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Easy Development of Industry 4.0 Remote Labs

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Abstract: Acquiring hands-on skills is nowadays key for engineers in the context of Industry 4.0. However, it is not always possible to achieve this in person. Therefore, it is essential to be able to conduct skill acquisition from a remote location. To support the development of remote labs for experimentation, this work proposes the development of an open Industry 4.0 remote platform that can be easily configured and scaled to develop new remote labs for IoT (Internet of Things), cybersecurity, perception systems, robotics, AI (artificial intelligence), etc. Over time, these capabilities will enable the development of sustainable Industry 4.0 remote labs. These labs will coexist on the same Industry 4.0 platform, as our proposed Industry 4.0 remote platform is capable of connecting multiple heterogeneous types of devices for remote programming. In this way, it is possible to easily design open remote labs for the digital transition to Industry 4.0 in a standardized way, which is the main research goal of our In4Labs project. Several users already conducted a series of IoT experiments on our remote Industry 4.0 platform, providing useful recommendations to be included in future versions of the platform.

Keywords: Industry 4.0; Internet of Things (IoT); emerging technologies; online learning; remote experimentation

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1. Introduction

The Internet has played a fundamental role in improving our lives in recent years. The number of people with access to the Internet has grown exponentially over the years. As our society has become increasingly digitized, new challenges and business opportunities have emerged in the Industry 4.0 paradigm. In addition, the growth of the Internet is closely linked to the expansion of the Internet of Things (IoT) [1], that is, the exponential growth in the number of Internet-connected devices and appliances. The exponential increase in the use of IoT elements is due to the great advance in the proliferation of wireless communications and their improved connectivity [2].

This digital transformation has also been made possible by the simultaneous development of additional technologies alongside the IoT paradigm, such as the artificial intelligence (AI) and cloud computing paradigms, among others. These technologies are considered key technologies because they enable remote interconnectivity and incorporate the intelligence of new manufacturing systems, extending Industry 4.0 to new dimensions. This fact has allowed us to achieve greater efficiency, greater process automation, and results that were previously unthinkable by improving the sustainability of Industry 4.0 over time [2]. As industrial capabilities and security continue to improve, we can expect further advances and improvements in many aspects of our lives thanks to the aforementioned technologies.

On the other hand, the Fourth Industrial Revolution has also created a major educational challenge. There is a need not only to train more than 2.76 million technical users in Europe but also to retrain workers in a sector that has more than 2 million companies and 33 million jobs in Europe. Users can learn through face-to-face training, but employees are likely to prefer a remote way to improve their skills. Thus, ensuring the acquisition of high-quality online practical engineering skills is a challenge. Recently, virtual and remote labs have emerged to provide time flexibility during the learning process.

Online learning benefits from the use of remote labs because it is very difficult to provide users with physical labs with real equipment [3] when a distance learning/training methodology is employed, as in our case. Subsequently, the use of remote labs to complement real labs has also had a great impact on education at all levels. Nowadays, online lab use has become even more relevant due to the health situation caused by COVID-19. Many face-to-face educational activities have been replaced by online activities, with hands-on activities using remote and virtual laboratories. Today, remote labs are an important part of digitizing the educational experience. For this reason, a concrete extension of this requirement is to develop a remote platform that hosts several industrial training labs by supporting scalability and user accessibility, as well as to implement and test a case of study in the IoT context.

In this way, skills acquired in distance learning courses can be supplemented with a learning-by-doing approach. Virtual or remote access to labs preserves the flexibility of the learning model by allowing learners to access them without time or space constraints. However, our analysis of the literature revealed that most educational labs for Industry 4.0 are designed for face-to-face activities. These off-campus remote experiments were mostly simulations or virtual labs. For example, a recent approach can be found in [4], which presents the implementation of a 3D digital twin simulator with augmented virtual reality.

A commonly explored area in remote lab studies involves microprocessors (ARM) and microcontrollers (Arduino, PIC, etc.) [5], which are taught in various formats and complexities within engineering programs; some, such as Arduino, are occasionally taught in certain school curricula. In [6], the LabsLand Arduino robot is introduced. It was used at the University of Fort Hare (UFH) in 2019. This remote lab was used at the university and in rural schools. Another example is in [7], where a remote mobile robotics lab based on the Arduino platform was first used at the National Open and Distance University (UNAD). Subsequently, they incorporated the use of LabsLand Arduino robots to minimize costs for users by supporting coverage for users located in remote areas and for whom access to laboratory practices is difficult. These contributions focus the authors' efforts in the context of robotics. A web system for remote programming of Arduino has also been developed in the technical school in Pravet [8]. They are working on the scalability of the systems and their integration with other microcontroller platforms and cybersecurity.

Acquiring hands-on skills is an essential part of an Industry 4.0 engineering education. However, it is not always possible to obtain hands-on experience when industrial training is employed, as in our particular case. Therefore, online learning of hands-on activities is necessary. To support the easy development of industrial remote labs, this paper proposes the creation of an open Industry 4.0 remote platform that can flexibly integrate and configure new remote labs in a scalable manner in areas such as IoT, AI, cybersecurity, perception systems, and robotics. This will allow the creation of sustainable remote labs over time and the connection of multiple heterogeneous devices for remote programming of industrial experiments. Our In4Labs project [9] aims to design and develop new open remote labs for the digital transition to Industry 4.0 and engineering education on the proposed Industry 4.0 remote platform.

