LAYERED SYSTEM ARCHITECTURE OF REMOTE ROBOTIC LABORATORY FOR REAL-TIME DISTANT LEARNING

FAISAL MAHMUD

FACULTY OF COMPUTER SCIENCE AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYA
KUALA LUMPUR
2022

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FAISAL MAHMUD

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF COMPUTER SCIENCE (APPLIED COMPUTING)

FACULTY OF COMPUTER SCIENCE AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYA
KUALA LUMPUR

2022

UNIVERSITI MALAYA
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Matric No: ***17007198/1 (new), WOA180007 (old)***

Name of Degree: ***Master of Computer Science (Applied Computing)***

Title of Dissertation: ***Layered System Architecture of Remote Robotic Laboratory for Real-Time Distant Learning***

Field of Study: ***Robotics and Artificial Intelligence***

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LAYERED SYSTEM ARCHITECTURE OF REMOTE ROBOTIC LABORATORY FOR REAL-TIME DISTANT LEARNING

ABSTRACT

Laboratory experimental practice is an integral part of every day's teaching and learning concerns in science and engineering courses. Under Industrial Revolution 3.0 schematic, the teaching of laboratory subjects has always been executed manually with the help of electrical instruments and data logging devices. Traditionally, a class full of students does not allow all participants to conduct laboratory exercises individually due to the minimal resources and time management. In this light, there is an urgent need to rejuvenate the current way of lab execution by injecting elements of Industrial Revolution 4.0 which centralizes internet tools coupled with the robotic system. Moreover, during an unprecedented time, such as the Covid-19 pandemic has enforced and proved a high demand to conduct laboratory experiments remotely by utilizing existing institutional online learning facilities. Therefore, working on laboratory exercises remotely via the server-based application may alleviate the difficulties in a traditional laboratory environment. In this research, a real-time online platform for performing lab exercises remotely has been proposed. This 'Remote Robotic Laboratory' would allow lab execution to be conducted remotely via an internet platform which promotes flexibility as well as brings more joy and excitement to the user. With this idea, the current project focuses on establishing a prototype of an online laboratory system that incorporates human interface software and hardware modules. The findings from our studies show that the proposed method was able to provide the students with a major increase in flexibility and performance. After the establishment of the system run time survey has been conducted with the help of students to evaluate the performance of the proposed facility. The investigation on the system response indicates good performance under different levels of internet bandwidth. The reliability of data recording was verified with the theoretical calculation which indicates a synchronized data transfer as low as 30ms interval. The survey on the user perception indicates more than 80% satisfaction over the concept.

Keywords: Remote Robotic Laboratory, Layered System Architecture, Remote Access, E-Learning, Management System.

SENIBINA SISTEM BERLAPIS MAKMAL ROBOT JAUH UNTUK PEMBELAJARAN MASA NYATA JARAK JAUH

ABSTRAK

Amalan eksperimen makmal adalah bahagian yang tidak terpisahkan dari pengajaran dan pembelajaran harian dalam kursus sains dan kejuruteraan. Di bawah skema Revolusi Industri 3.0, pengajaran subjek makmal selalu dilaksanakan secara manual dengan bantuan instrumen elektrik dan alat perakam data. Secara tradisinya, kelas yang penuh dengan pelajar tidak membenarkan semua peserta melakukan latihan makmal secara individu kerana sumber dan pengurusan masa yang minimum. Dalam keadaan ini, terdapat keperluan mendesak untuk meremajakan cara pelaksanaan makmal semasa dengan menyuntik elemen Revolusi Industri 4.0 yang memusatkan alat internet yang digabungkan dengan sistem robotik. Lebih-lebih lagi, dalam waktu yang julung kali belum pernah terjadi sebelumnya, seperti pandemik Covid-19 telah menguatkan dan membuktikan permintaan yang tinggi untuk menjalankan eksperimen makmal dari jauh dengan menggunakan kemudahan pembelajaran dalam talian di institusi yang sedia ada. Oleh itu, mengerjakan latihan makmal dari jarak jauh melalui aplikasi berasaskan pelayan dapat meringankan kesukaran dalam persekitaran makmal tradisional. Dalam penyelidikan ini, platform dalam talian secara langsung untuk melakukan latihan makmal dari jauh telah dicadangkan. 'Makmal Robot Jauh' ini memungkinkan pelaksanaan makmal dilakukan dari jarak jauh melalui platform internet yang meningkatkan fleksibiliti serta membawa lebih banyak kegembiraan dan keterujaan kepada pengguna. Dengan idea ini, projek semasa memfokuskan pada pembentukan prototaip sistem makmal dalam talian yang menggabungkan modul perisian dan perkakasan antara muka. Penemuan dari kajian kami menunjukkan bahawa kaedah yang dicadangkan dapat memberi peningkatan besar dalam fleksibiliti dan prestasi pelajar. Setelah penubuhan sistem ini tinjauan pengoperasian telah dijalankan dengan bantuan pelajar untuk menilai prestasi kemudahan yang dicadangkan. Penyelidikan mengenai tindak balas sistem menunjukkan prestasi yang baik di bawah tahap lebar jalur internet yang berbeza. Kebolehpercayaan rakaman data disahkan dengan pengiraan teori yang menunjukkan pemindahan data yang selaras bagi sela masa serendah 30ms. Tinjauan mengenai persepsi pengguna menunjukkan kepuasan melebihi 80% terhadap konsep tersebut.

Kata Kunci: Makmal Robot Jauh, Senibina Sistem Berlapis, Akses Jauh, E-Pembelajaran, Sistem Pengurusan.

ACKNOWLEDGEMENTS

All praise is for Allah the Most Glorified and Forever Merciful. It is His blessing, guidance that allowed me to complete this research work as a Master's dissertation.

I would like to express my deepest and my sincerest gratitude to my supervisors, Dr. Unaizah Hanum Binti Obaidellah and Dr. Mohd Nashrul Bin Mohd Zubir, for guiding me and helping me to overcome challenges through my research journey by constantly answering my queries and by being a never-ending ray of hope and motivation. Their continuous support inspired me to complete my research work with the best possibility. It was a great pleasure for me to get the opportunity of working and do research with them. Also, I would like to thank other people who contributed to this dissertation

The warm thanks to all relatives, friends, and well-wishers whose presence and support made this research journey easier and helped me complete this research. In this troublesome and challenging journey, they supported me every second to survive any complicated situation and encouraged me to resolve any problem so far. Finally, I would like to dedicate this dissertation to my parents whose prayers, presence, advice, and support held my hand in the adversities I faced in this research journey and the journey of life.

Last but not least, I would like to dedicate this dissertation to my parents – the pioneer in my life - whose prayers, presence, advice, and support held my hand in the adversities. All of the achievements of my life come through their sacrifices; cordially, thanks for them.

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LIST OF SYMBOLS AND ABBREVIATIONS

ALM	:	Autonomous Learning Machines
DL	:	Deep Learning
DNN	:	Deep Neural Network
LLS	:	Laboratory Learning System
AI	:	Artificial Intelligence
LLO	:	Laboratory Learning Objects
VSL	:	Virtual Simulated Lab
ROL	:	Remote Operated Lab
FPAA	:	Field Programmable Analog Array
IR	:	Industrial Revolution
VISIR	:	Virtual Instruments System in Reality
RL	:	Remote Laboratory
ACT	:	Automatic Control Telelab
CAM	:	Configurable Analog Module
CAB	:	Configurable Analog Block
PCI	:	Peripheral Component Interconnect
CSS	:	Centralized Supervision System
DAQ	:	Data Acquisition
IOT	:	Internet of Things
DMS	:	Data Management System
DAP	:	Data Acquisition Process
WAN	:	Wide Area Network
WFA	:	Windows Form Application
Fi-Fo	:	First In First Out

WPF	:	Windows Presentation Foundation
DBMS	:	Database Management System
RTVSD	:	Real Time Vibration Sensor Data
TAM	:	Technology Acceptance Model

CHAPTER 1: INTRODUCTION

Internet technology has given extra learning strategies, one of the most interesting improvements are being online education and experimentation. Now in this era, the big challenge is how to extend traditional hands-on laboratories to the Internet for science and engineering facilities. There are presently two methods for web-based facility, virtual and remote laboratory testing. A virtual laboratory relies on software to simulate the laboratory atmosphere while, by definition, a remote robotic laboratory is an experiment executed by robotics and controlled remotely via the Internet (Budai & Kuczmann, 2018). These experiments use actual parts or instruments where they are monitored or performed at a separate place. This proposal presents a concept of the various internet distribution techniques for the growth of robotic and remote laboratories.

