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An online virtual laboratory model based on the Internet of Things for use in the field of Renewable Energy

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Abstract

Engineering has always relied on experimentation to deepen students' knowledge. During the Corona pandemic, the importance of remote laboratories emerged as universities closed their doors due to this pandemic. From here came the idea of the research: the design and implementation of a prototype remote laboratory suitable for conducting practical experiments based on the Internet of Things (IoT) technique. The proposed remote laboratory is based on a client-server model, where the server side represents the laboratory side, and the client side represents users, divided into three user types: administrators, lecturers, and students. The proposed experiments are based on the Effects of various environmental parameters on PV-module power and efficiency. Students can access it securely through an interface provided as a web page; all users need to experiment with is a web browser, internet connection, username, and password. The low-cost Hardware part involves the Microcontroller, the solar cell, and the sensors required for data acquisition from the overall experiment environment, in addition to actuators to control the environmental parameters. The hardware part is designed to be controlled by software created in several programming languages (Python, HTML, JavaScript, MySQL, and LabVIEW). Finally, a Web camera was connected to the server to provide a live video stream to monitor the device's status to give the student the feeling that he is close to the real laboratory. Finally, the proposed system is supported by an automatic assessment mechanism to evaluate the student's performance during the conduction of the experiment and thus reduce the effort of the supervisor of the laboratory.

Keywords: virtual laboratory; Internet of Things; renewable energy; programming applications

1. Introduction

The scientific study field has always been centered on experimentation to deepen students' knowledge. The instruments used in each laboratory are considered one of the major expenses in the laboratory structure. The simulation or virtual laboratory becomes integral to the traditional laboratory, deepening the theoretical level. Simulation experiments provide accurate results based on calculations independent of real-time errors or environmental factors (Elmoazen et al., 2023; Yousif M., 2022). A simulation or virtual laboratory can imitate a traditional laboratory. Still, it is not a substitute because there is always a lack of instrumental guidance, an essential element of experimentation. A new solution, dubbed "Online Labs", has been proposed, allowing students to work in their own space and practice anytime, anywhere (Chan et al., 2021). The invention of the Internet of Things (IoT) has greatly impacted these methods, which help teachers harness knowledge through innovative and interactive learning environments developed on the basis of the Internet (AlKishri & Al-Bahri, 2021). Therefore, distance is no longer an issue as students can register for different courses to obtain the certificate without attending in person. In the mid 90's, a new solution called "remote labs" emerged, which proposed an exciting emergence of technology and distance learning (DL) in engineering to allow students to work with physical processes 24/7 Location interaction (Haleem et al., 2022). Various technologies have transformed the lab environment, allowing students and labs to be in two locations. Depending on how experimental results are communicated, educational laboratories can be divided into three categories (Bernhard J.,2018).

a. Practical laboratories. Instructional labs originally took the form of practical learning labs, where students and equipment are present within the same space (Sanchez, et al., 2022). Practical learning labs are an efficient way to develop practical skills because they allow students to work with and practice using actual physical instruments and obtain actual data Practical learning laboratories required a space for learners to use experimental tools, and they also have some drawbacks such short time slots, inadequate tools, pricey apparatus, risky processes, and the requirement for teachers to be present (Ferri, et al., 2020).

b. Virtual Laboratories. Simulations or virtual laboratories model how actual laboratory equipment operates. In technical labs, simulations are used in place of or in addition to actual laboratory activity to illustrate theory and knowledge. Some typical advantages of using virtual labs in engineering education are; encouraged students to predict the results of experiments, reduced laboratory space required for students, instruments and teachers, and the virtual lab may replace the too expensive physical labs (Grodotzki, et al., 2018). On the other hand, virtual labs cannot completely replace physical hands-on labs due to the following limitations (Faulconer& Gruss, 2018); some simulators is not cheap, and students must learn how to process and use simulation software to complete their labor and time-intensive tasks.

c. Remote Laboratories. The final type, known as a remote laboratory, aims to integrate internet and e-learning capabilities. To enable remote operation of real equipment, remote laboratories are created as web-based labs (Esquembre F., 2015). In a remote lab, the student's computer is connected to the internet and a remote server interacts with the physical equipment on the student's behalf. The primary benefits of distant laboratories include (Achuthan et al., 2021); get accurate results from scientific tools, the students have the opportunity to repeat laboratory experiments, enable the students to sense the differences between theoretical and experimental results, including experimental errors, and lower the expense of tools and machinery.