In particular, the two specific objectives covered in this work can be broken down as follows:

- The development of an open-source Industry 4.0 remote platform to support and facilitate the development of new remote labs in a scalable way. We tried to create our remote platform as open source for sustainability purposes over time. For this reason, proprietary and non-open-source tools were discarded.

- Deployment of an Industry 4.0 IoT remote lab as a use case. Currently, several users are conducting remote experiments on our remote platform to provide recommendations for its improvement.

The remainder of this research manuscript is organized as follows. Section 2 reviews the state of the art in the context of this work. The material and methods used are detailed in Section 3. The architectural platform design of our Industry 4.0 remote platform is given in Section 4. Section 5 presents our IoT remote lab, which is already in use. Some conclusions and future work are given in Section 6.

2. Background

2.1. Remote Laboratories

Basically, remote labs refer to physical labs that can be used remotely, as opposed to virtual labs that replicate the desired environment. As a result, remote labs have the following characteristics:

- *Accessible*. Remote labs give users the flexibility to access labs at their convenience, 24 h a day, 7 days a week, from anywhere with an Internet connection.
- *Collaborative*. These labs can be easily shared between universities or institutions. Numerous projects and consortia have been formed for this purpose. Despite these benefits, remote labs present a significant challenge, as the reliance on automated support systems can mean the absence of physical staff to assist and guide users. Thus, there is still much room for improvement, although some progress has been made, as detailed in this paper.
- *Available*. Laboratories must be available at all times, without errors or technological problems.
- *Simultaneous*. Labs must be able to support multiple users simultaneously.
- *Cost-effective*. The cost of building and operating labs should be as low as possible.
- *Durable*. Labs must be designed to provide effective control over misuse.

A common way to create these remote labs is to deploy an embedded web-enabled system that offers several additional advantages over a server-hosted system in a general-purpose computer like a PC. These are as follows:

- *Costs*. These are related to the use of low-cost hardware elements and open-source software tools and libraries.
- *Power consumption*. The power requirements of these systems should be minimal.
- *Size*. The size of the associated equipment is usually small.

All of these features and benefits will be built into our proposed Industry 4.0 remote platform, in addition to facilitating the integration of new plug-and-play remote labs in a standardized way. The source code and hardware designs of the platform and remote labs will be published in an open access repository.

2.2. Previous Works

Anhelo et al. [10] describe a remote lab design that allows one to remotely program three Arduino-compatible boards (NodeMCU) through a web interface with a webcam. It is specifically designed to perform IoT practices using Wi-Fi communication among the three nodes and their peripherals. De Zarate [11] describes the WebLabPRO architecture, which is used to develop and deploy multiple remote laboratories and is mainly focused on Arduino or FPGA (field-programmable gate array) boards.

El-Hasan [12] presents a remote IoT system using several Arduino components, sensors, cameras, and other components. Its main drawback is that the laboratory allows a few electrical quantities under different load conditions, covering only a set of experiments and limited interactions with users.

Fernandez-Pacheco et al. [13] describe a remote Arduino-based system, using a Raspberry Pi as a low server, for remote code programming of microcontrollers. In addition, Bordel et al. [14] present a similar approach to assess the impact of the early adoption of

Industry 4.0 in engineering education. In the case of Gueye et al. [15], they propose to set up a remote, on-demand lab environment on IoT hardware controlled by a Raspberry Pi that is remotely accessible via the web. The lab benches will be connected to the GPIOs (general purpose inputs/outputs) of the Raspberry Pi.

In addition to this, Martin et al. [16] propose a web platform that allows users to send and execute their C code to a remote PIC microcontroller board in the context of IoT and as an open-source perspective. The proposal includes setting up a lab station, as well as solved examples that can be implemented in the environment. Users can develop different tasks related to the programming of PIC microcontrollers, Wi-Fi connectivity, and MQTT communication protocols, among others.

On the other hand, Robles-Gómez et al. [17] focus on the presentation and evaluation of an architecture called Labs of Things 3.0 (LoT@UNED), whose network infrastructure consists of a set of low-cost Raspberry Pis. It covers the entire life cycle of efficient management of networks and sensors/actuators, communication protocols, cloud services, and processing and visualization of the information generated. Both exploratory data and statistical validation of the proposed models were analyzed.

Rajurikar et al. [18] describe IoT experiments using REST and CoAP protocols. Multiple sensors were connected to a platform using an Arduino board and a Beagle Bone device that is designed for endpoint data collection and decision making.

Table 1 compares the most relevant remote labs available in the literature in terms of the hardware platform used as the basis for remote experimentation. They all focus on a specific hardware technology but do not cover the easy addition and integration of additional types of remote labs from a hardware point of view, as proposed in our current work. In addition, most of them are proprietary.

Table 1. Hardware comparison of the state of the art in Industry 4.0 remote systems.

	FPGA	**PIC**	**Arduino**	**Rasp. Pi**	**AI**	**Open**
Anhelo et al. [10]			X			
de Zarate et al. [11]	X		X			
El-Hasan [12]			X			
Fernandez-Pacheco et al. [13]			X			
Bordel et al. [14]			X			
Gueye et al. [15]				X		
Martín et al. [16]		X				X
Robles-Gómez et al. [17]				X		X
Rajurikar et al. [18]			X			
Authors		X	X	X	X	X

According to this analysis, the digital transition of industry to Industry 4.0 requires educational systems that can support the online acquisition of these practical skills in a scalable, affordable, and quality-assured manner for large numbers of users. Some efforts have been made using PIC microcontrollers and Raspberry Pis.