1.1 Research Background

Internet is the most useful technology of modern times which helps us not only in our daily lives but also in professional lives. For educational purposes, it is widely used to gather information and to do research or add to the knowledge of various subjects. The internet and artificial intelligence would serve a vital role while predicting the future of educational technology that is riddled with uncertainties and extremes based on the analysis of socially and traditionally oriented education systems (Schiff, 2021). It is no doubt that in this modern era everyone prefers to go to search engines for their queries, problems, or doubts such as Google, Yahoo, etc. These search engines contain a wealth of knowledge that can be searched at any time. The internet has introduced improvements in technology, communication, online education, and experimentation. Individuals can use it according to their needs and interests such as exploring different things, searching in different topics, and relearning the content taught in the school.

Web-based education is a part of internet technologies which is an advanced form of online education. It uses streaming videos and more advanced functionalities available in educational software, where there is no actual face-to-face contact between the teacher and the student. These online operations of web-based education use project-based learning and virtual reality, which is dependent on the online operation, that can be used on any computer or mobile device (Chatwattana, PinantaPrachyanun Nilsook, 2017).

It is irrefutable that, in this age of globalization, the web has become an indispensable tool for people to manage their daily lives, especially in the field of information gathering and communication. On the other hand, the COVID-19 pandemic has altered our life tremendously, the affecting majority of sectors including education. On this note, WHO's recommendation of social separation has resulted in more virtual interaction, which has increased the adoption of Robots and Artificial Intelligence technology (Demiralay, Gencer, & Bayraci, 2021). High-speed networking has allowed activities to be performed and tracked from tens of miles apart without individuals' physical presence within the facility of interest. Within the scope of education, particularly on the aspect of performing laboratory exercise, the way experiments have been conducted has changed tremendously since the dawn of industry 3.0, where computers and electronic devices have rapidly dominated the traditional routine of the laboratory. It reduced the time required to complete the test, allowing more students to take part in the concurrent exercise. However, the issue of evaluating the progress of the student learning domain under the implementation of the above-mentioned cooperative computer-based laboratory-assisted work has been a persistent challenge (Beck, Butler, & da Silva, 2014) (Feisel & Rosa, 2005). Research has shown that students performing team laboratory workouts tend to fall into passive learning modes (Abdulwahed & Nagy, 2013). This is mainly due to time and space limitations as well as challenges in developing the skills of the experiment's scientific and organizational sides (Abdulwahed & Nagy, 2011). Moreover, as the number of students enrolled in the science and technology stream continues to rise every year, it has become increasingly difficult for the laboratory to accommodate students' laboratory sessions within the normal working hours. In addition to the above challenges, stakeholders, especially students and the government, continue to urge educational practitioners to incorporate element IR4.0 into the current laboratory course, which requires the establishment of a new procedure for laboratory exercise. This concept is said to improve worker performance and encourages participation in virtual laboratories (Alnagrat, Ismail, Idrus, & Ehkan, 2021). It includes injecting the dimension of unrestricted flexibility, freedom of time and space, as well as a wider forum for communication and resources. The ability to reconfigure the current laboratory system with a touch of state-of-the-art electronics and communication technology would ensure that during the knowledge transfer process this exercise remains an exciting and stimulating effort for the student (Ma & Nickerson, 2006).

A virtual laboratory can be used for both classroom and distance learning. It is a cost-effective alternative to traditional laboratory conduct which requires costly equipment (Gubsky, Kleschenkov, & Mamay, 2019). In addition, the high cost of equipment limits the number of setups and students who can work on assignments at the same time. Furthermore, distance learning, which is a common trend in higher education, necessitates remote lab sessions. As a consequence, traditional hands-on lab classes are no longer appropriate. Virtual laboratories can greatly alter the teaching mode, reducing equipment costs, overcoming time and space constraints, and overcoming a lack of experimental tools. In different areas of physics and electronics, computer simulations have become increasingly more available for teaching and learning. Interactive virtual laboratories are widely used in a variety of educational settings around the world, and they are often the focus of international conferences and research projects. Virtual laboratories are currently being created using a variety of modeling tools and programming languages. Many authors have recently investigated computer simulations of various processes and remote access to real laboratory equipment through modern communication technologies, including cloud technologies. However, most existing virtual laboratory tools have a major flaw: Although they accurately explain all essential procedures, the machine model's user interface represents only a conceptual work with a lack of resemblance to the actual prototype. Since such models are designed mainly for the in-depth and precise analysis of physical phenomena rather than the study of the function of specific devices, they are unlikely to have the practical skills needed for working with real equipment.

It is interesting to note that remote laboratories can now be incorporated into a Learning Management System, making them accessible to users as supplementary tools. These laboratories have provided the foundation for the development of new experimentation approaches. It is important to use a booking system incorporated into the learning environment system to ensure that one person has exclusive access control at any given time. Virtual and remote laboratories are currently being adopted during the practicing stage before handling the real experiments.

There are many benefits of combining a virtual laboratory with a remote laboratory that uses the GUI. First, it allows students to experience hands-on study and learning on how the laboratory functions work before using the real robot. As a result, the students will make the most of the time given with the real robot as they have already learned how to use it. Second, the timetable is more flexible because the simulations are available at all times, allowing students to adjust their schedules to complete the experiments. As a result, they will gain trust in their work before putting it to the test on a real robot. Finally, it is important to note that the virtual lab cannot replace the real lab because creating a perfect model of the real system is nearly impossible. However, a remote laboratory makes it possible to perform lab work in real-time remotely with the help of a robotic system given if the internet connection is stable.

Researchers have developed what is referred to as a breakthrough robotic lab assistant or robotic arm, able to move around a laboratory and conduct scientific experiments remotely (Casini, Chinello, Prattichizzo, & Vicino, 2008). Laboratory robotics is the act of using robots in biology or chemistry labs (Choi et al., 2011). Pharmaceutical firms, for instance, use robots to transfer biological or chemical samples to synthesize new chemical entities or measure the pharmaceutical value of existing chemical matter. As shown by the Robot Scientist project, advanced laboratory robotics can be used to fully automate the scientific method (Koç & Büyük, 2021).

The capabilities of this platform allow researchers and students to apply techniques ranging from the most simple to the most complex operations (Rengifo, Segura-Quijano, & Quijano, 2018). Experiments for single or multiple robot control using capabilities such as locomotion, communication, perception, and autonomous decision-making are carried out using the hardware that is to be designed and built.

Despite this, students only spend a few hours per week in the lab, and they are not always able to run the experiments by themselves or even outside of the lab. There has been significant work on remote laboratories, which are focused on embedded hardware systems and internet connectivity, to resolve access to laboratories. The main goal of these labs is to share and provide access to various types of experimental resources by using a dedicated infrastructure to support online services that use web platforms to display and monitor data from various control tools remotely.

Laboratories that have a robotic infrastructure comprising of actuators, sensors and can be accessed remotely to conduct lab exercises or experiments can be considered as remote robotic laboratories (Robinson Jiménez, Avilés S., & Mauledoux M., 2018). According to the previous work the setup was built incorporating robotic arms, Arduino, IP Camera, and internet connection has been used to operate and visualize the laboratory experiments remotely.

Remote labs are becoming more common as a way for students to practice with real experiments with minimal effort and expense. Knowing how to operate a robotic agent is not uncommon these days, given the rise of robotics in all aspects of human life. As a result, developing platforms for robot control training that are adaptable to a wide range of ages is critical for their effective use and growth. With the ability to monitor various systems remotely, as well as the advantages of virtual laboratories, remote laboratories provide services based on the necessity of different fields.

The above scenario where robotics can be adopted in realizing that remote experiments have motivated researchers to propose a new breed of laboratory concept called 'Remote Robotic Laboratory'. The goal is to allow users to perform laboratory exercises without their presence in the laboratory with the help of robotic mechanisms to handle physical processes. This is achievable with the help of actuation and sensory tools coupled with interfaces for interaction and data transmission to perform specific tasks within the facility (Feisel & Rosa, 2005).

1.2 Research Motivation

The creation of this web-based learning system has the motivation to promote self-learning equality. It also allows students to use information technology to help them with their studies. However, a real-time web system enables data to be exchanged between users and the server almost instantly (and, by extension, between users and other users). This is in contrast with traditional web apps where the client has to ask for information from the server. In essence, a real-time web system must be able to create a persistent connection between the client and the server. Ideally, the browser closes the connection after a stipulated time, generally, it's 45 to 60 seconds, after a request is sent to the backend for information. However, in use cases like online multiplayer games, this needs to be continually connected between the client and the server to stream information. This is generally achieved with the help of web sockets or server-sent events. The continual streaming of information between the client and the server makes a real-time application. To develop a real-time web-based system, a graphical user interface is also provided to visualize the system's data, parameters, and behaviors (Nuratch, 2018). A low-cost microcontroller is chosen to run the system program in this scenario. The non-blocking event-oriented real-time operating system is used to develop and execute the application software. It reads data from sensors, runs a classification algorithm, and sends data and system states to a web-based application. Furthermore, the microcontroller device is designed to accommodate a wide range of IoT applications.