2. Related Work

In Many scientists have created remote laboratories where a student can engage via an internet connection to carry out a certain experiment, according to literature. Among them is Kasim (Al-Aubidy et al., 2021) introduces a technical way to connect real equipment in the laboratory, so the students can reach this equipment through the web and real-world experiments are conducted on the equipment in the laboratory anytime, anywhere. This document details the hardware and software architecture of the remote solar at the Philadelphia University School of Engineering and Technology in Jordan. Abul Kashem M. Azad proposed a Design of Prototype Remote Laboratories based on Internet of Things (Azad A., 2018). This paper introduces a remote experimental setup that use a vacuum cleaner with a programmable embedded processor that can be controlled by remote control. This system uses Raspberry Pi as an add-on to the Python programming course. Tareq S. El-Hasan (El-Hasan T., 2019) uses mobile apps and internet of things devices to create a lab system in the Zarqa University Electrical Engineering Department. The proposed system allows students to perform experiments and collect data from anywhere. Once they're finished, they can submit their final reports through a dashboard built into the mobile app. The system includes cameras, sensors, interfaces and other devices necessary for conducting all their tests. Mershad (Mershad & Hamieh, 2019) used robotic and IoT tools to manage and observe the experiment in order to safely perform remote lab experiments, students use IoT and robotic tools. They can perform their experiments from any location at any time using the "Remote Experiments" app. Rouibah (Rouibah, et al., 2021) introduced an inexpensive Internet of Things (IoT) prototype for online monitoring of the maximum power produced by a household photovoltaic (PV) system. Many characteristics, including current, voltage, load current, load voltage, power at maximum power point, duty cycle, module temperature, and in-plane solar irradiation, and are designed to be monitored by the prototype.

Renewable energy helps reduce the cost of production and increase production capacity for all uses, whether personal or productive (Kazem et al., 2022). Therefore, evaluating the performance of renewable energy for various equipment, methods, and structure is essential, and then determining the variables for designing energy production systems, whether in the laboratory or real uses. Variables include equipment characteristics, quality, and climatic variables such as solar radiation, dust, temperature, humidity, etc Yousif J., 2021; KHAMIS & Yousif, 2022).

The goal of the present work is to create an Internet of Things (IoT)-based remote solar power laboratory platform that will allow scientists and engineers to remotely observe, manage, and evaluate the performance of renewable energy systems. In addition to strengthening the proposed laboratory with a mechanism for automatic student evaluation.

3. The Proposed system

The general remote laboratory that is shown in Figure-1 for photovoltaic (PV) testing involves a comprehensive hardware and software design to enable remote access and control of the lab's equipment.

3.1. The Hardware Design

Response The hardware design that are shown in Figure-2 includes several critical components, such as Microcontroller, PV cells, temperature sensors, light sensors, current sensors, and voltage sensors, in addition to actuators. The PV cells are used to measure the PV module's power output, while the temperature sensors are used to measure the module's temperature. The light sensors are used to measure the intensity of the light falling on the module's surface, while the current and voltage sensors are used to measure the module's electrical output. These sensors provide critical data for evaluating the module's performance and identifying potential issues. The software design of the remote laboratory consists of a web application based on Python and LabVIEW. The web application provides a user-friendly interface for remote access and control of the lab's equipment. The Python-based backend provides the necessary communication and data management capabilities, allowing users to remotely access and control the lab's hardware components. The LabVIEW-based frontend provides real-time data visualization and analysis, enabling users to monitor and evaluate the test results.

The hardware architecture of the PV Cell Remote Laboratory design with its components and subsystems are shown in Figure-3 The remote Lab hardware components and their functions are detailed in Table-1.