Therefore, the aim of this work is to accelerate the digital transition of engineering education towards Industry 4.0 by designing and developing an open-source remote lab based on low-cost Arduino boards.

3. Material and Methods

3.1. Materials

To facilitate the development of remote laboratories related to the Industry 4.0 pillars, a new remote Industry 4.0 platform was developed within the In4Labs project [9]. It consists of two main modules, the first being the core for the Arduino Labs, a web platform that is easily configurable and scalable to enable the development of new remote labs for IoT, cybersecurity, systems integration, perception systems, and robotics. These labs are designed to run on a low-cost server, such as a Raspberry Pi, to which multiple Arduino-like boards can be connected for remote programming.

On the other hand, the second module manages the AI Labs, an infrastructure that allows the concurrent and remote execution of machine learning algorithms (within the AI paradigm) and the inclusion of big data experiments on a GPU server with high computational and storage power.

The entire platform is designed to be easy to use and accessible to a wide range of users, from consumers to industry professionals. The platform is also designed to be scalable in terms of the number of concurrent users. The implementation of the designed infrastructure will be conducted with these tasks in mind.

To take advantage of the scalability and accessibility of the proposed Industry 4.0 Remote Platform, it is necessary to provide its infrastructure with a set of services, both for the platform itself and for the hosted labs. The main web services implemented in this context are the following:

1. Easy authentication for access to an interactive environment. Facilitating automatic user identification is important. Users need to log in only once but should be able to access all services transparently (SSO, single sign-on). Depending on their role, the user will be automatically directed to access fewer or more services.
2. Interaction with platform services and associated devices. Users can interact with and develop customized remote experiments for their specific needs using the labs hosted on our remote platform. This includes specific access to the hardware components of the deployed labs.
3. Creation and editing of training experiments. Labs can be easily configured by selecting the sensors, actuators, and other devices needed, as well as the software and experiments to run. Depending on their specific role, the user can only use and program the experiment, or they can even configure it for administrative purposes.
4. Administrative and analytical activities. The platform provides tools for managing users and experiments for administrative purposes and analyzing results.

All of these aspects are discussed exhaustively from a technology perspective in the next section.

3.2. Methods

As described above, our main goal is to accelerate the digital transformation of education towards Industry 4.0. Specifically, we want to undertake the following:

- The development of an open-source industry remote platform to support and facilitate the development of new remote labs. This is the main scope of the current work.
- The deployment of a set of Industry 4.0 remote labs. In this way, a set of IoT experiments was developed to be integrated into the practical activities of the "Digital Systems for the Internet of Things" subject, which is part of the *connected industry* master's degree at UNED for the academic year 2023–2024.
- Pilot testing of these remote labs with the developed infrastructure. We are working towards the first tests with real users for the IoT lab in terms of satisfaction and performance.
- Dissemination and international collaboration with technical associations, companies, and institutions interested in Industry 4.0. This is a transversal objective along with the In4Labs project.

We defined a set of eight remote labs within the In4Labs project, five of them developed within the Arduino subplatform and another three for the AI infrastructure. Each of them is described in detail below:

- *IoT Lab*. It consists of the development of a remote lab, including several Arduino-compatible boards that can be interconnected in different communication protocols.

Each board will be connected to several input/output components, and the user will be able to develop remote practices.

- *Cybersecurity Lab*. This remote experiment will use such an Industry 4.0 remote platform to develop different cybersecurity practices. For example, one node encrypts data and sends them to another node, which decrypts them. A third malicious node acts by intercepting the communication (man in the middle). Other possible examples of remote practices include buffer overflow and denial of service.
- *Perception Systems Lab*. A large number of sensors within the Industry 4.0 remote platform, such as gas, light, temperature, humidity, pressure, etc., will be experimented with. The user will be able to remotely program these sensors.
- *System Integration Lab*. This remote experiment will use our Industry 4.0 remote system integration platform with Node-RED. Node-RED is a programming tool for connecting hardware devices, APIs, and online services in new and interesting ways. In this remote lab, it can be used to configure graphical user interfaces that communicate with hardware using the MQTT protocol, for example.
- *Robotics Lab*. This remote experiment will use the Industry 4.0 remote platform with the addition of an Arduino robotic arm. This allows the user to remotely program the movements of the arm.
- *AI Lab*. This remote experiment will allow users to perform machine learning exercises thanks to a high-performance server that will be integrated into our Industry 4.0 remote platform.
- *Big Data Lab*. This remote experiment will use the Industry 4.0 remote platform to perform data analysis of the system. Users will be able to create dashboards on IoT data.
- *Cloud Lab*. This remote experiment will allow users to perform remote exercises by connecting the lab to a cloud provider.

The In4Labs project will also have a direct impact on European companies, in terms of personnel trained to support the digital transformation towards the Industry 4.0 model; on professionals who will improve their skills and employability; and on European universities and training providers, in terms of improving the didactic offer in the Industry 4.0 sector. The long-term benefit of the project will be to accelerate the digital transition towards the Industry 4.0 model in all economic sectors, promoting the growth of the Spanish and European economies thanks to the digital transformation of the business sector.

4. Architectural Platform Design

4.1. Software Elements

The Industry 4.0 Remote Platform uses Moodle [19], an open-source learning management system (LMS), to manage registered users and centralize access to all remote labs developed. This software is installed on a Raspberry Pi 5, running Ubuntu Server as an operating system. Figure 1 shows the proposed software architecture for our remote platform.