These IoT applications have given extra learning strategies, one of the most interesting improvements is in the field of online education and experimentation. In this era, the contemporary challenge is to extend the traditional hands-on laboratories to the Internet for science and engineering facilities. Currently, on the Internet for science and engineering facilities, there are two ways for laboratory testing namely virtual laboratory testing and remote laboratory testing. A virtual laboratory relies on software to simulate the laboratory atmosphere while, by definition, a remote robotic laboratory is an experiment executed by robotics and controlled remotely via the Internet (Budai & Kuczmann, 2018). These (remote robotic laboratory) experiments use actual parts or instruments where they are monitored or performed at a separate place.

A non-Simulated laboratory means a traditional hands-on laboratory (Taj, Fabregas, Abouhilal, Taifi, & Malaoui, 2021). Few studies show that not all virtual labs are compatible with laboratory experiments but rather serve as a supplement to a traditional laboratory (Serrano-Perez et al., 2021). The results show that virtual lab had substantial differences in terms of the overall scores for both the subject awareness and the creation of hands-on skills when compared to hand-on experiment by which the latter had better scores (Cha, 2013). In another way, it is critical in robotics education, especially in e-learning environments in higher education, to use laboratories that enable students to practice what they have learned and experience real-world errors or problems that do not occur in simulated or virtual laboratories (Chaos, Chacón, Lopez-Orozco, & Dormido, 2013). According to that, Web-based laboratories are an intriguing solution. Remote laboratories are e-learning tools that improve the usability of experimental setups and provide a distance teaching environment that meets the users' hands-on learning needs, according to this approach.

It is well understood that the rapid development of internet technology has changed different aspects of human life and their communication with the environment. Throughout the structure of the educational system, the essence of the laboratory exercise has remained relatively unchanged since the dawn of industrial development 3.0, where computers and electrical devices control the performance of laboratory-related activities. Furthermore, the execution of the concept of ' grouping ' in laboratory activities during this time was not critically assessed, especially on the dimension of its efficiency in stimulating the learning domain of students. The problem derives from the essence of the laboratory behavior in which different levels of participation from the participants result in students being passive observers rather than engaging actively. Moreover, with the sharp growth in the number of students completing an annual laboratory program, offering a suitable learning platform for individual students has become increasingly complicated for the current experimental facility. In this context, the present laboratory system needs to be turned into an exciting, engaging, and stimulating curriculum that could reinvigorate the student's interest by conducting the laboratory work. The birth of the 4 G internet revolution has paved the way for students to take the laboratory activity to a new dimension where, in conjunction with automation technology and state-of-the-art sensory devices, laboratory work can be done with a fingertip using personal communications tools such as laptops and smartphones. In a particular way, the participant must perform physical activities independently within the web-based platform experiment with the aid of an online streaming system combined with hardware and software interfaces for efficient real-time communication with the facility. This special approach is supposed to add a new dimension to the learning environment of students by introducing IR4.0 elements into the laboratory exercise.

1.3 Problem Statement

Laboratory experimental practice is an important teaching requirement nowadays. Not only in such a situation but also, the pandemic like Covid-19 has enforced and proven that doing lab work under a remote robotic laboratory platform can be an effective solution and can further bring massive evolution to the education system. Ironically, a class full of students do not allow to conduct laboratory exercises individually by each student, due to the minimal resources and time according to the traditional procedure. Also following the previous studies not all remote laboratory systems have active and passive user functionality. For this reason, other students won't be able to follow the activity of active users. In addition, previous studies have not taken considerably the high-speed data acquisition requirement based on different experimental demands. This limits the functionality of the system and compromises the interaction between the facility and the user to the point where the user would lose the interest in conducting the lab remotely. This is the why system design of remote laboratory need to be highly structured, which can manipulate hardware and application in a significant manner. In this research, to overcome the considered situations, an online platform for real-time remote lab experiments has been implemented. Following this concern, research has been conducted to establish a remote lab infrastructure that can do lab experiments remotely and is also capable of high-speed short interval data retrieving.

1.4 Research Objectives

The idea of a remote robotic laboratory has been adopted at all levels of primary, secondary, and tertiary education, emphasizing its significance in reinventing a new learning paradigm in the education system (Kist et al., 2011). However, with the rapid proliferation of data logic technology with GHz processing speed, high internet bandwidths, fast response, and robust feedback and sensory devices as well as an innovative touch of artificial intelligence and cloud computing systems, the effort to perfect the remote laboratory formula may finally have reached a promising breakthrough.

In this light, the current work illustrates three main objectives to address the persistent challenges of achieving a fully-featured remote robotic laboratory. These are:

1. To design an architecture of a remote robotic laboratory for engineering experiments.
2. To develop a robotic laboratory system that incorporates hardware, and software specifications for real-time remote access.
3. To evaluate the remote lab architecture, system performance, and user assessments based on the Technology Acceptance Model (TAM).

1.5 Research Questions

a. What kind of architecture can be implemented to build a remote robotic lab?
b. What are the requirements based on facility, experimental setup, hardware, and software features to develop a remote robotic lab system?
c. How to evaluate the effectiveness of the proposed system?

1.6 Research Scope

The primary scope of the current research work involves building a web-based architecture to enable remote control of an experimental facility using the internet. The tasks consist of converting the existing lab facility into a remote-robotic infrastructure via the incorporation of sensors, actuators, microcontrollers, and servers. A dedicated interface web layer between the user and facility will be developed which is compatible with different mobile devices. A data transfer and recording application will be developed within the web system to enable two-way data communication between the user and the lab. A user access and authentication layer will be built for the personalization and recognition of user identity. A passive and active layer system will be incorporated to allow multi-user engagement within the lab activities. After the establishment of the system, an evaluation will be conducted to get the efficiency of system performance based on the accuracy level of experiment data. Finally, information on the user's level of satisfaction will be obtained using a specific survey model which involves getting responses via a set of questionnaires. For the time being this prototype can serve as a specific experiment. The experiment involves measuring and analyzing the deflection of a beam as well as getting the vibration response of the beam under external excitation.

1.7 Dissertation Organization

The structure of the dissertation is as follows: Chapter 1 presents the background, motivation, purpose, and scope of this research. Chapter 2 entails the review of the literature related to robotics on education, AI and laboratory, remote lab systems, web access functionality, the hardware part of the system, software description, experimental setup of remote laboratory, and proposed system. Chapter 3 encompasses the layered system architecture of a remote robotic laboratory, and the setup of vibration and load facility to conduct experiments remotely. Chapter 4 presents the detailed results of the system performance and the statistical test based on the user's perspective. These results are discussed thoroughly in Chapter 5 along with the evaluation of these results. Chapter 6 summarizes this entire research work, highlighting the limitation of the research and further directions towards more improvements to the maximum goal of system efficiency.

CHAPTER 2: LITERATURE REVIEW

The relevant literature and previous work on the remote labs and proposed methodologies are reviewed in this chapter. To establish a remote laboratory conception, many researchers have contributed several methodologies to provide efficient support to the students.

2.1 Approach of AI Robotics on Education

Robotics is one of the most cutting-edge educational systems available today. The major goal was to examine the evolution of the “robotics” idea in the educational area based on existing literature. In this approach López-Belmonte, Segura-Robles, Moreno-Guerrero et al (2021) implemented a bibliometrics methodology to investigate the structural and dynamic evolution of robotics in education. Although the target was on gathering research with educational knowledge areas and other knowledge fields, such as engineering and computers were also included. This transformation from manual to robotics-assisted operation has emerged in a variety of domains across society, including economic, social, and health care, as well as education. The essence of educational robotics is to teach students how to design and build a programmed robot capable of performing a variety of tasks, such as moving, responding to external inputs, and communicating via sound, light, or graphics. The approach of bibliometrics analyzes and classifies scientific documents in great detail. Further, according to their study, the architecture that enables several tasks such as searching, recording, evaluating, and anticipating represent the state of the art literature. Using impact studies as a guide, the document analysis process was organized into several steps. The initial step was to choose the database that will be analyzed. In this situation, Web of Science (WoS) was picked since it is a database with a well-known global reputation. The second step was based on concept delimitation. The term "robotics" was used in this case since it was the most important term for this investigation (López-Belmonte, Segura-Robles, Moreno-Guerrero, & Parra-González, 2021). The final step included formulating a precise search equation. Several variables were utilized to carry out the literature analysis process. The year, authorship, country, type of document, institution, language, media, and most cited papers were all defined using the Analyzer Results and Creation Citation Report. A limitation worth noting is that the above-mentioned work is a lack of data for the year 2020. Furthermore, researchers indicated that false data analysis procedures could be included in future work.