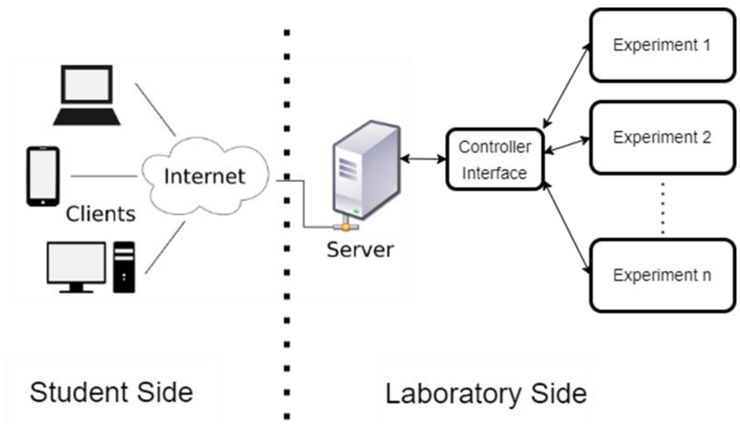

Figure 1: General structure of the remote laboratory

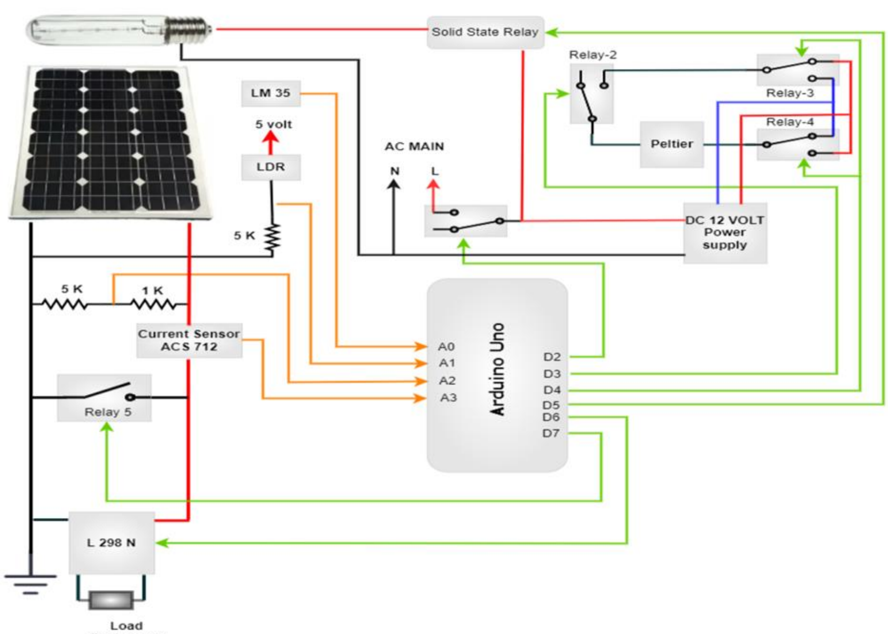

Figure 2: The hardware design components of the PV Experiment

These sensors provide critical data for evaluating the module's performance and identifying potential issues. The software design of the remote laboratory consists of a web application based on Python and LabVIEW (Shalgar & Bindu, 2022). The web application provides a user-friendly interface for remote access and control of the lab's equipment. The Python-based backend provides the necessary communication and data management capabilities, allowing users to remotely access and control the lab's hardware components. The LabVIEW-based frontend provides real-time data visualization and analysis, enabling users to monitor and evaluate the test results. The hardware architecture of the PV Cell Remote Laboratory design with its components and subsystems are shown in Figure-3. The remote Lab hardware components and their functions are detailed in Table 1.

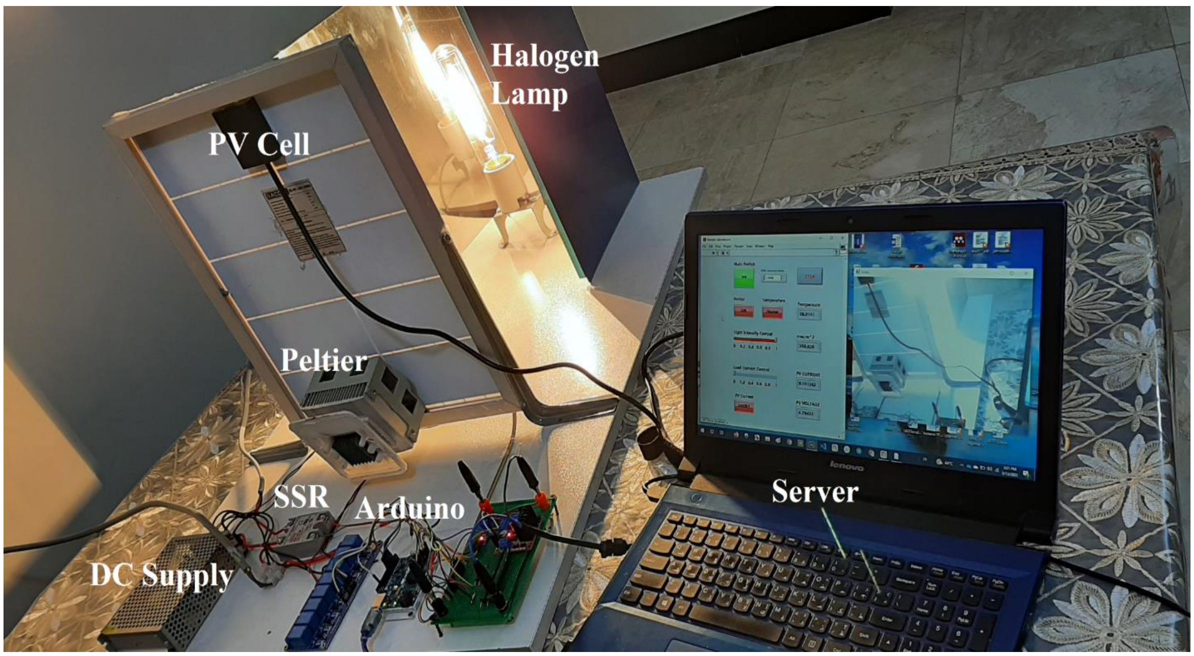

Figure 3: Hardware Layout of the server side

Table 1: The remote Lab hardware components and their functions

The Hardware Components	The Function
The Student/Client.	Used by Student to access the Remote Lab via Web Browser.
The Remote server.	Used to manage the data transfer between The Student and the Remote Experiment.
Arduino Microcontroller with Sensors and Actuators.	Used to read PV environmental parameters sensors and to control these parameters by the actuators.
Variable Load Resistance.	Used to vary the PV Current.
Peltier based Temperature Controller Subsystem.	Used to regulate the PV Temperature during experiment.
500-Watt Light Source.	Used to apply variable light intensity on PV Panel.
Web Camera.	Used to monitor the experiment side by the student.
Power Supply.	Used to supply the Peltier with power.