The LTI (Learning Tools Interoperability) [20] standard was used in our development to enable interoperability in two ways. Externally, Moodle acts as an *LTI provider* to any other LMS with LTI support, allowing our platform to be included in those systems through *dynamic registration*. Internally, Moodle acts as an *LTI consumer* for any Arduino labs that are developed as LTI tools. This design allows for the integration of any new remote lab to ensure scalability. Currently, LTI uses SSO without the user having to authenticate for each associated lab.

On the other hand, our development makes use of services based on lightweight containers through Docker [21,22]. Docker is an open-source project that automates the deployment of applications in software containers. It provides an additional layer of abstraction and automation for virtualizing applications across multiple operating systems. Arduino labs are developed using ephemeral Docker containers, so users have a completely clean working environment when they access a lab.

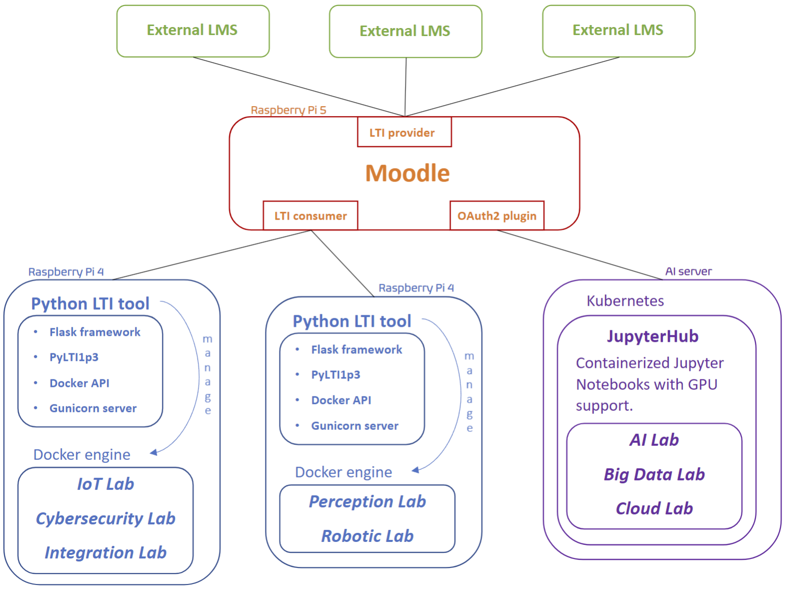

Figure 1. Architectural design of the Industry 4.0 Remote Platform.

A Python LTI 1.3 tool, using the Python Flask web framework [23] and the software library "PyLTI1p3" v2.0.0 , was created to combine the common functionalities for all labs: *user authentication*, *time-slot booking*, and *access control*. This tool runs on Raspberry Pi 4 servers and allows the allocation of time slots for users to use the associated remote labs. It is also responsible for managing the Docker containers that are created when a user accesses a session reserved for the lab and are removed when the user's time slot expires. In addition, the Gunicorn [24] web server was used. Gunicorn is an open-source Python WSGI (web server gateway interface) server that uses the HTTP protocol and is highly compatible with various web frameworks such as Flask. It is lightweight, efficient, and fast. Python 3.9 or higher is required to use it.

This programming language is suitable for our development because it is easily able to manage light services for the interaction of all the elements involved in the system, as well as satisfying the technical requirements of our proposal. In addition, it is widely used for programming low-cost computers (Raspberry Pi, BeagleBone, etc.). There are also specific Python-based web frameworks (such as Flask) that helped us with login, security, and visualization tasks, among others.

The Arduino labs are standalone, containerized Flask web applications with their own Gunicorn server, but unlike the previous application, they only accept authentication from one user, the one who reserved the time slot. These containers also have Arduino CLI v0.35.3 installed, a command-line tool that allows the user to compile, upload, and manage Arduino sketches and libraries. The Python back end makes use of this software when the user wants to interact with the Arduino boards.

A Jupyter Notebook is an open-source web application widely used in data science and machine learning that allows users to create and share documents containing live code, equations, visualizations, and narrative text. The AI server infrastructure has installed JupyterHub [25], a multiuser hub that spawns, manages, and proxies multiple instances of the single-user Jupyter Notebook server. There are several ways to install JupyterHub, but the only way to manage GPU sharing is through Kubernetes [26], an open-source container orchestration system designed to automate the deployment, scaling, and management of containerized applications.

The source code of our developments will be available on GitHub [27] and will be freely accessible to the scientific community. This is one of the goals of the In4Labs project to accelerate the digital transition of remote training to Industry 4.0.

4.2. Hardware Elements

The Industry 4.0 Remote Platform is essentially a web system that is easily configurable and scalable, enabling the development and integration of new remote labs for IoT, AI, cybersecurity, systems integration, perception systems, and robotics. The Arduino-based laboratories are designed to work on a low-cost server, such as a Raspberry Pi, where several Arduino boards can be connected and programmed remotely. Moodle is installed on a Raspberry Pi 5, the latest model available, as it requires more computing power. Figure 2 shows the proposed technological architecture for our Industry 4.0 remote platform, which consists of two main layers:

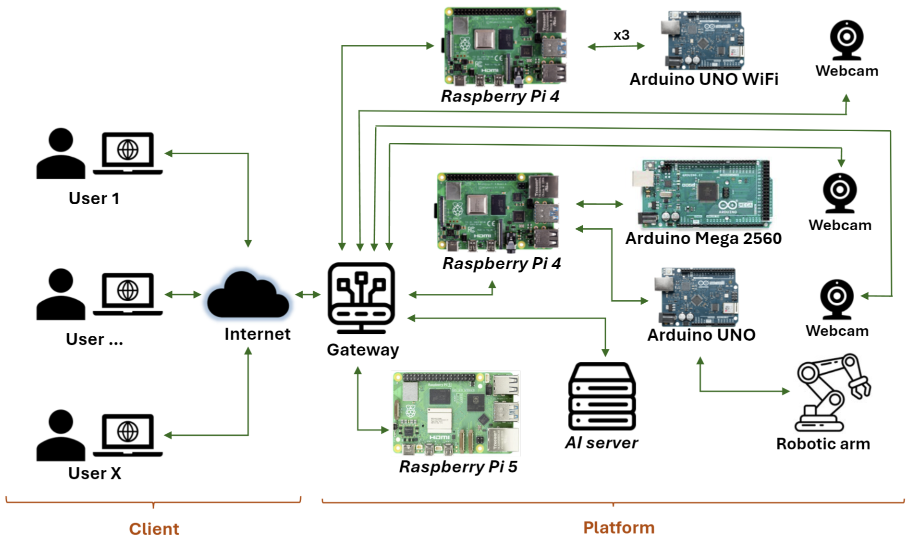

Figure 2. Hardware architecture of the Industry 4.0 Remote Platform.

- *Platform*. It consists of a set of elements, servers, physical components, and so on. These are the following ones:
    1. *Gateway*. It manages connections on the platform, both inbound and outbound.
    2. *Raspberry Pi 5 (Moodle server)*. This microcomputer is suitable for running Ubuntu Server, as Moodle requires a high-performance operating system.
    3. *Raspberry Pi 4 (Arduino server)*. The Arduino labs are designed to run on a low-cost server like a Raspberry Pi, which connects multiple Arduino-like boards for internal remote programming.
    4. *Arduino boards*. Up to four boards can be connected to each server.
    5. *Webcams*. A webcam installed in the Arduino-based remote labs allows users to see physical changes to hardware elements in real time.
    6. *AI server*. GPU server with high computing and storage capacity. This is a specific server centered on intensive computation tasks, such as the execution of AI algorithms.
- *Client*. Users can access the platform and associated labs through an Internet connection with their physical device. This remote lab can be accessed through any browser, such as Firefox, Chrome, or Opera, without the need to install any software on the device. In addition, a high-performance computer is not required for a good user experience.

A further improvement of the remote platform will include an AI infrastructure to enable the concurrent and remote execution of machine learning (ML) algorithms and the inclusion of big data experiments that require intensive computing power and storage. This module is beyond the scope of the current work, but the corresponding hardware equipment has already been acquired within the In4Labs project. Figure 3 shows an image of the server integrated into the storage cabinet in which it is housed.

Figure 3. Hardware equipment for executing AI algorithms.

5. Experimentation with the Industry 4.0 Remote Platform

The Arduino IoT Remote Lab currently consists of a set of Arduino-based experiments connected to a web server. As described above, its main purpose is to allow users to remotely execute the desired code on the Arduino boards and view their progress and results in real time through a connected webcam. The boards can exchange data with each other and interact with other components of each experiment, such as sensors and actuators. Thus, the lab provides a flexible access environment where users can test and experiment with real devices to apply theoretical knowledge about microcontroller programming and IoT.

5.1. User Access

The software interface is designed to allow users to experiment with Arduino boards. Several scenarios are included to promote a deeper understanding of potential vulnerabilities and mitigation strategies. Users can submit code to be executed on each Arduino board over the Internet and observe changes through the connected webcam. To access the IoT Remote Lab, users must first reserve an access time slot through the IoT Remote Lab reservation system. This requirement is detailed in Figure 4.

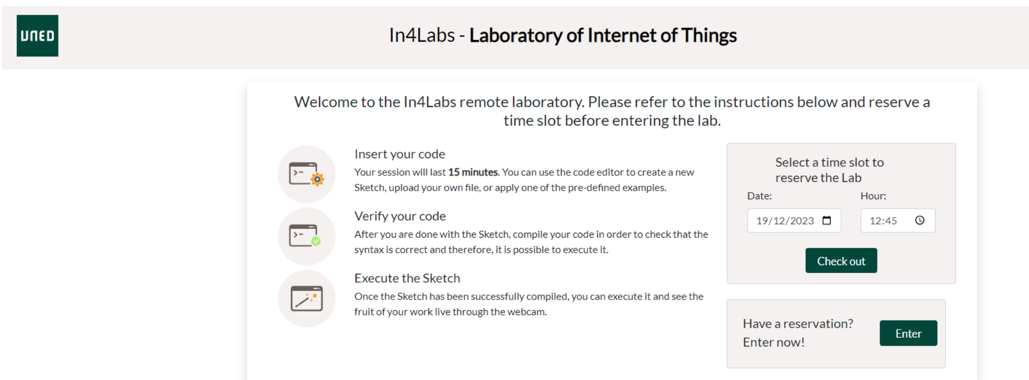

Figure 4. Session booking screen of the Industry 4.0 Remote Platform.

To schedule a session, the users enters the desired start time and date and clicks the *Check out* button. If the time is available because it has not been reserved by another user, the user will receive a confirmation message. In our specific example, the IoT lab was successfully reserved for 19/12/2023 @ 12:45. When the time arrives, the user must click the *Enter* button to access the remote lab.

