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Gömülü Sistemler Ders Deneyleri için Web Tabanlı Uzaktan Laboratuvar Tasarımı ve Gerçekleştirilmesi**

Design and implementation of a Web-Based Remote laboratory for Embedded Systems Course Experiments**

jalal Miladi[1*], Halil İbrahim Akyüz[2]

[1*] Kastamonu University, Institue of Science, Kastamonu, Türkiye
[2] Kastamonu University, Education Faculty, Kastamonu, Türkiye

ABSTRACT

Multiple factors, such as natural disasters, wars, security instability, and the outbreak of serious diseases such as COVID-19, may cause the complete cessation of traditional face-to-face education. Universities have turned to distance learning in order to avoid the difficulty of students being on campus.

Teaching laboratory courses remotely is one of the most difficult challenges facing academic institutions when switching to distance education. Most of the available alternative solutions to the traditional laboratory are ineffective or difficult to implement and may cause a negative impact on student achievement.

This article presents the Web-based remote laboratory system as an alternative technical solution to the traditional laboratory for teaching programming experiments for Arduino boards. In this system, the student can conduct the experiment remotely on devices and equipment located in the university laboratory.

The remote laboratory system is multi-user, scalable, flexible and low cost. The system is implemented using low-cost hardware resources and free and open source software.

The system underwent user acceptance testing based on the Unified Theory of Technology Acceptance and Use approach. The results were encouraging, as participants in the system acceptance test showed a good acceptance rate of 70.75%, which confirms the effectiveness of the system and its ease of use.

Keywords: Remote laboratory, Arduino, Students' Academic Performance.

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[1*]Sorumlu yazar: Kastamonu Üniversitesi, Fen Bilimleri Enstitüsü, Kastamonu, Türkiye; E-mail: jmiladi@gmail.com; ORCID: 0009-0005-9795-8024
[2] E-mail: hakyuz@kastamonu.edu.tr; ORCID: 0000-0002-1614-3271

1. INTRODUCTİON

Engineering education institutions aim to educate an engineer who can adequately use physical and engineering tools and processes. Therefore, theoretical knowledge is insufficient to enter the labor market. Before graduation, emphasis should be placed on students knowing engineering processes and systems that go beyond the boundaries of theoretical knowledge. In other words, educational laboratories play the most crucial role in education, research, and vocational training, especially in engineering courses. (Hardison et al., 2008; Hofstein, 2017).

Education, like all other fields, has recently been based on modern technologies. It has been clearly shown that the use of modern technological equipment and tools increases academic achievement and improves student interaction (Raja & Nagasubramani, 2018).

1.1. Distance Education

For many years and decades, educational institutions have relied on face-to-face classroom education, where professors and students meet at the same place and time to teach students (Al-Masri, 2018).

Valentine (2002) states that distance education started 100 years ago in Europe. It was mainly based on traditional methods of messaging between people. With the advent of radio and television technologies, lectures and educational lessons have been delivered through these technologies. Some educational institutions have also made use of videotapes and compact discs (CDs) to record their lectures.

In the internet age that began in the late twentieth century, advances in communication and information technologies have enabled employees to work from home or elsewhere when certain conditions, such as wars or natural disasters, prevent them from going to work (Ozili & Arun, 2022). These technologies and their applications have entered the work environment and scientific learning process (Morris et al., 2020). A new teaching method based on modern technologies was developed, and the term distance education emerged (Al-Masri, 2018). Thus, many universities and educational institutions have started to offer courses over the Internet to provide distance education to their students, and distance education is expected to grow further, especially in higher education institutions (Kefalis & Drigas, 2019; Morris et al., 2020; Valentine, 2002). Distance education has changed the rules of learning and the way students and teachers participate in the learning process (Farag, 2017).

1.1.1. Remote laboratory

Transitioning to distance laboratory education is a complex project. It requires excellent study and effort, including developing a plan and preliminary study for the proposed system before implementation. Some university courses may be unable to integrate laboratory courses into their distance learning programs. Laboratory courses require students to be in the laboratory to perform experiments, which poses a difficult challenge for teaching lectures and laboratory experiments remotely (Lytvynova & Pinchuk, 2018).

Silva et al. (2016) also state that to implement this technology, each experiment must be redesigned to meet specific technology requirements.

Rossiter et al (2019) recommend the use of the Take Home Laboratory Kit method in teaching laboratory engineering subjects at the University of Sheffield. This method was effective in reducing the time students spent in laboratories. Financially, it is considered cheaper than setting up a private laboratory. The experience has satisfied students and faculty.

One of the commonly used solutions in laboratory distance education is computer simulation programs. A simulation program is software that relies on mathematical models to simulate the behavior of equipment and processes in reality (Haiyan, 2015; Penumadu et al., 2000). The students can enjoy the experience in these programs without using actual equipment. This method can be fully compatible with distance learning programs, as it requires students to have a computer equipped with a simulation program that allows them to simulate laboratory experiments. Thus, the student can perform laboratory experiments at home without being in the laboratory (Chowdhury et al., 2019).