3.2. The Software Design

In general, the design will have various components that work together to give consumers with a seamless and dependable remote laboratory experience. The software design of a remote laboratory will be determined by the laboratory's specific requirements and functioning, some of which are:

- The front-end component of the remote laboratory software is the user interface.
- user management system should be included in the remote laboratory software, allowing laboratory managers to govern user access to the laboratory.
- A system for identifying and handling defects that may arise during the experiment should be included in the remote laboratory software. This component should provide clear feedback to the user while also protecting the laboratory equipment.

A remote laboratory system's software design often contains algorithms in charge of managing and coordinating the system's numerous components (Guo et al., 2022). The algorithms that govern the hardware of the remote laboratory component are often in charge of operating the laboratory's physical components, such as sensors, actuators, and other devices (Yousif & Abdalgader, 2022). These algorithms may also be in charge of monitoring user activity and implementing use regulations to maintain the system's security and integrity. In the followings, various algorithms are detailed.

3.3. User Management Algorithms

It is common in remote laboratory designs to categorize users into distinct groups based on their roles and responsibilities within the system. The proposed design of remote laboratory system categorizes users into three main groups: Administrator, Teacher, and Student.

- The Administrator has the most access and privileges within the system and is responsible for maintaining the system's security and proper operation.
- The Teacher has significant access and privileges within the system, but not as much control as the Administrator. He is usually in charge of overseeing the laboratory experiments and activities within the system. They have the ability to design and edit experiments, assign them to specific students, and track student progress and performance.
- The student is the system's final user and typically has the least amount of access and privileges. They can gain access to the laboratory experiments assigned to them by their teacher, carry them out, and view the results.

3.4. Authentication System

The It is critical to create authorization procedures to control access to public services in a system that provides these services. Implementing a login and registration system is the most frequent way to accomplish these needs. To ensure that only authorized students have access to the laboratory, a login system that filters out unauthorized users must be established (Alattar & Azeez, 2021). Students may grumble about time constraints when doing experiments, a remote laboratory system can alleviate this problem by having the lab open 24 hours a day, seven days a week. However, it is critical to avoid a single student monopolizing laboratory resource by scheduling all available sessions. Figure-4 shows the flowchart of the Login Authentication system.

3.5. Registration system

The To gain access to the remote lab, a user must first log in via the login system, which verifies the user's presence in the associated users' account database. In the current work, the Administrator can add new users (Administrator & Teacher), however the Teacher can only add new Students. The registration process is divided into two stages, each with its own form. The first form would collect the user's personal information such as first name, last name, username, password, email, phone number, and position, which determines whether they are an Administrator, Teacher, or Student, during registration, while the second would collect the registrar's issued username and password.

3.6. Laboratory reservation system

The Because the reservation system is an important aspect of the student interface, a scheduling system must be implemented to provide equal access to system resources. To avoid one student seizing laboratory resources, the following guidelines will be followed:

- Each student will be given a one-hour opportunity to use the lab. This ensures that all students have equal access to the system's resources and that no single student can dominate the system by scheduling all of the experiment's available hours.
- The system booking hours will be displayed on a sharp clock ranging from 0 to 23. This means that a day has 24 hours, and students can reserve a time slot, say, at 1. The system will track the student's time from the moment they check in until the end of their session, which is one hour later.