5.2. Remote Experiments

Three types of Arduino-based remote experiments are currently implemented. These are *IoT Lab Basics*, *IoT Fundamentals*, and *Advanced IoT*.

- *IoT Lab Basics*. The basics of the IoT remote lab are presented. This includes testing the components of an Arduino-based remote lab and configuring the sensors/actuators. Specifically, the user will be able to explain the functionality of the experiment, change the color of the LED and its blink time, create new colors, change the message displayed on the LCD, take a screenshot of the values read, and explain why the relay works with inverse logic.
- *IoT Basics (IoT Blink)*. This experiment introduces the different forms of communication that Arduino boards can use to exchange data in the IoT Remote Lab.
  This experiment uses two primary–secondary Arduino boards, with the primary on the LCD board and the secondary on the sensor or fan board. The communication protocols used are UART, RS484, I2C, BLE, and Wi-Fi. Specifically, the user must be able to explain the functionality of each protocol, explain the interaction between the boards and create a flowchart, and modify the module so that the Arduino secondary turns on the LED with a specific color.
- *Advanced IoT*. The experiment describes an experiment that acts as a basic IoT system for controlling temperature and humidity, suitable for experimentation purposes.
  This experiment uses three Arduino boards: the primary is on the LCD board and the secondaries are on the sensor and fan boards. The communication protocols used are UART, I2C, BLE, and Wi-Fi. Specifically, the user must be able to explain the interaction between the boards and create a flowchart. He or she must also be able to load the code to observe the values of the DHT22 sensor on the LCD display. Then, in the primary code, the user must change one of the temperature or humidity thresholds to operate the fan.

In a previous study, an Arduino-based hardware version was proposed [28]. Our approach can be considered as the next iteration, focused on achieving the goals of the In4Labs project and defining new advanced Industry 4.0 experiments. The remote lab is fully integrated with our open-source remote platform as described above.

5.3. Environment Operation

The IoT Arduino-based remote platform is built on top of lab software based on Arduino boards. The user interface is simple and consists of two parts, as shown in Figure 5. On the left side (in green color) is the code section where users can write their programming code for each of the three Arduino boards (LCD, sensor, fan). This interface includes buttons that allow the user to compile and execute the code on the remote Arduino board. On the right side, the code execution is visualized in real time by a webcam pointing at the physical board in the experiment.

The execution flow consists of three main parts: *load code*, *compile*, and *execute device* (which happens after the code has been compiled). Other interface buttons include a drop-down menu of example code, buttons for creating and saving sketches, a serial monitor button, and a button for stopping code execution on the board. Figure 6 is an example of code sent to the Arduino board for real-time execution. This is a simple example that turns a red LED on and off.

There is also a button that, when pressed, sends the written code to an AI to suggest possible errors or areas for improvement. The text provided by the AI should be considered as suggestions only (see Figure 7).

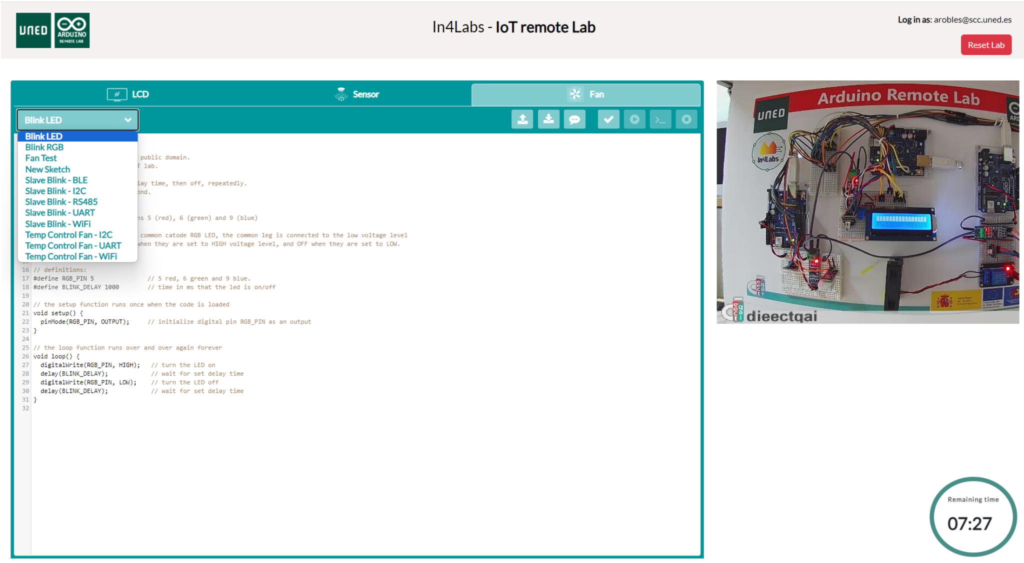

Figure 5. Web interface of the Industry 4.0 Remote Platform.