With the growth of the Internet and its applications, Ko et al. (2001) developed a new technology called a Web-Based Laboratory for teaching laboratory courses. Later, it was called a Virtual Laboratory. Thus, students can perform laboratory experiments online from anywhere.

A virtual laboratory is defined as a system that uses software to simulate a laboratory environment and provides an interactive platform where users can engage in a range of activities, such as conducting experiments, accessing learning materials, and submitting reports. Virtual laboratories are often used in laboratories where equipment is expensive or unavailable or to simulate an unsafe environment (Chen et al., 2010).

According to Gustavsson et al. (2008), the use of simulation software in the education process has increased significantly in recent years, especially in engineering faculties.

Typically, simulation programs were stored on laboratory computers. Students would perform experiments directly on these computers. However, with the development of new services provided by the Internet and cloud computing technologies, the student can perform experiments remotely by accessing the computer containing the simulation program over the Internet. This technology provides a virtual environment for natural laboratories (Karadimas & Kostas, 2007).

One of the most critical conditions for a successful remote laboratory is that the student must feel that the laboratory looks natural. This is done by integrating visual, text, and even audio technologies, if possible, and using the webcam to transmit a live feed to closely monitor the actual results of the experiment (Farag & Wael, 2017).

Virtual laboratories can be useful educational tools for teaching laboratory topics. Due to its many advantages, many university administrators and professors are planning to switch to these technologies (Altalbe, 2019). In addition to reducing costs, the virtual laboratory is available 24/7, allowing students to work whenever they want (Evangelista et al., 2017).

Although virtual laboratories offer solutions for distance laboratory education, they have distinct disadvantages. Students do not deal with actual laboratory equipment and processes but with mathematical models that attempt to model and represent reality (Orduña et al., 2018). Another disadvantage of the virtual laboratory is its cost, which can be expensive for students.

The latest development in this field is the possibility for students to access and interact with the physical equipment of laboratories remotely; this technology is known as Remote Laboratory System (RLS). Virtual and remote laboratories are two types of distance laboratory training, but there is a crucial difference between them. In contrast, the virtual laboratory allows experiments to be carried out in a virtual environment or simulation applications, while the remote laboratory allows access and interaction with actual experiments and equipment; this is a significant innovation in the development of remote laboratories (Chen et al., 2010; Karadimas & Kostas, 2007; Kozič et al., 2016).

A remote laboratory is defined as a laboratory that allows experiments to be conducted, monitored, and controlled remotely (Chen et al., 2010; Gustavsson, 2008; Karadimas & Kostas, 2007). De Lima et al. (2016) defined the remote laboratory as a laboratory that gives the student control and observation capabilities of the physical components in the laboratory through computer network techniques.

Kefalis and Drigas (2019) define this educational technology as a system that allows students to use the Internet to access real laboratory devices.

2. MATERIAL AND METHODS

In order to achieve the goal of this article, the researchers followed the following basic steps:

1- Developing and testing a Web-based remote laboratory system dedicated to learning the laboratory aspect of the Microcontroller Systems course, where a web application was developed based on the client-server architecture using the Anvil full-stack framework.

2- Conducting a experimental study at the College of Electronic Technology - Tripoli, Libya, aiming to evaluate the RLS system using User Acceptance Test (UAT) Based on the Unified Theory of Acceptance and Use of Technology (UTAUT).

3- Conduct a descriptive statistical analysis using the SPSS software system to determine the result of UAT.

2.1. Development of Remote Lab System

The remote laboratory system was created using a combination of iterative and incremental development methodologies. The process began with the basic version of the system, which included only some of the essential functions and services. This version was tested, and any issues were fixed. Once this version was confirmed to be correct, new requirements were added to create the next version with additional functions and services. This process was repeated until the final version met all the requirements and provided all the desired functions and services of the remote laboratory system. Iterative and incremental development methodologies are applicable when a complete list of requirements is unclear from the beginning of system development, it also reduce the risk of failure by focusing on small parts of the system in each iteration, improve quality through continuous testing and refinement, offer greater flexibility for new requirements or modifications, and enable the quick delivery of an initial product containing basic requirements for early customer feedback (Hossain, 2023).