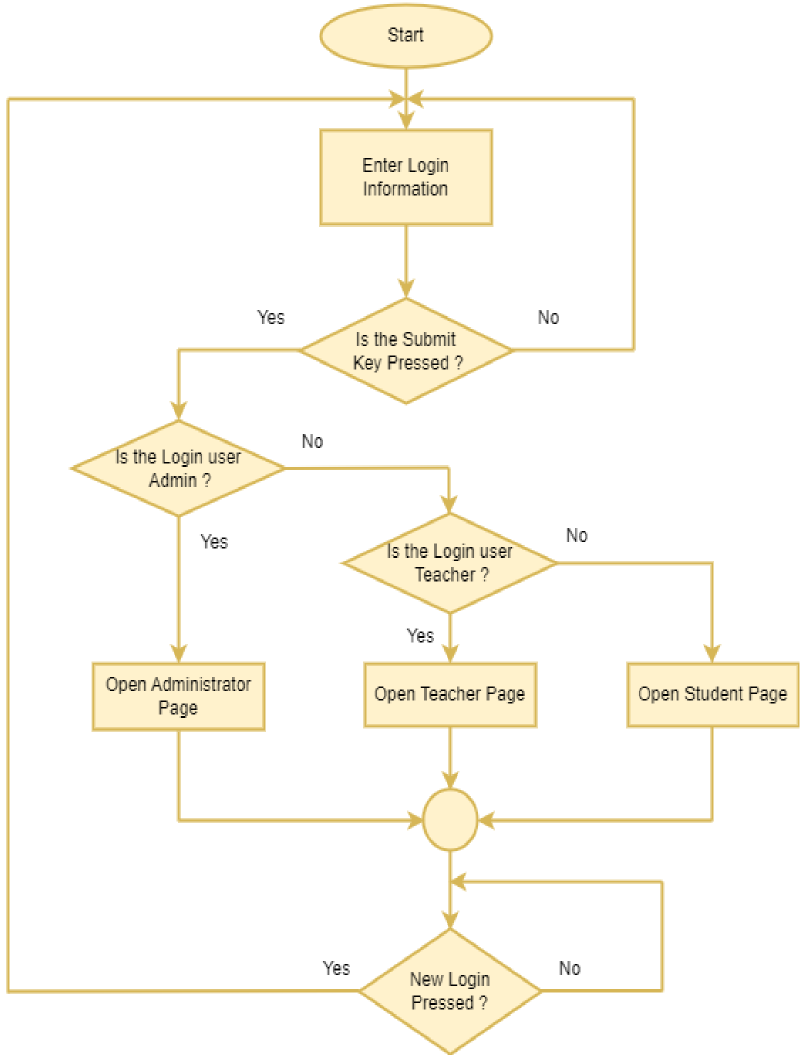

Figure 4: the flowchart of the Login Authentication system.

4. The Flow diagram of experiment operations

After the completion of Lab reservation operation successfully, the student can access the experiment through pressing the "open Lab" tab. The system operates on a client-server architecture utilizing internet connection. Figure-5 shows the main access flowchart of the proposed Remote Lab system.

In order to monitor and characterize the output data of a PV panel in real-time, this project proposed prototype reasonably priced remote laboratory system that makes use of LabVIEW and Arduino. A PV panel, an Arduino UNO board, as well as voltage, current, light, and temperature sensors, in addition to the supplementary actuators are among the hardware elements employed in the system. The software consists of LabVIEW, the Arduino IDE, and the LabVIEW Interface for Arduino (LIFA) (Ichim-Burlacu et al., 2023; Sasikala G., 2022), which enables serial communication between LabVIEW and the microcontroller. The Arduino UNO board's microprocessor receives the signals from the current and voltage sensors, (which measure the PV panel's output current and voltage respectively) in addition to the light, and temperature sensors to acquire the PV environment parameters. For real-time monitoring and analysis, the data is subsequently sent to computer software called LabVIEW. The student manages the environment of the PV through the actuators and manually records these sensors data throughout the time allotted for the experiment, which is allocated by the student.

4.1. Experiment LabVIEW Code

Figure-6 shows a flowchart of the proposed Remote Lab Experiments. The front panel of the remote laboratory system are shown in the Figure-7. There are three sections in the front panel. The setup and configuration of the serial connection and the execution stop are shown in the GREEN section. In the second RED section, the microcontroller uses the analog read function to display readings for temperature, light, voltage, and current from the Analog Input pins.

The third BLUE section of the block diagram involve the Digital and Analog output signals that are used by the student to control the environment of the PV to test it under various conditions as follows:

- Digital output pin D2 to activate Relay-1 which is used to Connect/ Disconnect the main power supply to the hardware components of the experiment.
- Digital output pin D3 to activate Relay-2 which is used to Connect/ Disconnect the Peltier to the (DC 12 volts) power supply.
- Digital output pin D4 to activate Relay-3 and Relay-4 that are utilized to change the polarity of the applied (DC 12 volts) power supply of the Peltier.
- Analog output pin D5 used to output analog voltage to control the Triac that used to regulate the Halogen Lamp light Intensity.
- Analog output pin D6 used to output analog voltage to control the L298 Driver that connected between the PV and the load resistance to change the amount of current that drawn from the PV Cell during the experiment.
- Digital output pin D7 to activate Relay-5 which used to make short circuit across the PV Cell to get short circuit current (Isc).