Iphofen and Kritikos (2021) placed an argument that if the ethics of robotic intelligence are not taken into consideration, either to assure an "ethics by design" or to protect them from being "independent moral agents," legislation and regulations will fail. Artificial intelligence has already taken over many repetitive manufacturing jobs that previously required human labor. With the introduction of drones, autonomous automobiles, robots, and human repair and augmentation, the general public faces significant threats to safety and privacy. As robots already can learn and become automated in their decision-making, policymakers become concerned significantly (Iphofen & Kritikos, 2021). Robots are 'artificial' by essence because they are being manufactured by humans. According to the study, the terms "robots" and "autonomous learning machines" (ALMs) are being used alternately. Like computers, ALMs may function without mobility or manual functionality. Fully autonomous machines with the ability to learn could only be claimed to exist if no human was involved in their decision-making, and only then they would have something identifiable as intelligence. As a consequence, AI has a high tolerance for tedium, as well as pattern detection abilities much better than humans. The nature of ALMs' supporting algorithms, which enable complicated computations, huge data processing, and trend projection, is a critical aspect of their evolution. Consumers and civilization are increasingly affected by algorithmic decisions, which include applications for financing, healthcare, environmental sustainability, and employment (Jordan & Mitchell, 2015). Not all risk-reduction and compensation decisions are ethical. Following the situation, in 2017, the Sackler Forum (National Academies of Science/Royal Society) concluded that ALM algorithms must be fair and bias-free. According to the Forum, if the data used to develop such models were made publicly available, the results could be checked or replicated, and improvements or limits might be incorporated. The human ideology in robotics raises complex issues that must be handled directly during the designing process of necessary AI algorithms, which includes data collection, as well as community involvement.

2.2 Artificial Intelligence and Laboratory

Laboratory testing is the procedure that is used to help researchers to innovate new things and make better judgments (Islam, Poly, Yang, & Li, 2021). However, in most cases pre-analytical errors occur for the laboratory test report, resulting in misdirected or delayed diagnosis. An automated laboratory test selection system can help researchers, physicians, chemists perform tests quickly and appropriately, thereby boosting workflow, especially for clinical matters. In this approach, Islam, Poly, Yang et al (2021) formulated an automated system, based on deep learning (DL) to identify appropriate laboratory tests. Following this method, a deep neural network (DNN) based automated recommendation system was established, that can predict fast and reliable laboratory test reports. DNN is a high-performance technique that uses numerous layers to create an Artificial Neural Network. All the input of variable of DNN runs through the layers, computing the possibility of each output. The model has been developed with three hidden layers. Following the system, one of the activation functions in the hidden layers was triggered, while in the output layer Sigmoid was used. The activation function is a crucial component of a neural network's non-linearity, which describes the input and output relationships in a non-linear manner. On the other hand, the non-linearity feature allows greater flexibility and creates a complicated function throughout the model learning process. A test run was conducted using “lab test online” that is comprised of all data related to human-health issues and lab test details to evaluate the accuracy level reports. According to the findings of this study, The DL model performed quite well in terms of predicting laboratory test results. However, the study mentioned a few drawbacks. Such as, the temporal dimension that had not been considered in the study. Also, the procedure codes are linked to some laboratory testing whereas the following method didn’t include the procedure codes.

The lack of suitable online laboratory management systems has triggered a problem for industries that require laboratory activities, such as engineering, science, and technology. The global epidemic of COVID-19 has sparked a surge of interest in e-learning (Elmesalawy et al., 2021). Elmesalawy, Atia, El-Haleem et al (2021) presented the specifications and architecture for a configurable AI-based laboratory learning system (LLS) that can enable online experimental studies. The LLS has been built to accommodate a variety of online experiments, including virtual or remote-controlled experiments utilizing desktop or web apps. Furthermore, the LLS incorporates the use of artificial intelligence (AI) techniques to give an effective virtual lab assistant and adaptive assessment procedure. The authors want to support a variety of interfaces and implementations, as well as, operating remote laboratory to a hybrid laboratory that combines a remote lab with a virtual lab. The Laboratory work is a modular platform that allows educators to develop and modify online experiments using Laboratory Learning Objects (LLOs). Also, one of the key components of the Laboratory Learning Objects (LLOs) is an AI-based Virtual Lab Assistant (E-Instructor), which allows students to have a similar educational experience of experimental work in real laboratories. The study imposed high-level system architecture emerged on the aspects of the laboratory learning system. Laboratory experiment activities, assessment and evaluation, virtual lab assistant, administration and integration, lab resource management, and infrastructure hardware and software are the major components of the system architecture. Teachers can simply build or change lab courses for their students following the LLS. With the conceptual system authoring tool included in the LLS, teachers will not require any programming skills to design courses. According to the simple forms and a built-in Hyper Text Markup Language (HTML) editor, teachers can create their courses. The LLS is intended to serve as a generic infrastructure for virtual simulated labs (VSLs) and remotely operated labs (ROLs), among other forms of online laboratory experiments. The laboratory resources, including available analytical methods and computational capacity, should be managed to allow numerous users to access remotely and conduct their experiments online through the Internet for the LLS to operate efficiently. The client-server architecture has been employed for this reason, in which the user can use a conventional web interface to visit the lab server, which holds the laboratory resources for various experiments.

2.3 Remote Lab System

Angrisani (2020) focused on the drawbacks of typical laboratory procedures. A crowded class along with the limited resources cannot meet the proper desire of lab work for individual students in a typical way. To overcome these limitations, the authors in this study suggest integrating Field Programmable Analog Array (FPAA), compatible devices for a remote laboratory to be configured remotely. Their proposed system can change the test circuit based on the different types of experimental requirements. To this end, they propose a modular remote laboratory in which a Field Programmable Analog Array (FPAA) links the measurement instruments. Following these procedures, students can modify the circuit remotely to figure out the specific measurement from a large library on a single measurement platform.

Casini (2014) proposed a system of multiple robot functionality including Automatic Control Telelab for experimenting with the help of cell robots is introduced where robots are operated remotely with the help of Lego Mindstorms NXT mechanism. The control laws for the multi-robot team can be coded in a MATLAB environment. According to the hardware model of the proposed system, there are four specific robots in the experimental area. Here, complex environments can be defined arbitrarily by defining the virtual obstacles which make it possible to test and compare various control laws in the practical world very quickly. Following the architecture of the setup, users can experience collision avoidance system multiple robot movement. Not only that but also this system allow students to create numerous educational aspects which are appropriate to generalize their thinking ability. The feature of collision avoidance helps to test and compare different collision avoidance algorithms with virtual obstacles. Also, multi-agent motion coordination is one of the experiment concerns that allow decentralizing controlling system for multi-agent collective circular motion.

In another research on remote laboratory systems (García-loro et al., 2019), the authors mentioned that there are some unavoidable drawbacks regarding remote interaction towards laboratory facilities. Primarily, technical people would be unable to provide or engage in manual skills in laboratory work. To deal with these limitations an alternative approach to operating systems has been implemented. The approach is titled Virtual Instruments System in Reality (VISIR), which is a Remote Laboratory (RL) designed to construct and test electrical and electronic circuits. A VISIR system on a virtual workstation reproduces a hands-on analog electronics lab. It is based on an instrumentation framework and a switching relay matrix to provide users with a versatile experimental environment. It enables students to track signals, acquire measurements, design electronic circuits, and in essence, communicate with an electronics lab remotely.

Remote laboratories are becoming more popular as a means for allowing students to work independently on laboratory experiments, to solve different restrained scenarios. In this study (Casini, Garulli, Giannitrapani, & Vicino, 2012) proposed a characteristic of a multi-robot system integrated with Automatic Control Telelab (ACT) functionality and developed utilizing the LEGO Mind storms technology. To achieve this a multi-robot setup with virtual impediments has been demonstrated. In this approach, students can test motion planning algorithms by controlling single or multi-robot vehicles with static or dynamic impediments, based on the implemented architecture included with the ACT remote lab system. A dual-drive function is used on robotic vehicles, with two separate motors directly attached to the left and right wheels. A graphical user interface, implemented as java apple, helps users to keep track of the experimental setup. The interface is used to display the position of robotic vehicles and virtual impediments that may have been placed in an online workspace. The artificial potential is oriented in a way that helps the robot to avoid obstacles while moving towards the targeted point.