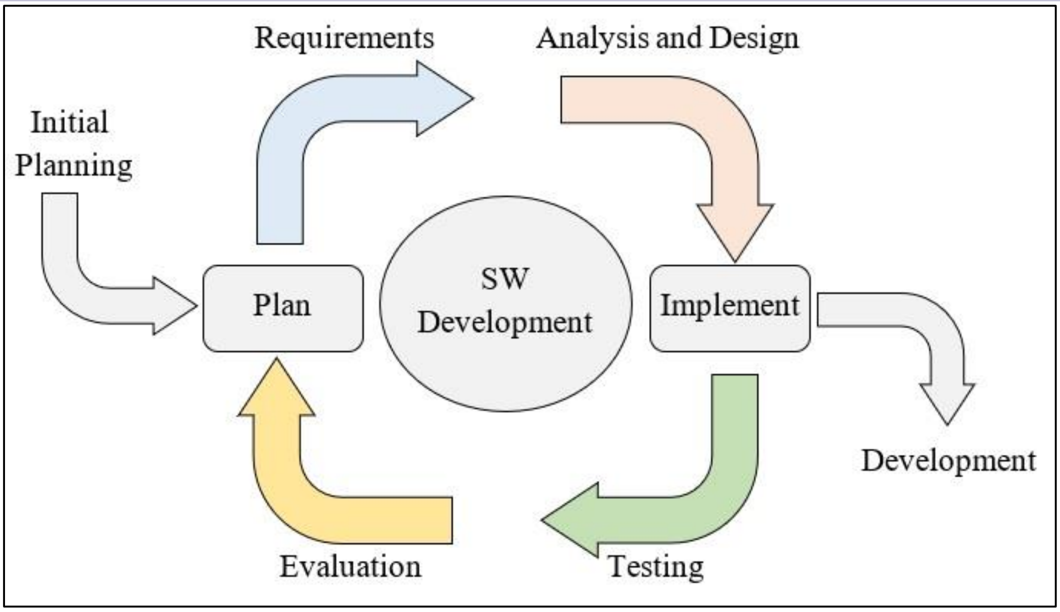

Figure 1. RLS Development Methodology

The Remote Lab System (RLS) is made up of three subsystems: the RLS client, the RLS server, and laboratory workbenches. The Internet serves as the data transfer link between these components, allowing for seamless and uninterrupted transfer of data and commands that are essential for the RLS system to function. Figure 2 illustrates the configuration of the remote lab system.

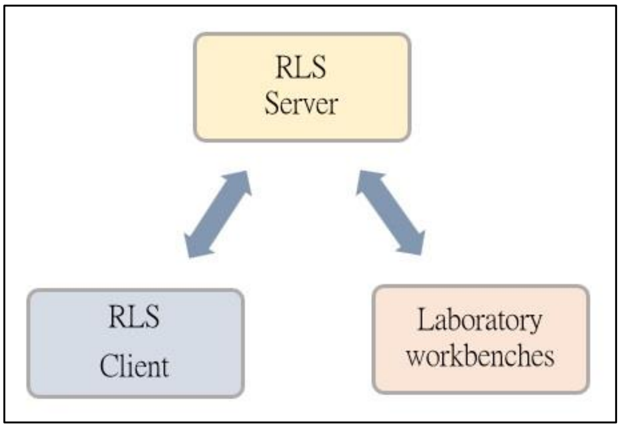

Figure 2. Remote Lab Configuration

2.1.1. Remote lab system hardware

In Figure 3, the client subsystem consists of the student's device (computer, smartphone, or tablet). Students use a web application (frontend app) to connect to the lab and conduct the experiment. The client subsystem also interacts with the lab by watching and tracking the experiment's operation using video streaming technology.

The RLS server is a powerful computer server. It runs the backend application, hosts all system services and data, and ensures reliability and robustness.

At the core of the lab, there are three workbenches connected to a credit card-sized computer called Raspberry Pi, each workbench representing an experiment circuit, which is an Arduino board connected to the experiment hardware. Figure 4 shows how to connect the Raspberry Pi board to the experiment board. The Raspberry Pi functions as a regular computer but has specific characteristics that make it well-suited for this application. It is an open-source single-board computer that can easily communicate with laboratory workbenches, supports wired and wireless internet connections, and is a small, low-cost computer (Jolles, 2021). This computer is utilized in various applications, including web browsing, gaming, and creating and controlling hardware circuits and systems. Furthermore, it is commonly used in educational institutions, from primary to higher education (Jolles, 2021; Kushwah et al., 2023).