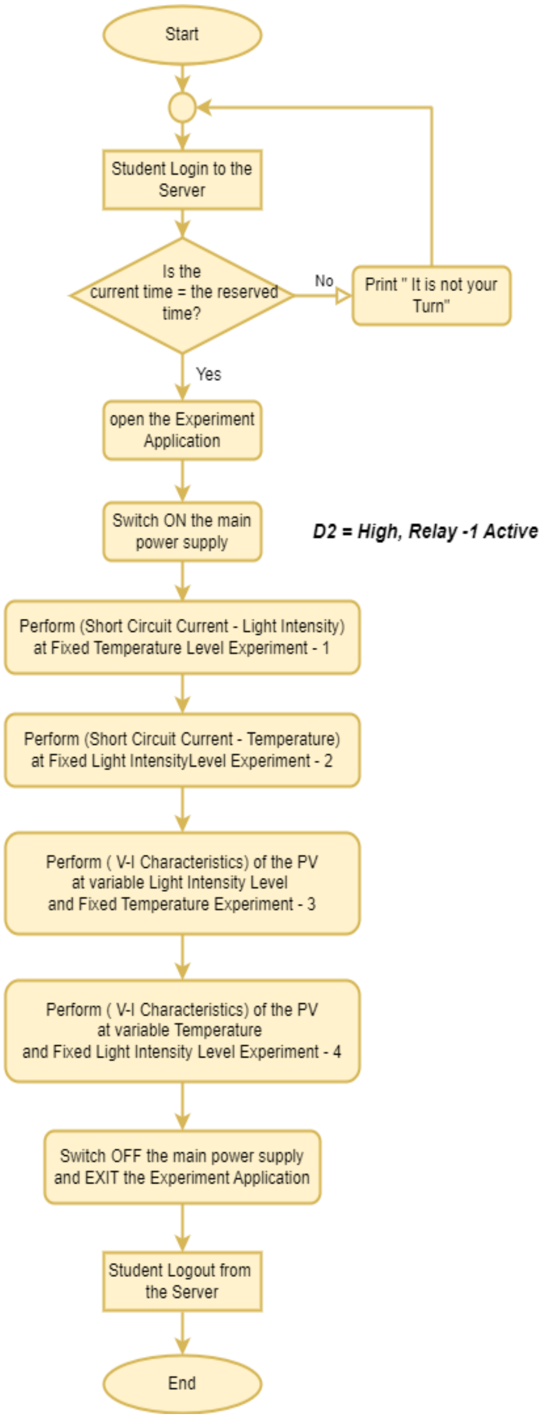

Figure-5: the main access flowchart of the proposed Remote Lab system.

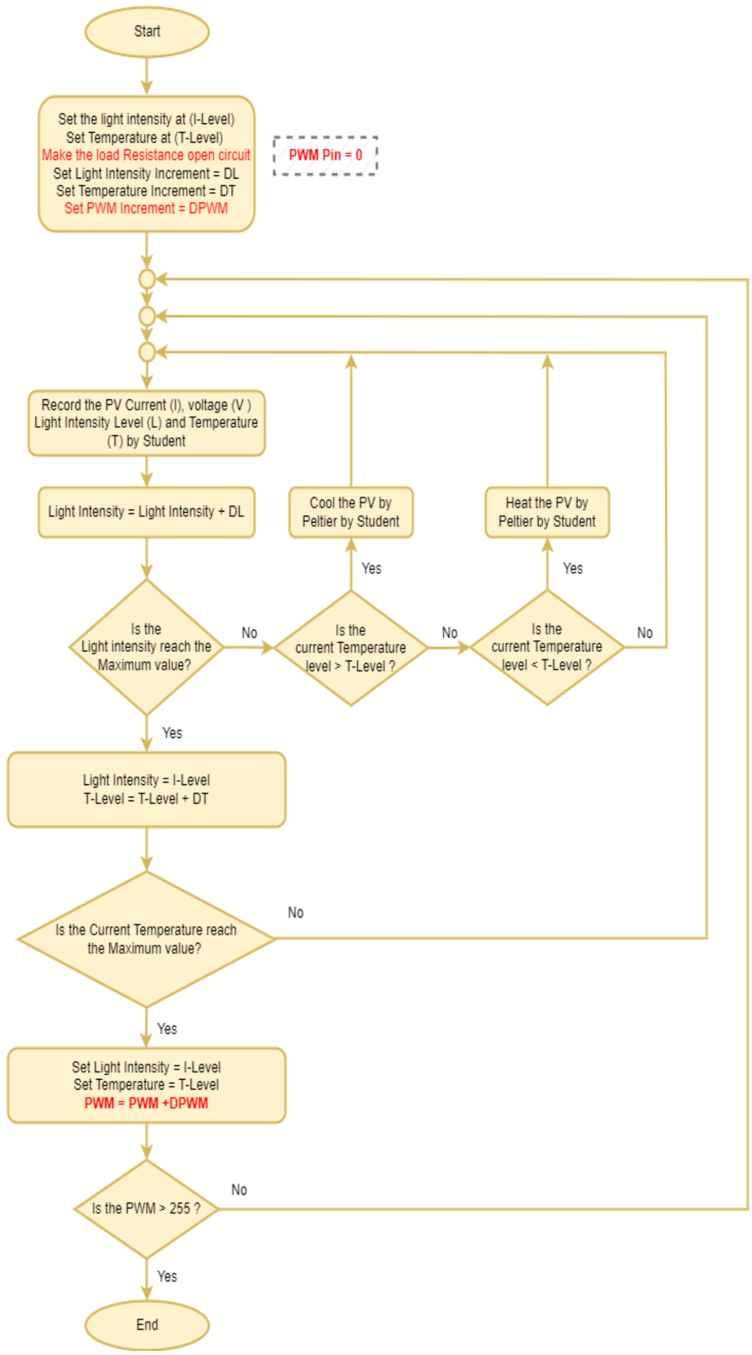

Figure-6: the flowchart of the proposed Remote Lab system.