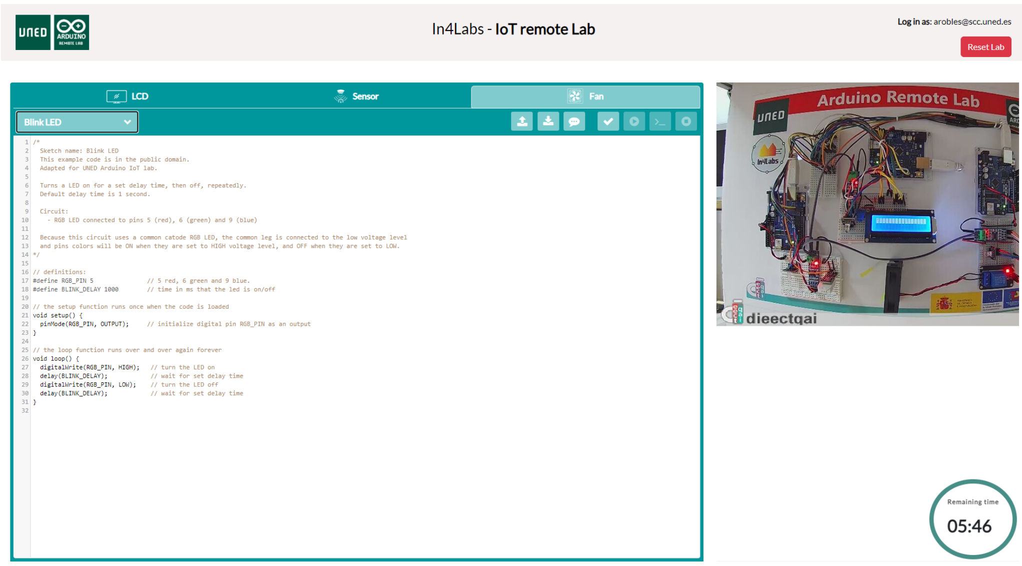

Figure 6. Example of programming code in the Industry 4.0 Remote Platform.

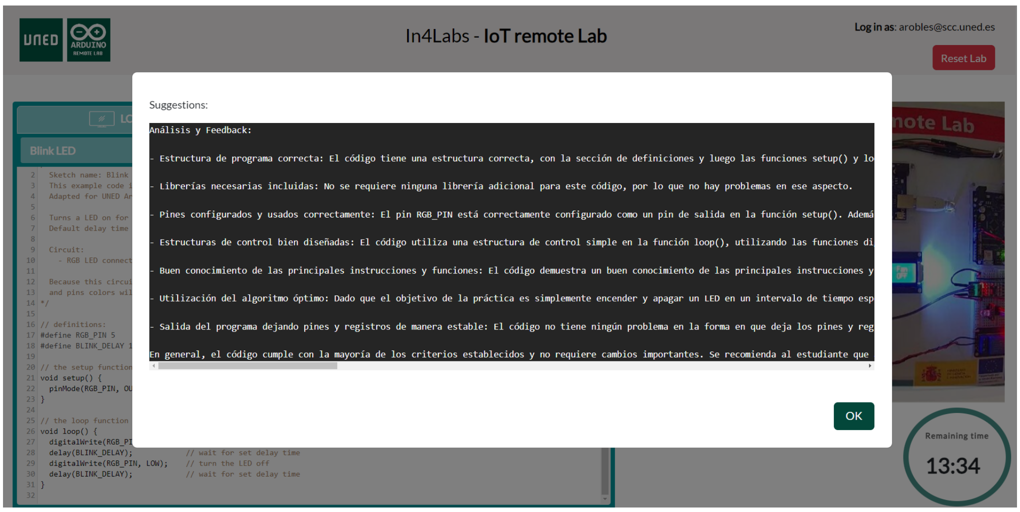

Figure 7. Interface for AI recommendations in the Industry 4.0 Remote Platform (*In Spanish*).

In addition, the web interface includes a countdown timer that displays the amount of time remaining in the IoT Remote Lab. The default time limit is 15 min. When the time limit is reached, the system will notify the user and offer the option to download any sketches developed during the session. It is recommended to download any sketches before ending the session to avoid losing any changes made. An example of the pop-up message that appears when the booked time slot on the platform has expired is shown in Figure 8. During early testing of the IoT Remote Platform, some users recommended that this time period be extended.

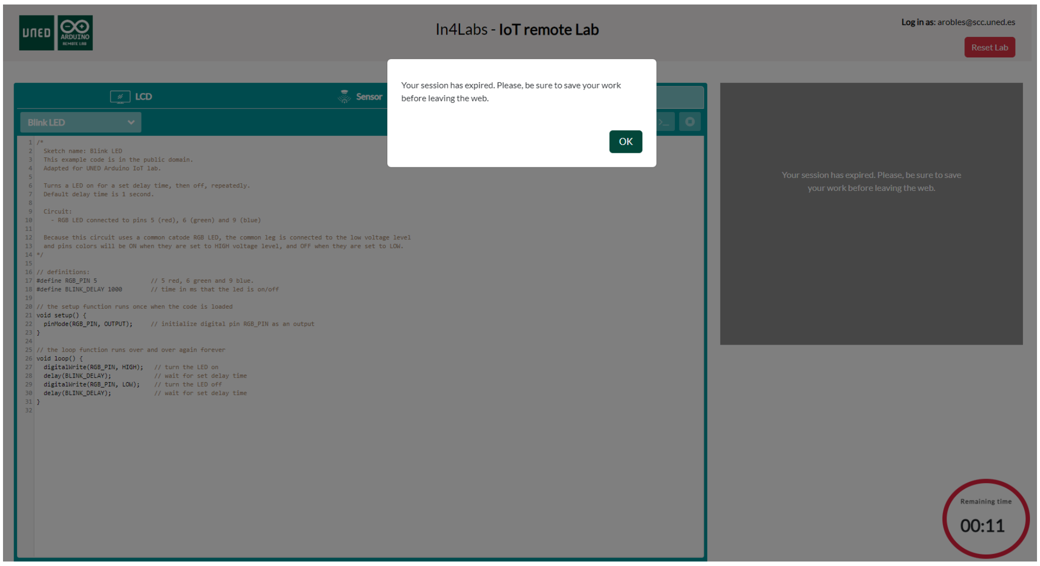

Figure 8. Example of pop-up expiration message of a booked session in the Industry 4.0 Remote Platform.