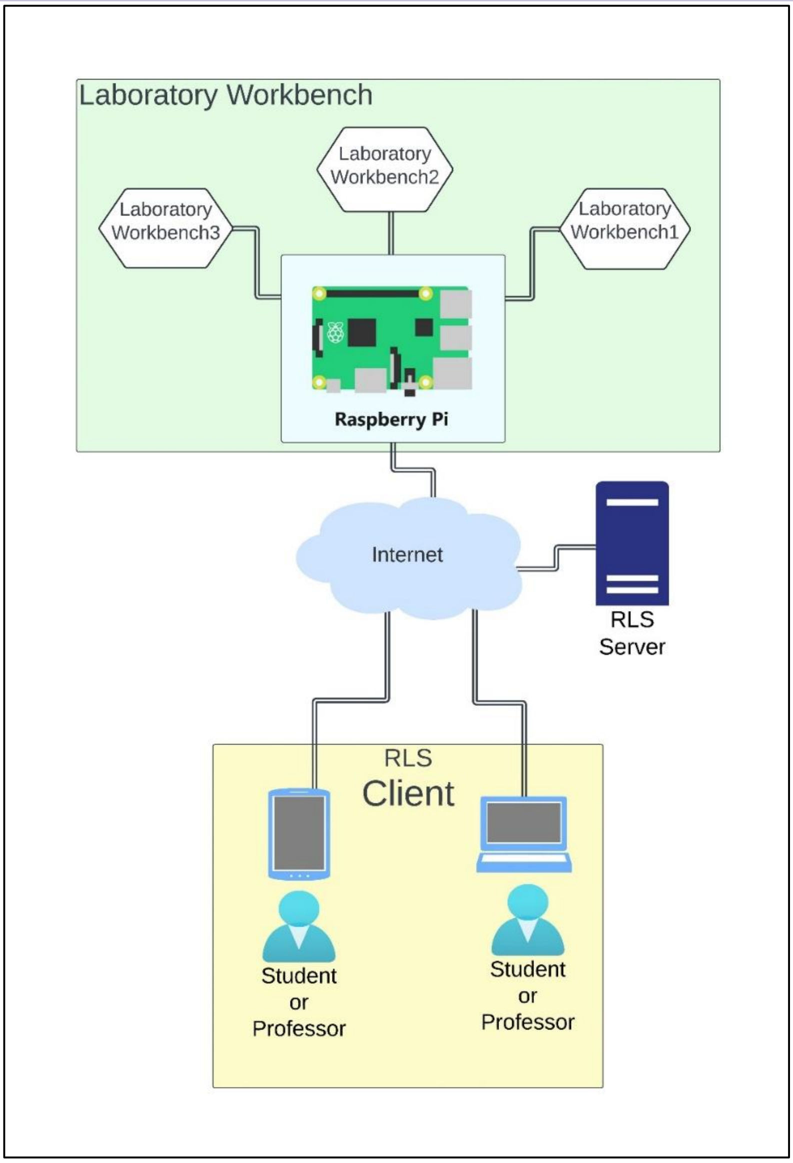

Figure 3. Remote Lab Architecture

The Raspberry Pi 4-B model is an advanced single-board computer with four USB ports. Three of these ports are used in this system to establish connections with three separate experimental workbenches through USB cables. The USB connector is also utilized for uploading students' program code to the Arduino board.

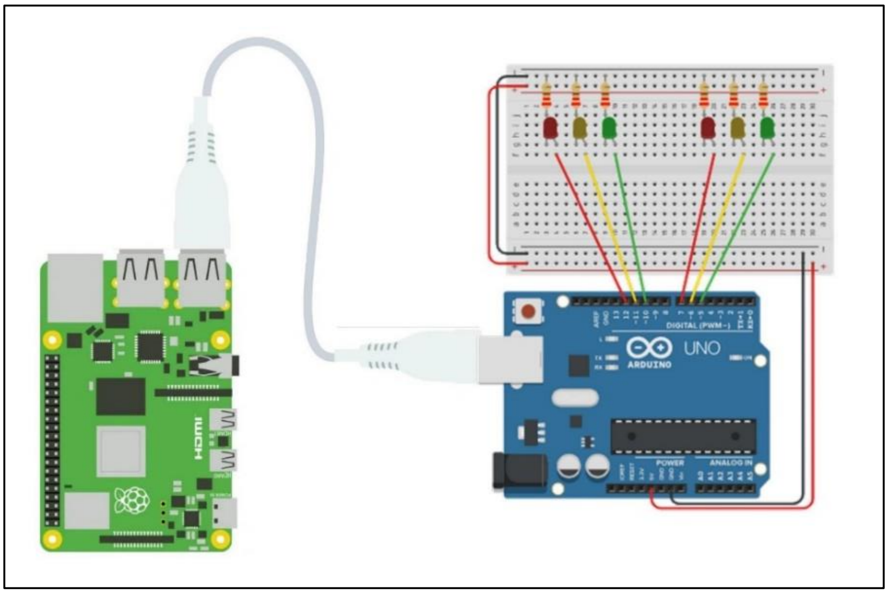

Figure 4. Connecting the experiment board to the Raspberry Pi board

2.1.2. Remote Lab System Software

The RLS software application was developed using the Anvil framework. This web-based development environment simplifies building the backend and front end, including the database, using only Python. This framework was chosen for its ease of use and ability to streamline development.

As shown in Figure 5, the RLS system software is conveniently built on the robust client-server model. It comprises the server (Backend) part, a program that operates on the RLS server, and the client (Frontend) part, a web application that students run on their devices to access the laboratory remotely.