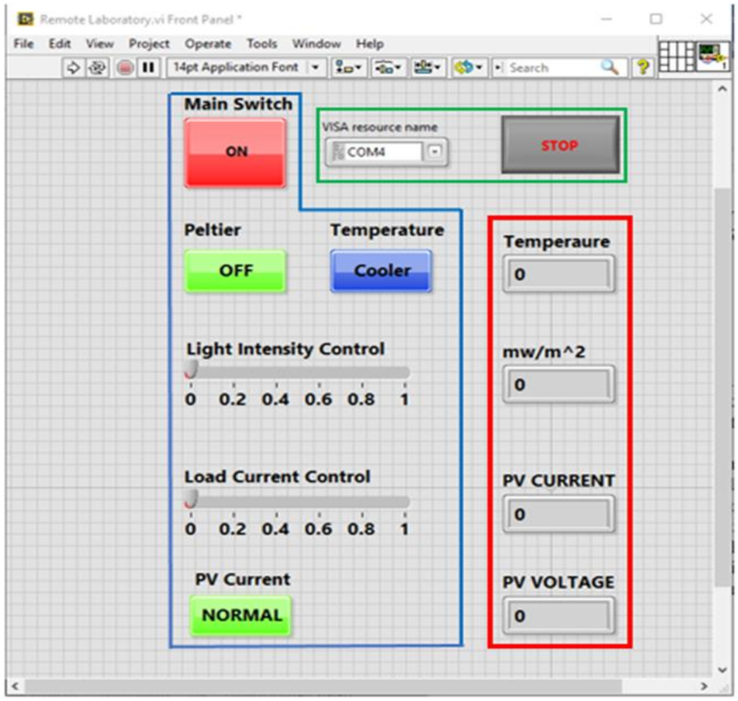

Figure-6: the LabVIEW Front Panel of Remote Lab Experiments.

5. The results

After the completion of the Lab Reservation operation, the student can enter the Laboratory if the current time within the reserved time and date. On the contrary, if the current time and date outside the reserved time, the system display an objection message as shown in Figure-8. If the Open Lab tab pressed with no objection message, the student can enter the experiment by pressing the Open Experiment button.

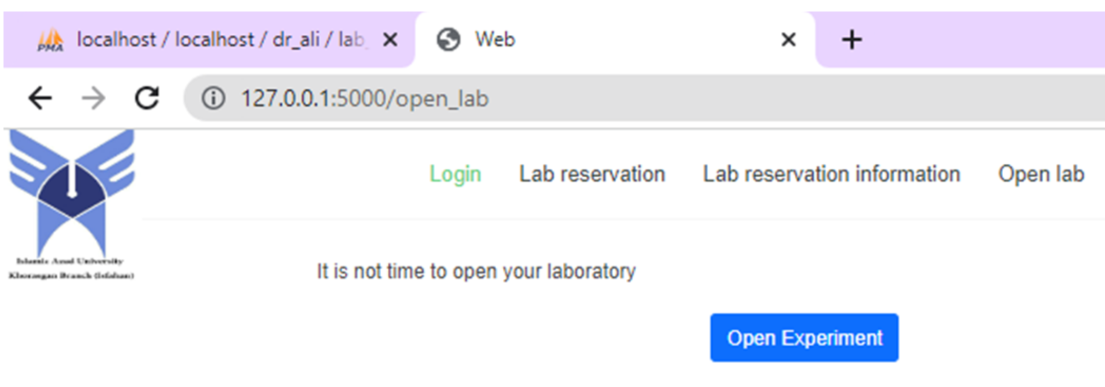

Figure 8: The objection message to the student

When the student presses the Open Experiment button, two pages are activated. The first one concern with the google form that contains the quiz questions for the student to answer during the experiment access. The second page concern with the GUI that are utilized by the student to manage the actuators of the PV characteristics experiment and record different sensors reading that are used to answer the quiz questions. As we mentioned earlier, the google form are generated randomly from the saved question bank that must be prepared by the Teacher. The first job that must be done by the student is Looking at the quiz questions of the google form in order to be able to answer these questions by conducting the experiment according to what is required from him. All the google form questions that are designed by the teacher are centered on the experiments available in the remote laboratory.

Figures 9 and 10 show samples of results that gained by the student.