The first pilot test carried out with the proposed remote platform is detailed next. The users' satisfaction with the platform is detailed from both a quantitative and a qualitative point of view, as well as its main current limitations and areas of improvement.

5.4. The Pilot Test

Table 2 presents our initial statistical data from the user opinion survey in a quantitative way. It shows the standardized mean, standard deviation, median, and minimum and maximum values. This survey was completed by a total of 12 users involved in the case study (out of a population of 20 users). In this way, a number of indicators are presented and measured below:

1. *Usefulness* of our remote platform for practical activities.
2. *Ease of use* of our remote platform for practical activities.
3. *Ease of access* to the remote platform in a clear and compressible way.
4. *Intention of use* of our remote platform in other contexts.

Regarding the mean values of the indicators, on a five-point scale, they can be considered as really good. The best one is the usefulness with a value of 4.33, and the worse one is the ease of use with a value of 3.75. The standard deviation values are low, and median values very high. Therefore, the statistical values are satisfactory in general, considering the literature [17,29], as an initial basis for further analytical studies.

Table 2. Initial results from an opinion survey after testing our Industry 4.0 Remote Platform (statistical data).

	Usefulness	Ease of Use	Ease of Access	Intention of Use
Standardized mean	4.33	3.75	4.08	4.25
Standard deviation	0.89	0.97	0.90	0.87
Median	5.00	4.00	4.00	4.50
Minimum value	3	2	2	3
Maximum value	5	5	5	5

As for the qualitative results, a total of six users responded to the opinion survey with suggestions and additional improvements for our remote platform for Industry 4.0. Some users commented that they really liked the idea of the remote lab and that it was generally easy to use for practice.

In addition, some users explained that a 15 min time slot may be too short, since it takes nearly 3 min to compile and boot each board. For this reason, multiple time slots were needed to complete the entire activity. For example, new sketches had to be uploaded or code changes had to be uploaded to the board. They felt that it would be more efficient to be able to book the lab for half-hour periods. This would put less pressure on the user.

In this sense, some users were concerned that they would not have enough time to complete their internships during nonworking hours, but in the end, there were few problems with session reservations. Figure 9 also shows a word cloud highlighting the most used words and expressions (in Spanish) in the users' comments when filling in the opinion survey. The most-used word was "code", and other words or phrases that were quite relevant included "15 min", "practice", "fact", "little time", "problem", among other words.

Figure 9. Word cloud in Spanish from the initial opinion survey of users of the Industry 4.0 Remote Platform.

Other users also commented that the lab fails in a timely manner and that nothing is printed through the serial output. Some additional minor improvements might be to improve the fan display or to center the camera on the panel.

6. Conclusions and Further Works

The implications of the Fourth Industrial Revolution are enormous. It is estimated that Industry 4.0 can deliver annual efficiency gains in manufacturing of between 6% and 8%. This is why the results of the In4Labs project will have such a significant impact on the economy, accelerating the digital transition to Industry 4.0 and enabling a significant reduction in the development costs of online laboratories. As a first estimate, the deployment of one of our hosted remote labs to our Industry 4.0 platform at other institutions by other researchers is expected to take only about 2 h per lab for complete software and hardware setup, which would normally take several months of work. This huge reduction in development time translates directly into cost savings. Considering this significant reduction in programmer hours and the potential number of institutions worldwide that could use our system, it is possible to imagine the large overall economic savings that the results of this project will bring, thus enabling the development of many more online labs based on our industry platform as they become more economically viable, thus growing the Industry 4.0 community.

On the other hand, the acquisition of practical skills is key in engineering education, but it is not always possible in a face-to-face manner. For this reason, it is necessary to be able to acquire practical skills in a remote manner. Therefore, this work proposes the development of an open Industry 4.0 remote platform that allows the easy and scalable addition of new remote labs for IoT, AI, cybersecurity, system integration, perception systems, and robotics. As a result, hundreds of international users will be able to improve their hands-on skills online through these Industry 4.0 labs around the world, balancing work and family responsibilities with skills development. In addition, users with disabilities will be able to enhance their education by having easier access to hands-on training activities without having to leave their homes or healthcare facilities. Online labs have become even more relevant today as COVID-19 has called for a large proportion of face-to-face training activities to be replaced by online activities.

For this reason, this work first proposed an open-source Industry 4.0 remote platform to support and facilitate the development of new remote labs in a sustainable and scalable way. Second, an Industry 4.0 IoT remote lab was developed as a use case, and a first pilot test was conducted. User satisfaction was found to be very promising, from both a quantitative and a qualitative point of view, and some limitations and possible improvements were suggested.

As future work, a more in-depth pilot study will be conducted. This opinion survey will be developed based on the satisfaction indicators associated with technology acceptance models. User performance, usability, anxiety, social influence, and attitude towards the platform will be some of the features evaluated. On the other hand, the suggested initial limitations and possible improvements will be included in our remote platform. In addition, we plan to integrate additional remote labs into our remote platform, in terms of cybersecurity, perception systems, robotics, etc. The acquired high-performance server will be integrated into our platform in order to design a series of practical activities related to AI.

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