The last program is the workbench program. This small program runs on a Raspberry Pi board and remotely connects the laboratory workbenches to the laboratory application.

The backend and frontend applications were developed using the Anvil framework, while the workbench program was programmed using an open-source Python IDE.

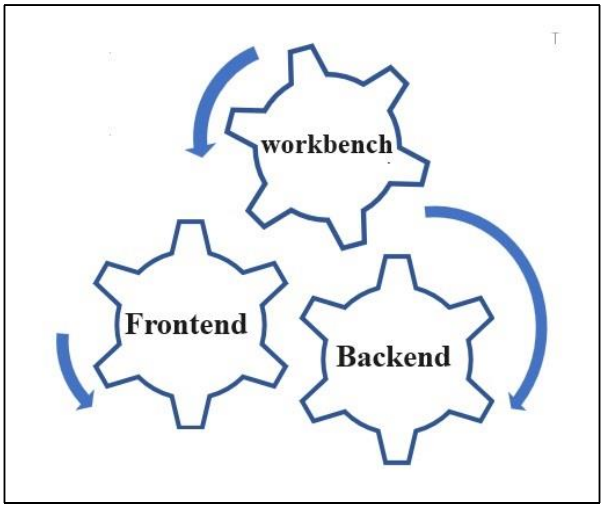

Figure 5. Remote Lab Software System Architecture

More description about these three software are described as follows:

1. Workbench Software

The workbench software for the Raspberry Pi board is programmed using Python 3.9. It serves students by enabling them to perform various tasks and functions, including:

Establishing a reliable connection between the experimental board and the RLS server using the ANVIL platform's Uplink service ensures data communication over the Internet.

Testing the validity of the student program and checking for errors.

Upload the student code to the Arduino board using the reliable Arduino command library, which verifies and uploads the Arduino sketch into the Arduino board.

Running the experiment and broadcasting a video stream so the student can watch it remotely, using the Daily video stream API service.

2. Backend Software

The backend software of the RLS systems was carefully designed to handle user requests, manage user authentication, store user files and host databases, and establish a seamless connection between users and the workbench system. The ANVIL framework supports designing and building a database table using a simple integrated Graphic User Interface (GUI) tool. The RLS database stores experiments, students, and lab application settings information. The RLS database consists of 6 entities (Tables):

User Table: This table stores student information such as name, registration number, and student group.

Experiments Table: This table contains data about laboratory experiments, such as the experiment's number, title, and date.

Workbench Table: This table stores workbench information, such as the workbench number, connected experiment number, and availability status of the workbench.

Experiment Schedule Table: In this table, the appointments students can book to carry out laboratory experiments are stored.

Setting Table: It contains a variety of variables that control the operation of RLS. The administrator can change the setting values to give the system more flexibility.

User Log Table: This table stores all student system activities, such as login and logout operations, including the date and time of each operation. This table gives the system administrator the ability to monitor the system and verify operations that occurred in the laboratory system.

3. Frontend Software

The Frontend Software, also known as the user or client side of the RLS, is an application that runs on a student's device. It enables students to conduct experiments and communicate remotely with the server and workbench software. Figure 6 shows the home page of the RLS Frontend software.

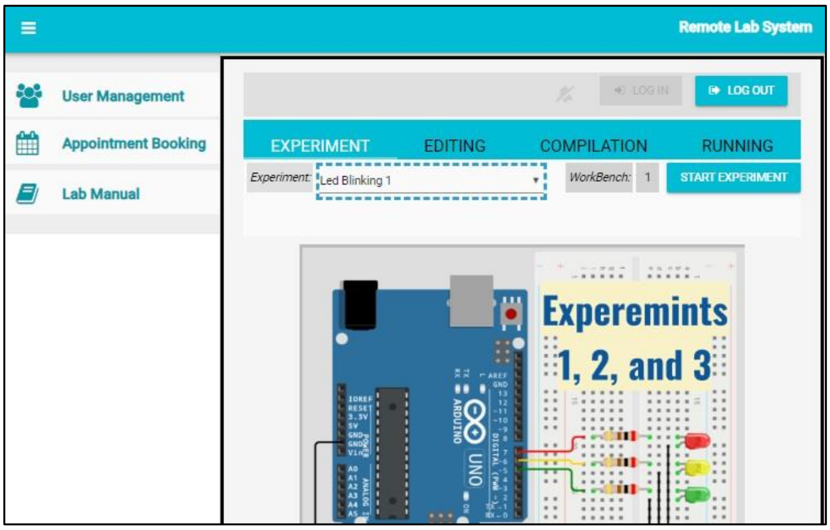

Figure 6. The Home Page of RLS

Through the Frontend application, students can perform various tasks such as:

1- Log in

2- Booking an appointment.

3- Editing experiment code

4- Compiling experiment code.

5- Running the experiment.

6- Download the lab manual.