According to the study by Robinson Jiménez, Avilés S., and Mauledoux M. (2018), their remote laboratory environment comprises elements and devices based on two robotic arms, a network link, an Arduino card, and an Arduino shield for Ethernet. From the web page of the system, there is a control functionality to manipulate the angle of robotic infrastructure to different degrees. The first prospect required is to do the robotic kinematic analysis, by determining the angle of the robotic component, and this analysis used Denavit-Hartenberg (D-H) algorithm. Different movement patterns have been performed on a robotic arm to evaluate the performance. The experimental setup helps to enhance the learning strategies on the tele-control robotic systems. Though the system is developed for robotic kinematic analysis, there is limited functionality for high-speed data processes based on different experimental requirements. Also, the system was not designed following any layered architecture while there are microcontrollers and actuators are manipulated by other applications.

2.4 Web Access Functionality

García-loro & Pablo (2019) implemented a VISIR system that allows remote interaction with the real world. However, in addition to the inherent advantages of testing in the real world, RLs suggest limitations and constraints: for example, an isolated system cannot provide all the experiments needed for a single degree. The VISIR federation allows for the existing restriction to be exceeded without the need for additional equipment (García-loro et al., 2019). The beneficial results of using a VISIR RL are multiplied and empowered by the Platform Integration of Laboratory based on the Architecture (PILAR) federation. As a result of the federation of VISIR capital, the overall result is much more than the amount of the enumeration of each of the facilities. The resulting VISIR system federation has mitigated the aforementioned drawbacks in VISIR system operation by adopting the facilities. The user requests to monitor the lab are sent to the measurement server. It verifies the user's identity, manages the user queue, and compares the user's built circuit to the permissible circuits in the max files previously designed by the instructor. The equipment server is in charge of configuring the instruments and physically assembling the circuits in accordance with the measurement server's validated order. The first visible result is a large and comprehensive online collection of real-world tools. It has also established a dependable framework delivered over the Internet by a strong RL service provider. Allowing for a structured and combined service that takes advantage of each VISIR node individually while making them all available through a federation of those same nodes. The essence of the federation's programs means that students can access courses from their home countries, ensuring virtual accessibility without the need for additional funding. The services are also readily changeable and upgradeable, allowing for the development of new and improved electrical and electronics real-time activities.

Angrisani, Francesco & Liccardo (2020) focused on the server software architecture that has been designed to ensure maximum flexibility in terms of integrating client software. Using a web browser, users can access the laboratory by digitizing the command string in the Url sector. In any software environment capable of transmitting strings through HTTP, this interface can be built. Several tests were carried out by Mathworks, Excel of the Suite Office, Java applets using MATLAB (Angrisani et al., 2020). Therefore, for these students, only insightful material is given to effectively invoke the RemLab Web Service process. In the industrial sector, the advanced client is the specialist technician who can use the remote laboratory without being restricted to a particular interface as for the Simple Client by designing the program customized to its need. In this situation, to test circuits or perform remote instrument calibration or computer diagnostics, the user can execute his sequence of commands. Despite the system allowing users to interact with the facility via online services, it does not include the multi-use management functionality. In this case, if the facility is occupied other users will not be able to conduct the system.

Casini, Garulli, Giannitrapani & Vicino (2014) used a Transmission Control Protocol (TCP) link for system interaction which is accomplished by MATLAB mechanism and JAVA applet (Casini et al., 2014). According to the system, users can save all experimental data from web access in a MATLAB function. The system will not allow users to run the experiment if robots go out of the workspace or if any issue occurred while preventing robots to go out of control. In these cases and a process is started that drives the robots to a secure location. A standard web server with PHP capabilities runs on a remote lab server, in addition to the previously mentioned Matlab functions. Users can conduct the experiments remotely, while experimental functions can be loaded from the web accessibility of the system through internet browser. At this level, a problem might happen if any user wants to follow and observe the activity of active users working with the facility. This is the limitation that doesn't allow users to work passively and remotely at the same time with the active user.

2.5 Hardware Part of the System

One of the most needed components of any remote robotic laboratory facility is hardware. Based on various experiment facilities there is specific hardware to establish the robotic infrastructure. According to the previous works, it is found that conducting a laboratory experiment work remotely, requires the integration of some critical aspects of different hardware parts that manipulate robotic functions into the remote architecture. This section will be dedicated to reviewing all aspects of hardware from diversified methodologies for various remote laboratory setups.

According to the study of Angrisani, Bonavolontà & Liccardo (2020) the Field Programmable Analog Array (FPAA) AN231E04 was used for the recognition of remote laboratories. The former deals with the introduction of the necessary analog circuit, known as the Configurable Analog Module (CAM). The purpose is receiving and writing in a Shadow RAM memory of the configuration bytes specifying the analog circuit to be emulated. The Configurable Analog Block (CAB) is the center of the analog portion. In a specific way, the AN231E04 FPAA (Angrisani et al., 2020) comprises four different CABs. In particular, each CAB consists of a matrix of analog switches, followed by eight switchable capacitors and an additional matrix of analog switches. Switches are both realized and powered by four clock signals on the system in CMOS technology. The CAB contains two operational amplifiers downstream of the circuits and a comparator, whose values can be transferred to the first switch matrix for feedback loop understanding. The

SRAM memory material defines the specification of the matrices of the two switches and, accordingly, the established analog circuit. While the hardware is highly configurable with analog circuits and switches, the setup is not able to perform a high-speed data acquisition process since there is no module that requires high-frequency data.

Andrea (2014) suggested a configuration consisting of four identical mobile robots capable of moving in a workspace with a specific dimension. Robots have two-wheel driving mechanism with two substantial motors, and the third support system is a steel ball transfer unit. Each movable robotic components have a microprocessor that provides computing, motor controlling ability, and interaction capabilities with the hub. Robots have been designed to avoid failure in the event of a crash. A visual device consisting of two wide-angle cameras mounted on the lab ceiling is used to detect robot location and orientation (Casini et al., 2014). A key feature of automatic recharging of robot batteries is to ensure long-term device availability. To this end, there is a system based on an ad-hoc mechanism, implemented in robots that helps robots to return to the charging station automatically while the experiment is over. This is contributed by two metal plates mounted at the bottom of each device.

On a virtual workbench, García-loro, Baizán & Castro (2019) found that a VISIR device can simulate a hands-on analog electronics lab. For the instruments and equipment, it uses a NI-PXI platform, and for the modules, it uses a switching matrix relay. As a consequence, the laboratory setting is more adaptable. It enables students to track signals, collect data, design electronic circuits, and, in essence, remotely control an electronics lab. The hardware in a VISIR system can be divided into two types: instrumentation hardware and exploration hardware, as previously mentioned. The instrumentation hardware is the equipment that allows the remote lab to work. It doesn't matter what circuits or modules are being used to play with. A standard laboratory collection of instruments and equipment is included. To be a functional electronics laboratory, a VISIR device must have at least the Instrumentation platform. The instrumentation platform is made up of a chassis that houses National Instruments' Peripheral Component Interconnect (PCI) eXtensions for Instrumentation (PXI) boards (NI). Each board is a piece of laboratory equipment. However, using the necessary communications interface, the controller may be an external PC (García-loro et al., 2019). A function generator, power supply, multi-meter, and oscilloscope are all needed in a VISIR RL, just like they are in a traditional electronics hands-on lab. According to the VISIR system, the relay switching matrix serves as the standard hands-on lab's breadboard. It's a stack of four different styles of boards. Boards for DMMs, oscilloscopes, sources, and components. Each board has a controller, and the matrix's controller is located on the source board. A USB cable and a controller housed on the source board are used to communicate between the relay switching matrix and the instrumentation controller. An oscilloscope board, a source board, a DMM board, and four to ten part boards comprise a standard VISIR relay switching matrix. The configurable elements for the creation and design of circuits make up the experimentation hardware. It is made up of the components and their relations in the relay switching matrix's node matrix. According to the study it was mentioned that the system is capable to control an electronic lab remotely. However, in the study, the system has only modules and functions that help to design electronic circuits and track signals with the help of oscilloscopes. There are several experiments that need to be conducted by the remote lab system which requires a high-speed data acquisition process. In that case, the functions and modules of above mentioned system, will not be able to fulfill all requirements in handling such types of experiments.

Antonio (2014) implemented the idea of virtual obstacles to allow more complex experiments while still maintaining ease of use. Within the robot controllers, students can now describe geometrical areas that simulate impediments in the robot workspace.

