0.85 s, including 0.3 s between the web page and the server. One of the concerns being improved is the real-time synchronization of the webcam, which has a delay of 1.5 s due to the use of the transfer of a set of images captured via sockets. During the evaluation process, 20 students tested the developed system in order to verify, as a first step, the ability of the system to be adopted to perform remote practical work and to detect its advantages and limitations.

Third IoT-based Contribution: The comparative study of this work provides an opportunity to detect the perception of students toward the PW environment. This kind of information is important to highlight the path of development in the field of engineering PW, Each type of PW environment has its advantage and disadvantages. Regarding the limitation, the result presents student opinion about the comparison of one PW prototype, more complex PW designed in the three environments are needed.

Event-based lab control contribution: The RIP-Python server implementation provided by the UNEDLabs has been leveled up to cover more features that allow more precise and sophisticated management of the communication process in control systems. As a limitation of the research, evaluation of students' perception about the use of the new implementation on the Air Levitation system is needed to test the multiple user access.

First blended learning contribution: The hybrid system allows for the transmission of solid fundamental knowledge of solar energy. The indicator results prove that the proposed systems can be used as an alternative to improve the student's skills in the solar panel concepts of our renewable energy courses. On the limitation side, some connection problems were mentioned by some students due to technical issues related to the performance of their computer or the Internet connection. On the other hand, some delay was noticed in the connection to the remote PW work for current and voltage measurement.

Second Blended learning contribution: Several good reasons to configure Raspberry pi 3 as a server offering educational services. The size of this card makes it useful as a portable device. Another alternative is to host the classroom response system on a local server in the teacher's computer, comparing this solution with our architecture, the Raspberry Pi 3 can be turned on for a long time. As this card has low energy and economic footprint, this makes it a good choice under a low charge. The proposed solution was tested during a course on renewable energy with 40 students. The interaction between the students and the teacher is more complex in the amphitheater lecture with a larger number of students. We have noticed a delay in interaction with the Raspberry-based system when the number of students connecting to the system exceeds 35 students simultaneously.

5.2 Proposal for future studies

We present here the main research perspectives, both theoretical and technical, that we wish to investigate in the rest of our work.

- Development of a more complete platform of electronic practical work using EjsS and the new extension of the RIP Protocol.
- We are looking to address the communication between teachers and students during remote practical work by developing software modules that handle this exchange in the online platforms of engineering practical works.
- Conducting investigation studies toward the integration of the developed platform with a big number of students enrolled in different universities suffering from the new challenges of higher education.
- As future lines of the work, we have to implement the level 3 that allows for a generic user-defined sampling through the definition of a function that determines when the sampling of each signal must be carried on the RIP Python server.
- Propose a more blended technological architecture of the educational system to address the lectures' challenges because the lectures do not produce the learning goal that is presumed to achieve in a mass context.
- We are looking to host the classroom response system in a cloud server and investigate its effectiveness in the learning process in amphitheater lectures in an open-access university.

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Appendix

A. Sampling code of the RIP Python server

The main feature integrated into the RIP-Python server implementation in order to enhance its capabilities. The RIP Python server refers to a middleware that enhances any Python application with the capabilities required to be deployed as a remote laboratory. It enables the use of Arduino, MATLAB, Red Pitaya (and many more) programs through the internet as web services. The new version of the RIP Python server that implements the new functionality is presented in the following link:

The code displayed in the next lines presents the sampling of the RIP Python architecture. The code shown allows the periodic sampling strategy as well as sending on delta sampling.

```
import random
import time
import cherrypy

class Signal(object):
  '''
  A Signal that can be sampled
  '''
  def sample(self):
    '''
    Get the instantaneous value of the signal
    '''
    return 5*random.random()


class Sampler(object):
  '''
  An abstract Sampler
  '''
  def __init__(self, signal):
    self.signal = signal
    self.observers = []
    self.steps = 0


  def register(self, o):
    self.observers.append(o)
```

```
  def remove(o):
    try:
      self.observers.remove(o)
    except:
      pass


  def notify(self, data):
    for o in self.observers:
      try:
        o.update(data)
      except:
        pass


  def start(self):
    self.running = True
    while self.running:
      self.steps += 1
      data = self.signal.sample()
      self.notify(data)
      self.wait()


  def stop(self):
    self.running = False


  def wait(self):
    pass


class PeriodicSampler(Sampler):


  def __init__(self, first_sample, period, signal):
    super().__init__(signal)
    self.Ts = period
    self.reset()


  def notify(self, data):
    data = {
```

```
      'timestamp': self.last,
      'value': self.signal.sample(),
    }
    super().notify(data)


  def wait(self):
    # Wait until the next sampling time
    self.next = self.time / self.Ts + self.Ts
    interval = self.Ts - self.time % self.Ts
    time.sleep(interval)
    self.time = time.time() - self.t0
    self.last = self.time


  def sample(self):
    self.signal.sample()


  def reset(self):
    # Reset to the initial state
    self.t0 = time.time()
    self.time = 0
    self.last = 0
    self.next = self.Ts


  def delta(self):
    # Compute the time elapsed since the last sampling time
    return self.time - self.last


  def lastTime(self):
    # Last sampling time
    return self.last
class PeriodicSoD(PeriodicSampler):


  def __init__(self, first_sample, period, signal, threshold):
    super().__init__(first_sample, period, signal)
    self.threshold = threshold
    self.firstStep = True
```

```
        def condition(self):
          sample = self.signal.sample()
          return abs(sample - self.lastSample) > self.threshold


        def wait(self):
          event = False
          while not event:
            try:
                if self.firstStep:
                    event = True
                    self.firstStep = False
                    self.lastSample = self.signal.sample()
                else:
                    event = self.condition()
            except:
              print('Cannot evaluate sampling condition.')
            super().wait()
```

B. Python Unit testing codes example

The test aims to verify a very important feature which consists of programming the server to record events when a user is disconnected and to return these events if the user manages to reconnect before the session is terminated. The Unittest code that verify the set of the functionalities integrated in RIP Python server are presented in the following link:

```
Import Unittest

        from selenium import webdriver
        import threading
        import time
        from selenium.webdriver.common.by import By
        from selenium.webdriver.common.action_chains import ActionChains
        from selenium.webdriver.support import expected_conditions
        from selenium.webdriver.support.wait import WebDriverWait
        from selenium.webdriver.common.keys import Keys
        from selenium.webdriver.common.desired_capabilities import DesiredCapabilities


        class TwoUsersTesting(unittest.TestCase):


            def setUp(self):
                self.options = webdriver.ChromeOptions()
```

```
        self.options.add_argument('--incognito')
        self.options.add_argument('--start-maximized')
        self.drivers = []


    def open_browser(self, i):
        print("new browser")
        print(self)
        print(i)
        try:
            driver =
webdriver.Chrome(executable_path=r"C:\Users\34603\PycharmProjects\Rip_Python_Test\
Drivers\chromedriver.exe", options=self.options)
            if i == 1:
                driver.set_page_load_timeout(10)
            elif i == 2:
                driver.set_page_load_timeout(15)
            else:
                driver.set_page_load_timeout(30)
            driver.get('http://localhost:8080/RIP/SSE?expId=PeriodicSendOnDelta')
        except Exception:
            print('time out')
            events = driver.find_element_by_xpath("/html[1]/body[1]/pre[1]")
            result = events.is_displayed()
            if i == 1:
                try:
                    time.sleep(9)
                    driver.set_page_load_timeout(1)
                    driver.refresh()
                except Exception:
                    events =
driver.find_element_by_xpath("/html[1]/body[1]/pre[1]")
                    lostEvents_received = events.is_displayed()
                    liste_lostEvents = events.text.split("\n\n")
                    if lostEvents_received and (len(liste_lostEvents) > 1):
                        result = True
                    else:
                        result = False
            elif i == 2:
                try:
                    time.sleep(7)
                    driver.set_page_load_timeout(1)
                    driver.refresh()
                except Exception:
```

```
                    events =
driver.find_element_by_xpath("/html[1]/body[1]/pre[1]")
                    lostEvents_received = events.is_displayed()
                    liste_lostEvents = events.text.split("\n\n")
                    if lostEvents_received and (len(liste_lostEvents) > 2):
                        result = True
                    else:
                        result = False
        # Do something validate results...
        # Store the result
        self.results[i] = result


    def test_Server_Access(self):
        # How many browsers/clients
        N = 3
        # Each thread must modify only its own results (stored at position i)
        self.results = [False for i in range(0, N)]
        threads = []
        for i in range(0, N):
            t = threading.Thread(target=self.open_browser, args=[i])
            threads.append(t)
            time.sleep(0.5)
            threads[i].start()
        # Wait for threads to end
        for i in range(0, N):
            threads[i].join()
            self.assertTrue(self.results[i])
        # Do any other global check


if __name__ == "__main__":
    unittest.main()
```