The professor can function as a system administrator through the system's front end. The system allows professors to carry out a range of tasks, such as:

1- Log in

2- Managing student profiles.

3- Adjusting system settings.

4- Scheduling laboratory experiments.

5- Overseeing the system while tracking and controlling student activity.

2.2. Remote Laboratory System Evaluating

RLS's User Acceptance Testing (UAT) examines the factors influencing user acceptance of a system identified by the Unified Theory of Acceptance and Use of Technology (UTAUT). According to theory, four important metrics significantly affect user acceptance: expected performance, predictability of effort, social influence, and facilitating conditions (Venkatesh et al., 2003).

Eighteen people participated in this study and were given a copy of the remote laboratory system manual. This document defined the RLS system, explained its function, and provided a step-by-step guide for conducting experiments. Armed with this resource, participants conducted two remote laboratory experiments.

Study data were collected through a questionnaire; questions were directed to participants who had previously tested in the remote laboratory. The questionnaire was prepared based on the UTAUT theory and aims to measure the four main factors that most influence user acceptance of the system, as the theory concludes.

2.2.1. User Acceptance Test Factors

The four main factors that measure user acceptance of the remote laboratory system and the associated constructors (interview statements) are shown in Figure 7, and described as follows:

1. Performance expectancy: This measure is determined by obtaining information from the user about the importance and benefit of using the system in his work, whether the system increases productivity and speeds up tasks, and whether it is possible to use the system to obtain a reward or advantage for the user over his colleagues.

2. Effort expectancy: This scale is determined by a set of indicators: clarity and understanding of how to deal with the system, ease of using the system, and ease of becoming skilled at using the system.

3. Social influence: The measure of social influence depends on multiple indicators, such as the extent to which he believes that those in charge of his work or those who influence his behavior need to use the system, as well as the amount of support and assistance of the organization and senior management when using the system.

4. Facilitating conditions: Facilitating the conditions can be determined by answering the following questions:

- Does the participant have the necessary resources and information to use the system?
- Is the system compatible with other systems?
- Is the support team available when needed?