Moreover, the supervisor estimates the distance between each robot and the obstacles at each time following to the position of robots. With this knowledge, a user may program an obstacle avoidance module into his or her controller to prevent vehicles from colliding with virtual obstacles or with each other (Casini et al., 2014). The use of simulated obstacles rather than actual objects increases the system's flexibility while lowering the likelihood of harmful physical impacts. A passive ball transfer unit provides a third support that ensures the robot's stability while avoiding the collision with obstacles. The motors of the vehicle are controlled by an NXT module, which is equipped with a PID control system that monitors the speed reference signals. Two wide-angle webcams are positioned on top of the setup, focusing downwards to monitor the entire lab space. The aim is to determine each robot's location and orientation by extracting spherical identifiers mounted on every single object from the acquired images. The Centralized Supervision System (CSS), which manages the overall multi-robot system, communicates with each NXT microcontroller via Bluetooth. A user can link to the device through a dedicated web server if they want to run a multi-robot experiment. One can choose whether to run a pre-defined experiment or a user-defined one right from the start tab.

Robinson Jiménez, Avilés S., & Mauledoux M. (2018) proposed a remote laboratory that consists of controlling two telecommand robotic arms, a visual feedback monitoring camera, and an Arduino with web communication, to access the laboratory remotely. There is a web interface on the remote site to operate robots for conducting laboratory exercises. The virtual environment allows each degree of freedom to be manipulated, using the D-H matrix for the rotational case (Robinson Jiménez et al., 2018). The kinematic analysis is derived to define the D-H matrix, which enables the movement of a robotic arm with different angles. A power source of 12 volts with 5 amperes is needed to energize all degrees of movement, operated by 12 servo motors. Servomotors are controlled by Arduino board and the internet shield is used to send commands to the

Arduino. A voltage regulator L78S05 is used to regulate different voltages for different motors of the robotic arm. The robotic interface command each degree of freedom per arm is located on the remote device. To control the motion of robotic arms, shift bars are integrated that helps to decrease the angle towards the left side and increase it towards the right. Though according to this study the system is able to operate robotic arms remotely. Though the hardware infrastructure is not capable enough to work with high-speed data transmission and acquisition systems from the hardware level to the software level. Furthermore, the proposed work is specially focused on telecontrol robotic arm, hence it is difficult to convert different course-based laboratory facility which depends on experimental data and analytical results following this methodology.

2.6 Software Description

Software is considered one of the most essential parts of the remote robotic laboratory system. The software provides proper instruction for hardware to work with a system. According to the previous study, there are different types of remote laboratory prototypes with very specific requirements. Based on that various types of software and hardware has been developed. Each software has a very definite ability and functionality to run the dedicated hardware to conduct remote lab facilities. Some of these approaches and ways are included in this section of the literature review.

According to the study of Liccardo (2020), the manufacturer provides the AN231E04 with a graphical development environment, namely Anadigm Designer2, which enables the FPAAA to be programmed easily. The user can configure the IO cells in this environment and the desired circuit can be "drawn" by selecting the correct CAMs from a library and dragging them to the FPAA field. Unfortunately, this programming technique is not sufficient for remote control, unless the user uses a remote desktop application to take control of Anadigm Designer 2 on a server computer (Angrisani et al., 2020). However, once the CAMs are positioned, the same software allows C code to be created to make the FPAA configuration more versatile. A proper Dynamic Connection Library (DLL) in C has been developed for each circuit emulated by the FPAA to make the programming stage as versatile as possible. Primary Configuration and Reconfiguration functions return arrays that depend on the unique analog circuit generated by Anadigm Designer. For each circuit that has to be implemented, it is, appropriate to construct a different DLL. To this end, a dictionary of possible analog circuits has been generated on the server of the remote laboratory, from which the user can select.

Giannitrapani (2014) suggested a solution that consists of a server machine. Following the architecture of the suggested solution, servers perform tasks based on the Matlab feature. Matlab Acquisition System has been used to process the image to identify the position of robots (Casini et al., 2014). In this case, users need to upload the controller function in Matlab to execute the experiments. This role needs to return the necessary linear and angular velocities for each robot. According to this solution, users can create controlling functions by themselves with the help of Matlab.

A study conducted by Marco (2012) used the Matlab function that implements the desired control law in the above case. The CSS will call this function at each sampling time during the experiment, and send the information of rational velocity to robots. The user is allowed to download all of the data for offline review at the end of an experiment. A Matlab script is also provided to recreate a graphical animation of a real experiment using the downloaded data (Casini et al., 2012). Similarly, a Matlab simulator of a multi-robot team is available to test a controller before uploading it for a real experiment. An automatic recharge system has been installed to keep the lab open 24 hours a day. When a robot's battery voltage falls below a warning level, the CSS takes over and drives the vehicle to a charging station. It also explains how users can create virtual obstacles and what information the CSS returns that can be used to build the controller. Users must upload a Matlab feature to perform a customized experiment, as previously mentioned. While the software structure may interact with the lab facility that leads to the online platform with the support of Matlab. Limited information was described on the functionality to manage high-speed data with a very short interval mechanism. Hence, this study will not be influenced by high-level sophisticated laboratory exercises.

2.7 Experimental Setup of Remote Laboratory

According to the previous studies to implement remote laboratory, different concepts have been adopted to convert a specific experimental setup into the remote system. In this approach, various types of traditional laboratory exercises such as mobile robots, liquid level control, kinematic analysis with robotic arms, and a lot more were taken to convert and conduct under a remote laboratory system. This section will be reviewed the following experimental setup from previous works.

To introduce a remote mobile robotics laboratory Casini, Garulli & Giannitrapani (2014) implemented an experimental setup. Based on the setup, several tasks with different complexities can be implemented following the experimental output. In this manner, the facility of a remote robotic laboratory helps to draw the interest of students in research and make scientific studies more attractive. To implement the setup selected students were asked to develop an algorithm that helps to move robots in a free workspace. The students were given a predefined feature capable of moving robots to a specific point with a task. By this approach, the operating system returned desired reference position, instead of the real linear and angular velocity.

Ak, Topuz, Altikardeş, (2018) explored a remote laboratory system by implementing it in a mechatronic laboratory. According to this work, three experiment sets were established based on the preferences of the users to create a remotely controlled mechatronic laboratory. These experiment sets were a process control set, mobile robot, and electric and pneumatic handling system (Ak, Topuz, Altikardeş, & Oral, 2018). These training sets allow users to do experiments related to various parts of mechatronics and control areas from a remote. Four types of process control experiments can be carried out in the process control set using remote connections to a PLC or a computer and a data acquisition (DAQ) board. Such as liquid level control, flow control, pressure control, and temperature control.

Santos Lopes, Gomes, Antonio, et al., discussed the instructional applications of a mobile robot Control and Programming Environment (CPE). The system was built for robotics experiments, an online programming tool, and a virtual learning platform to conduct a laboratory remotely. According to the system, students are able to control mobile robots by doing basic commands. They do not have to work with hardware or any high-level programming to initialize the process. Following the system design, the proposed experiment uses a mobile robot that interacts with the lab server over wireless bridge. In addition, users can follow up with the robots and also can communicate with other users (Dos Santos Lopes, Gomes, Trindade, Da Silva, & Lima, 2017). Even though the system has an architecture, master-slave robotic functionality, active-passive user facility there is no module mentioned in the study which is responsible for the high-speed data acquisition process.

Bistak, Halas, Huba (2017) proposed necessary additional control loops for trajectory tracking system with the help of Matlab application on the real laboratory system of coupled tanks. The application can be used locally as a simulation tool with a Matlab/Simulink graphical user interface, also it can be used remotely as a virtual or remote laboratory through the Internet (Bisták, Halás, & Huba, 2017). The program is built following a client-server mechanism and is entirely implemented in Matlab/Simulink environment. Matlab commands are delivered via command channel with the help of Matlab Script on both client and server-side. The experimental data is transmitted with the help of UDP Send and UDP Received Simulink blocks which are connected with Instrument Control Toolbox Library. Even the system offers the functionality of data acquisitions and client-server architecture-based model there is no mention of the robotic system, high-speed data transaction, and necessary user functionality. In this scenario, there are drawbacks which indicate that the system is not capable enough to manage several types of remote lab experiments other than trajectory tracking system.

Garulli et al. (2014), Casini (2012), and Ak, Topuz, Altikardeş, (2018) implemented a remote laboratory system on pursuer-evader game systems, mobile robots on obstacle avoidance, and liquid level, pressure and flow control system. However, the above-mentioned facilities are in very specific areas of laboratory experiments under different courses. Also, these approaches are not compatible enough to conduct different types of lab experiments under remote laboratory systems. Hence, there are more opportunities and scopes to work on the laboratory experiments related to a high-speed real-time data acquisition system that can be conducted remotely with advanced remote robotic laboratory infrastructure.