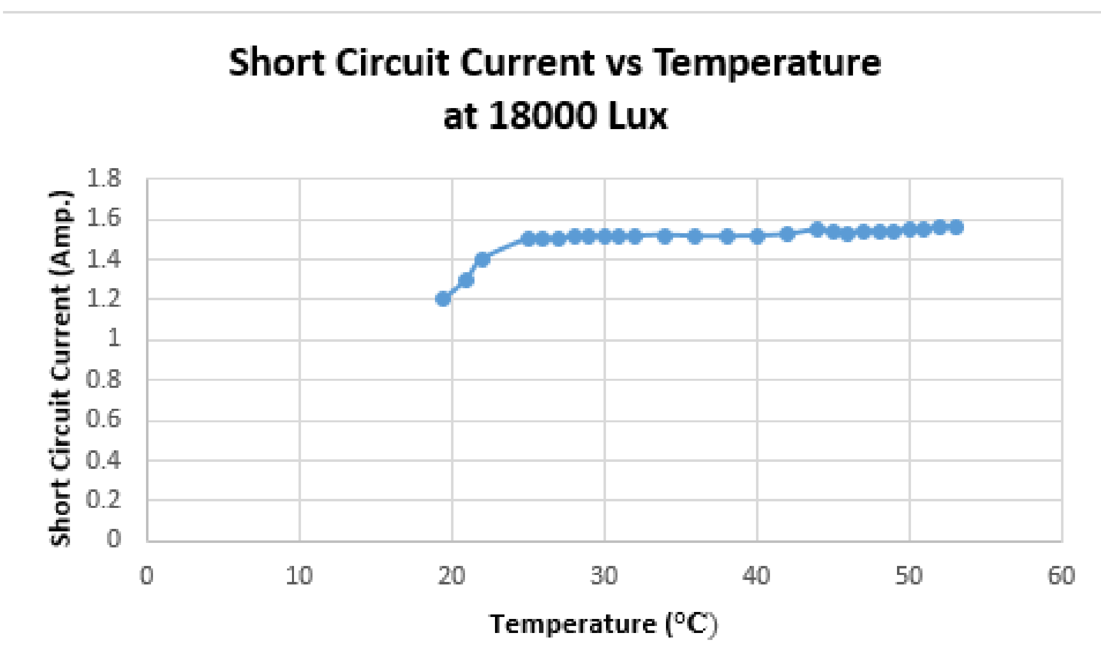

Figure 9: PV Short Circuit Current vs Temperature characteristics.

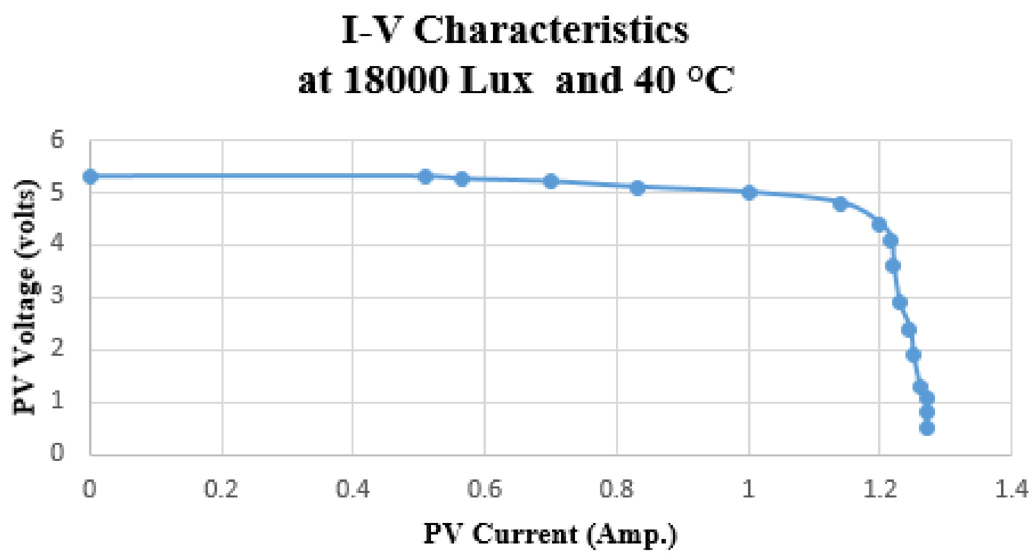

Figure 10: (I-V) characteristics of the PV.

6. Conclusion

With the help of IoT-based remote labs, scientists and engineers may conduct tests and measurements on solar systems without needing to be in the lab. Real remote lab technology has several benefits, such as enhanced flexibility and accessibility, lower costs, and increased safety. It enables scientists to do tests and measurements anywhere, from anywhere globally, using just a computer and an internet connection.

Moreover, for students taking part in laboratory experiments and measurements from a distance, cameras in distant lab design have several advantages. Even if students are conducting the investigation remotely, webcams can help them feel like they are truly in the laboratory by delivering live video feeds of laboratory procedures.

Here it should be noted that the automatic evaluation of a student's performance by the proposed system reduces the impact of the teacher's condition on the student's evaluation score, thus giving everyone his right according to pre-established criteria.

In conclusion, the use of the proposed remote laboratory has the following benefits:

- Reducing the exorbitant costs of laboratory equipment, which are usually high costs, especially educational ones.

- The maximum use of remote laboratory devices (twenty-four hours a day, seven days a week) by students instead of partial time utilization of traditional laboratories during the official working hours of the university.
- Reducing the number and effort of teachers supervising traditional laboratories when using the proposed system.

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