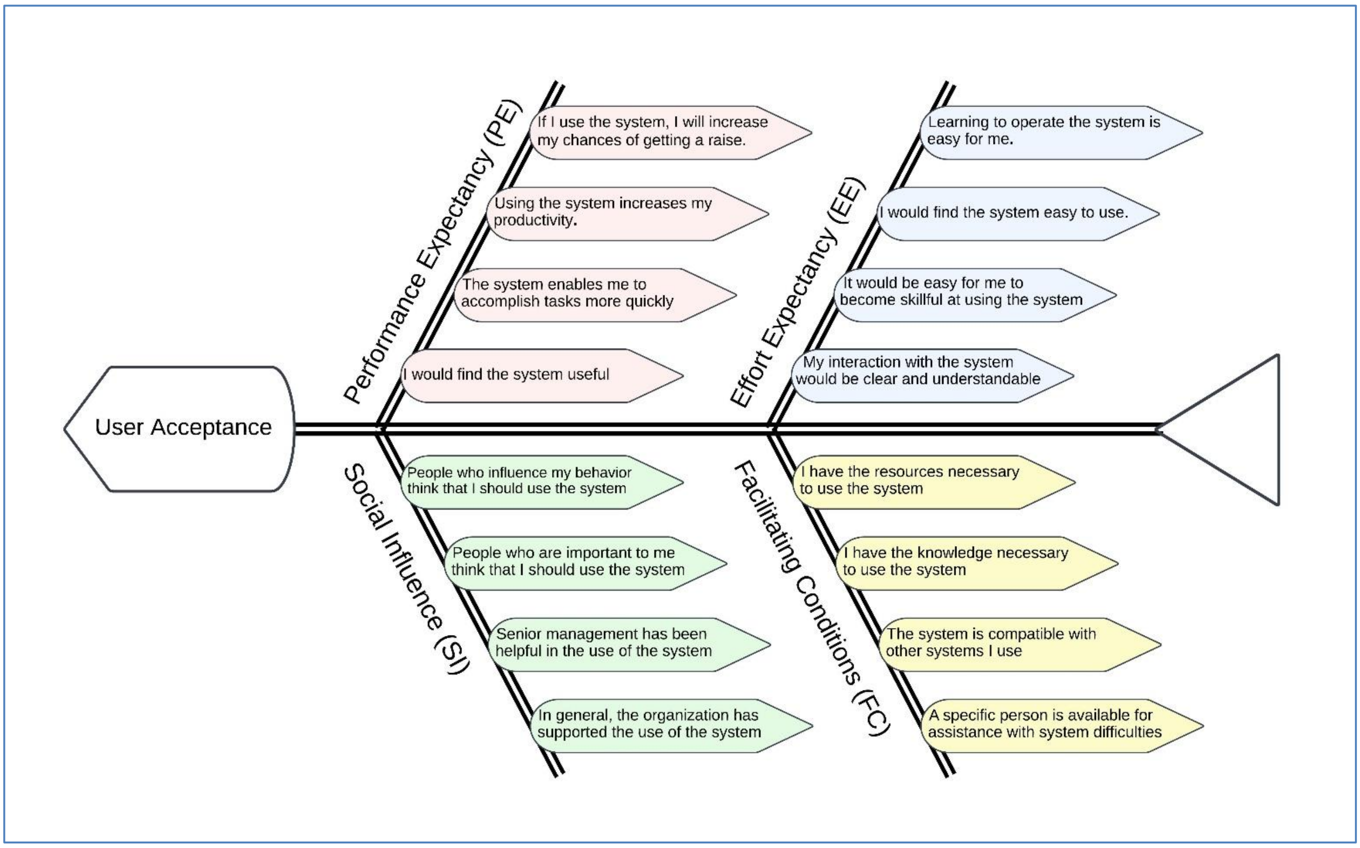

Figure 7. User Acceptance Factors

3. Data Analyses And Results

The data was collected quantitatively. A simplified questionnaire was designed based on 16 questionnaire statements, each containing four questions for one of the four factors identified by the UTAUT theory.

A 5-point Likert scale, weighted from 0 to 4, was used for questionnaire responses, where four is given to "strongly agree," and 0 is given to "strongly disagree."

A total of 18 people participated in the study, including students and professors in Tripoli City, Libya. Data were descriptively analyzed using the SPSS system.

Table 1. and Figure 8 shows the distribution of study participants' age groups.

Table 1. Participant Age Group Distribution

Age Group	Frequency	Percent
< 25	12	66.67%
25 – 35	3	16.67%
<35	3	16.67%

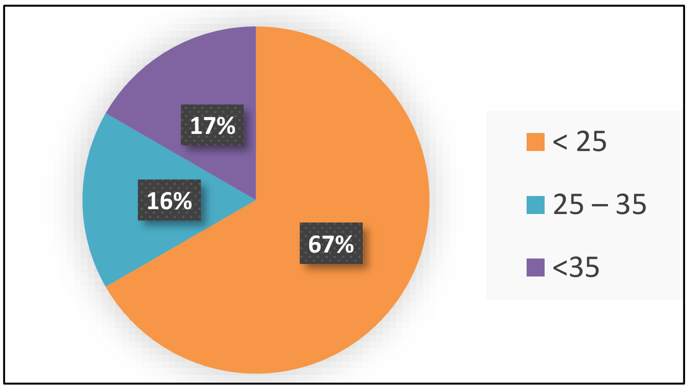

Figure 8. Participant Age Groups Distribution

The educational level of the participants varied: As shown in Table 2 and Figure 9, the majority are bachelor's degree students: 13 (72%), 3 (17%) are engineers with a bachelor's degree, and 2 (11%) are college professors with scientific specializations related to programming microcontrollers. Thus, helpful feedback could be obtained that may contribute to improving the RLS.

Table 2. Participant Job Role Distribution

Participant Job Role	Frequency	Percent
Student	13	72.22%
Engineer	3	16.67%
Lecturer	2	11.11%

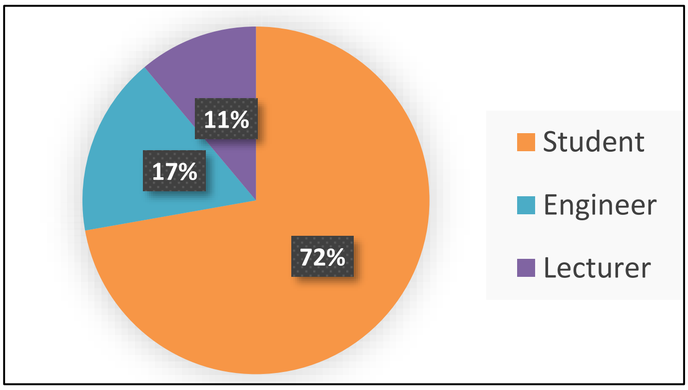

Figure 9. Participant Job Role Distribution

Also, the analysis shows that 7 (39%) of the participants are beginners, 9 (50%) intermediate, and 2 (11%) are experts. Table 5.3 and Figure 10, shows the frequencies of each experience level for study participants.