Table 2.1: Summary of the Literature

Research Work	Objective	Method	Tools & modules	Features
Angrisani et al. 2020	A flexible remote laboratory with measurement instruments that are connected to a suitable device capable of reproducing variety of analog circuits.	Field Programmable Analog Array (FPAA)	LabVIEW, MATLAB, FPAA AN231E04 (Analogue Switch)	FPAA system to control multimeter, generator to test analog circuit
García-loro et al. 2019	A hands-on analog electronics lab on a virtual workbench that allows students to monitor signals, acquire measures, design electronic circuits and, essentially, control an electronics lab remotely	Visual Instruments System in Reality (VISIR)	LabVIEW, MySQL, Apache HTTP, PHP	A federation of VISIR nodes, articulated through International Association of Online Engineering
Casini et al. 2014	Experimenting with a team of mobile robots through a remote lab	LEGO Mindstorms NXT Technology	MATLAB, JAVA Applet	Control LEGO NXT mobile robot with virtually placed obstacles
Robinson Jiménez, Avilés S., and Mauledoux M. 2018	Remote control of robotic arms with visual feedback.	Tele-command to control robotic arm, visual feedback by IP camera	C language, Visual Studio, Arduino	Kinematic analysis with the help of robotic arm
Dos Santos Lopes et al. 2017	Develop a remote robotic laboratory platform	Online compiler based on Arduino IDE to compile and transfer to the robot.	Java, LARA, Arduino IDE, MySQL, HTML-5	L1R2 is a mobile robot – can be configured to use different sensors
Bisták, Halás, and Huba 2017	Add necessary control loops for virtual and remote laboratory	Client-server architecture and control algorithm implemented on MatLab. Based on trajectory tacking simulation response, MatLab commands can be transferred into scripts to take proper action.	MATLAB, Simulink scopes	Trajectory tracking control algorithm for couples tanks system
Cardoso, Sousa, and Gil 2016	Identifying a model of a given nonlinear system and to design and apply controllers based on different methods.	Observing physical variables, for identification of the system's model and to test and apply controllers designed according to different methods.	Arduino IDE, Micro-controller W5100, Heatmap Module	Three-tank benchmark system
Esquembre 2015	Prepare for the integration of computers with cloud-based applications and laboratories	User interface and interaction tools developed by javascript simulation (EjsS) to connect to the hardware.	Java/Javascript Simulations, HTML-5	Implementation of pedagogical approaches based on computer integration
Domínguez et al. 2012	Development and integration of HTML-5 based client applications for Remote Laboratories	Clients would be implemented with web standards, i.e., HTML5, AJAX, and CSS3 technologies, to provide a better user experience without the need to rely on external plug-ins.	LabVIEW, HTML-5, AJAX, Java applets	Three-tier architecture
Ak et al. 2018	The design and implementation of the remote laboratory and learning management system.	The client-server architecture was used to build the EDUMEC remote laboratory network infrastructure. Four types of process control experiments can be performed via remote connections to a PLC or a computer and a data acquisition (DAQ) board.	Robotino View software installed, PLC-S7 PC adapter	Liquid level control, flow control, pressure control, and temperature control
Rodríguez et al. 1989	Remote laboratories were developed using LabVIEW software and enabled for remote control and monitoring of laboratory equipment, allowing engineering students to perform experiments in real time.	A laptop computer with LabVIEW software, as well as the requisite signal conditioning circuits, were connected to a NI-USB 6211 multifunctional DAQ board and a webcam and placed in the laboratory to conduct lab exercises remotely.	LabVIEW, HTML, a NI-USB 6211 multifunctional DAQ board	The control of two three-phase squirrel-cage induction motors, the manipulation of residential electrical circuits, and the control of an electro pneumatic system

Table 2.1 describes the objective, methodology, tools, and modules used and integrated features of relevant research works that have already been proposed previously. The goal of previous research works that are related to the remote laboratory system has been summarized and exhibited in the above table for better understanding in a short view. Also, related works have been explained elaborately and discussed including drawbacks in this chapter.

Table 2.2: Mapping of Different Methods and Techniques which are used in Various Related Work

Research Work	System layer architecture	Data acquisition system	Efficiency of High speed data	Active and passive user facility	Master-slave robotic system
Angrisani et al. 2020	Yes	Yes	No	Yes	No
García-loro et al. 2019	Yes	No	No	No	Yes
Casini et al. 2014	Yes	Yes	No	No	Yes
Robinson Jiménez, Avilés S., and Mauledoux M. 2018	No	No	No	No	Yes
Dos Santos Lopes et al. 2017	Yes	No	No	Yes	Yes
Bisták, Halás, and Huba 2017	Yes	Yes	No	No	No
Cardoso, Sousa, and Gil 2016	No	Yes	No	No	No
Esquembre 2015	No	Yes	No	No	No
Domínguez et al. 2012	Yes	Yes	No	No	No
Ak et al. 2018	Yes	Yes	No	No	Yes
Rodríguez et al. 1989	No	Yes	Yes	No	Yes
Proposed work	Yes	Yes	Yes	Yes	Yes

Table 2.2 indicates the research scope for the proposed work in a short view. There are several criteria that indicate the map between different techniques and methods of previous research works related to the remote laboratory and the proposed work. These are the functionalities that involve basic experimental requirements of a science laboratory to conduct experiments remotely. Even though experiments can be conducted remotely, the goal is to establish more specific and realistic functionality of a remote robotic laboratory that allows the user to feel a tangible experience while working remotely with the facility. In this manner, active and passive user functionality is necessary following real laboratory procedures. Also, robotic infrastructure is mandatory to conduct experiments remotely. On this note, there should have data acquisition processes for conducting the research work remotely.

Esquembre (2015), mentioned that WebSocket is the easy way to communicate with hardware modules while sending and receiving data from the user interface (Esquembre, 2015). Thus, there are advanced features that are more reliable for high-speed data acquisition processes with a very short interval. For this reason, structured architecture is needed to run hardware and software without any glitches. On the other hand, Domínguez

(2012) has designed and implemented three-tier architecture to establish a remote laboratory system. The main mechanism to interact with physical equipment has been developed with Java applet and AJAX (Domínguez, Prada, Morán, Alonso, & Barrientos, 2012). Hence, the system has data acquisition functionality based on the data storing process on a database, this is quite difficult for the system to work with high-speed data transmission. Also, there is no active and passive user functionality that could help students to learn more interactive ways. In another study, M. Dos Santos Lopes et al. (2017), discussed the instructional uses of a mobile robot Control and Programming Environment (CPE). According to the system architecture of CPE, mobile robots of the experimental setup communicate with the lab server via wireless link. And the lab server is connected with the LARA Server. LARA Server creates the bridge between user, web, and experiment setup (Dos Santos Lopes et al., 2017). Following the system architecture, there is no mention of layers directly but three major modules are integrated into the system. Based on the system design to conduct experiments or tests, users need to specify an example code to run the setup or they need to write and upload the code on the system. It could be difficult for the system to conduct and convert any physical lab experiment into remote infrastructure. In a few cases, experiments might require robotic movement and high-speed sensor functionality. In this case, the architecture won't be able to conduct such experiments remotely. Ak et al., (2018) implemented client-server based four-layered architecture to conduct lab experiments remotely. Here, users need to provide a virtual private network (VPN) to connect with the system and the system provides reservations for experiments (Ak et al., 2018). As the system is set for four types of control experiments such as liquid level, flow, pressure, and temperature control experiments, this is quite clear that the system is not facilitated enough to function for other experiments that require robotic environment. Also, Angrisani et al., (2020) developed an architecture with three main components to change the circuit wiring based on different experiments. The server, Field Programmable Analog Array (FPAA), and OI devices such as multimeter, and oscilloscope are the main component of the architecture. FPAA is capable to generate different type of analog circuits for specific measurement from a large library. The system is able to measure and modify different circuits remotely, though unable to manage high speed sensor data acquisition process and robotic conductivity of remote experiments. The proposed work would be able to overcome all the mentioned drawbacks according to the mapping table 2.2.

2.8 Proposed System

Considering the research gaps in the reviewed literature current remote laboratory system, the proposed work attempts to identify the most effective way for the establishment of a remote robotic lab system with a specific focus on science and engineering courses. In this study, the research work proposed three-layered system architecture as the most effective feature to achieve the accuracy, efficiency, and performance of a remote robotic lab by establishing the facility to experiment with "Vibration and Load Facility" remotely. The details of the system architecture implemented in the proposed work are explained in section 3.1. Accordingly, the features within the architecture are implemented as follows: robotic infrastructure and signal processing system, user authentication system, feedback mechanism, dedicated web interface, and database management system. The layered system architecture of the proposed research work will be able to achieve an advanced remote robotic laboratory facility that can cover drawbacks from previous studies as mentioned in Table 2.2.