Table 3. Participant Experience Level Distribution

Experience Level	Frequency	Percent
Beginner	9	50%
Intermediate	7	38.89%
Expert	2	11.11%

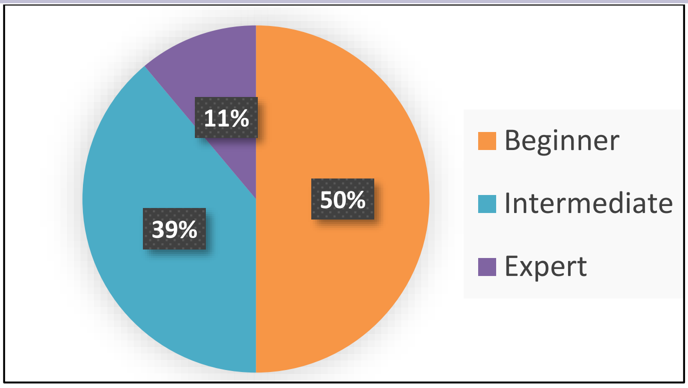

Figure 10. Participant Experience Level Distribution

Additionally, the preliminary results from data analysis indicated that 15 of the participants (83.33%) answered that the RLS is easy to use and that it is possible to become skilled at using it. Also, among the preliminary statistics, 13 out of 18 participants (72.22%) answered that the RLS is helpful in laboratory learning and conducting experiments to program Arduino boards.

As shown in Table 4 and Figure 11, the statistical analysis further supports the RLS's user-friendly nature. Effort Expectancy (EE) scored the highest acceptance rate. The mean EE was 3.33 (83.3%), indicating that the RLS is straightforward, easy to use, and quick to learn.

According to the participants, the second highest acceptance factor Was the availability of Facilitating Conditions (FC) to operate the RLS, with a score of 3.08. This indicates a strong consensus on the system's practicality and user-friendliness.

Third was Performance Expectancy, where FE=2.54 (63.5%). Participants differed slightly regarding their expectations of the system's capabilities and desired gains.

Finally, the Social Influence (SI) factor was the lowest factor that received acceptance from participants, and the mean SI was 2.38 (59.5%).

The statistical analysis concluded that most participants accepted the RLS, with an acceptance rate of 2.83 (70.75%).

Table 4 Acceptance Analysis Results

System Acceptance Factors	Min	Max	Mean
Performance Expectancy	0.67	4.00	2.54
Effort Expectancy	1.00	4.00	3.33
Social Influence	1.25	3.50	2.38
Facilitating Conditions	1.25	3.75	3.08
Overall	1.60	3.69	2.83

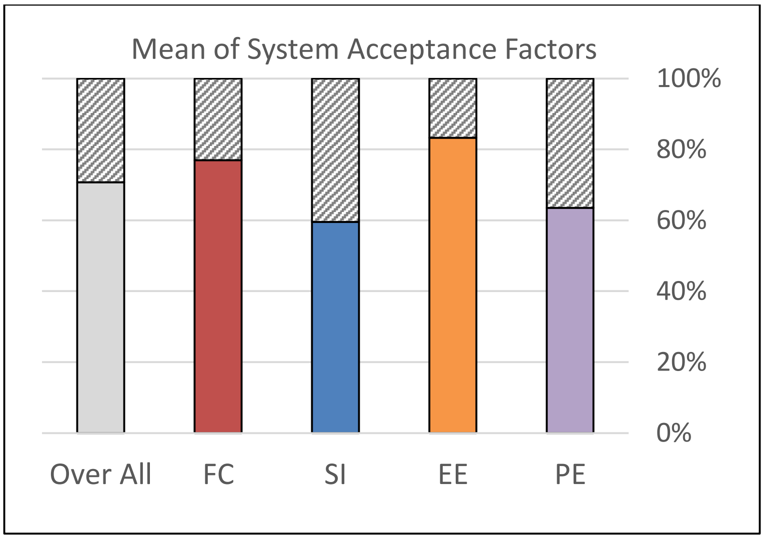

Figure 11. Acceptance Analysis Results

4 CONCLUSIONS

The digital transformation towards distance education has become a more critical need, especially in regions that suffer from several factors that cause the cessation of traditional studies, such as the spread of the COVID-19 pandemic, security conditions, earthquakes, and other natural disasters.

By studying the different solutions for integrating laboratory courses into distance education, remote laboratory technology is considered an appropriate solution for distance learning laboratory courses.

This paper presented the development of a remote laboratory system the authors built. The system allows the student to carry out his transactions remotely. It gives him the flexibility to choose the appropriate time from any place without the need to be present in the specified laboratory at a specific time.

The most advantageous feature of the designed system was its multiuser capability, which meant multiple users could carry out different experiments simultaneously. It was also characterized by a cost-effective, expandable design. It supports an increase in the number of users working simultaneously without the need for expensive additional equipment, and it offers flexibility in managing the system and following up on students' work.

The system's acceptance was tested with 18 participants, most of whom were bachelor's degree students, two professors, and three engineers. The test results were overwhelmingly positive, with 83.33% of participants expressing the ease of using the system and the speed of learning how to operate it. 72.22% confirmed the possibility of relying on the system in conducting Laboratory experiments for microcontroller boards. The statistical analysis found that the mean acceptance rate is 70.75%. This result indicates that the participants' answers instilled confidence in the effectiveness of the system and its ease of use and that it can be used to learn programming microcontrollers.

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