Traditionally, a student must have access to get in a Lab. Following that, online lab systems also need some authentication processes for safety and security reasons. Students must have to apply first through a registration process to get access to a remote lab facility. According to the proposed architecture on the application side, there are two phases for users. One of the phases is an active user and the other one is a passive user. Passive users will be able to follow up on the activity of the active user. One of the layers of the system architecture is dedicated to the data management system (DMS) that controls the data acquisition process (DAP). The most effective and important achievement of the proposed work is to do laboratory exercises remotely with real laboratory equipment, robotic limb, sensors, and actuators. Therefore, students can feel the real-time experience of research work remotely.

To achieve the above-mentioned motives, the study proposed a comprehensive remote robotic laboratory that will assist the student to do laboratory exercises remotely via an online platform. The proposed system architecture includes some significant features such as Student Login System, Active and Passive User Functionality, Data Logging System, Feedback from System, Virtual Assistance, and Real-time experience of lab work through remote functionality. In the proposed method, the system enables remote interaction between the users and laboratory instruments to conduct such kind of experiment. Moreover, several additional features are introduced with this system that will alleviate the drawbacks of the remote management system by providing a real-time and effective remote learning experience. The details of the proposed system including each of its components will be elaborated on in the next part of this study.

CHAPTER 3: METHODOLOGY

The experiment in this research was conducted in two main segments: Layered System Architecture of Remote Robotic Laboratory and Experiment Setup of Vibration and Load Facility. To evaluate the efficiency of the system, an experiment was conducted that exhibited the feasibility of the remote laboratory management system. To achieve this goal, hardware and software interaction is incorporated with the system for the real-time remote robotic facility. In the next section the implementation of a remote robotic laboratory system and the experiment setup of "Vibration and Load Facility" are elaborated accordingly.

3.1 Layered System Architecture of Remote Robotic Laboratory

The experiment involves measuring and analyzing the deflection of a beam to obtain the spring coefficient as well as getting the vibration response of the beam under external excitation. Compare to other laboratory experiments the following experiment involves the high speed of data acquisition to capture the motion with short interval functionality. On this note, two sensors have been employed namely a force sensor to obtain the load exerted on the beam and a laser displacement sensor to capture the current position of the beam. The force sensor (Figure: 3.1) works on a principle of a full-bridge strain gauge which detects the voltage difference with and without deflection. On the other hand, the laser sensor (Figure: 3.2) works by measuring the angle of reflection of the laser beam from the point of measurement to the position-sensitive device incorporated within the sensor which corresponds to the measured position. All these data acquisition procedures can be done with the help of the proposed remote lab facility.

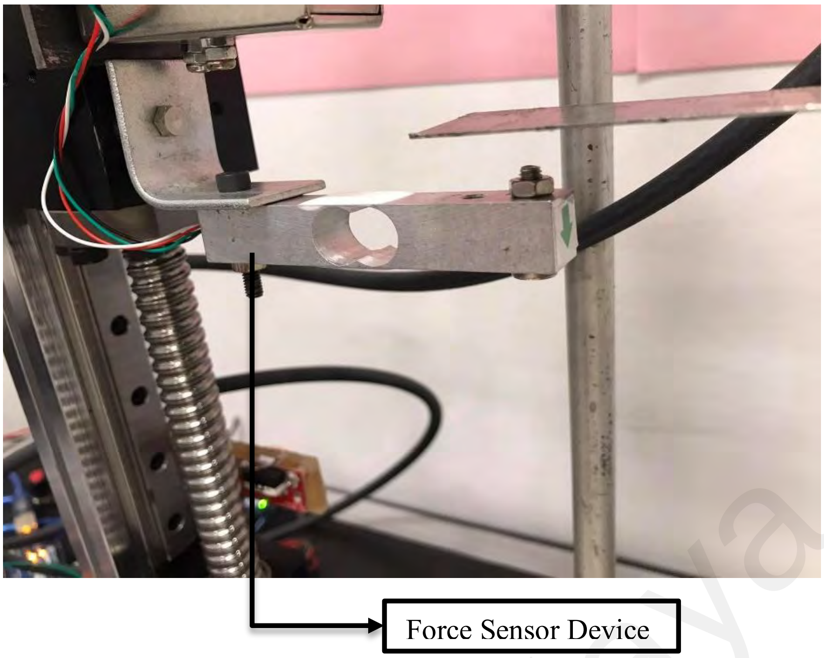

Figure 3.1: Force Sensor Device

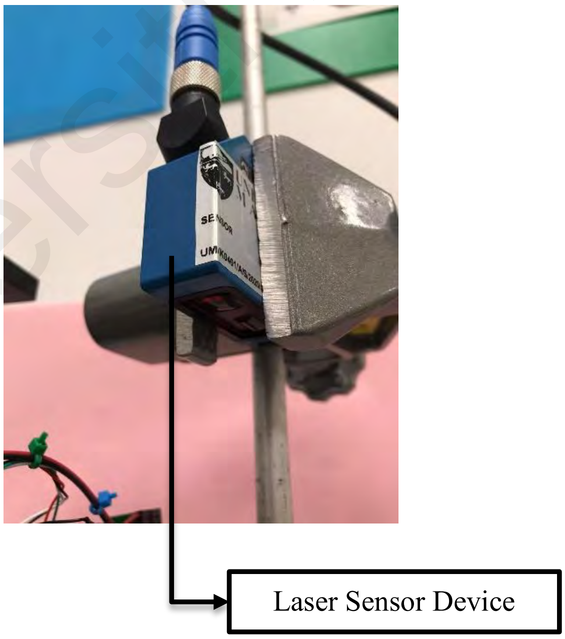

Figure 3.2: Laser Sensor Device

On this note, the system requires a highly efficient and sophisticated architecture that is capable of managing very short interval real data acquisition processes and robotic functionality. Therefore, architecture has been designed following the tri-layered structured system as shown in Figure 3.3. According to the structure, layers are consisting of three main components, which are the application layer, service layer, and data layer. Each layer is playing a different role and is connected as a mainframe of the whole system structure. The application layer is the front line engine that is responsible for responding to client requests and interfacing the real data from the service layer. The service layer is connected with the application layer, data layer, signalR, and as well as actuators. The service layer is the main control unit of the infrastructure. This layer is responsible to receive commands from the application layer to manipulate motors and actuators based on the client site request. Also, the service layer is the control engine that receives data and transfers signal to signal processing unit that is directly connected to the microcontroller and sensor. To process signals and high-speed data transactions, there is another unit which is called SignalR. The final layer, called the data layer is connected with the database and service layer. This layer serves to validate the user accessibility. Also, lab facility availability and user activity are managed by the data layer.

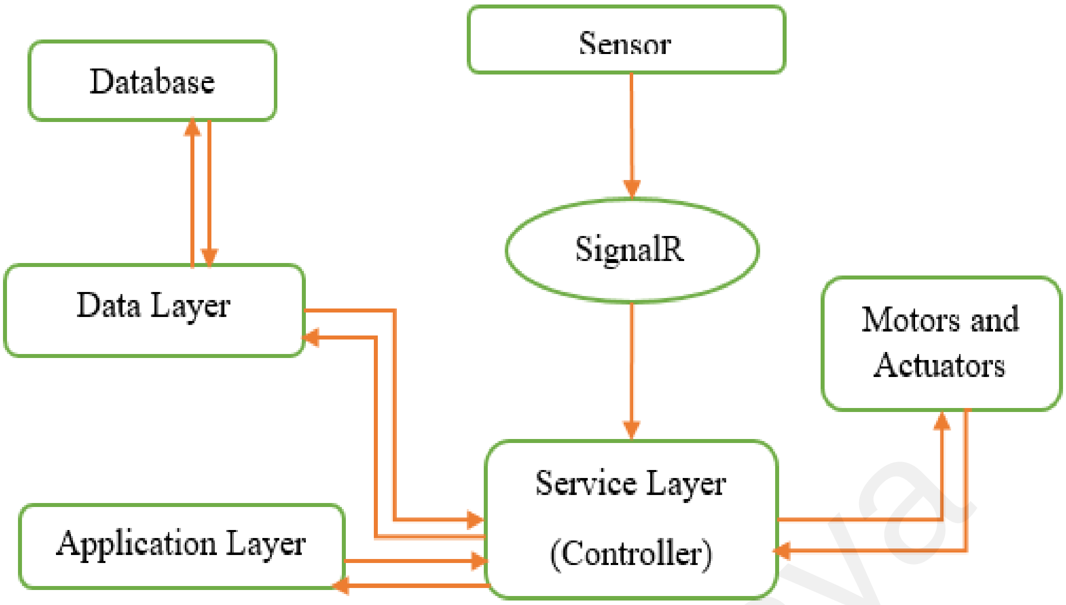

Figure 3.3: Layered Architecture of Web Application

The architecture involves three layers followed by Service Layer, Application Layer, and Data Layer. The next section will briefly illustrate each of the components of layered system architecture.

3.1.1 Service Layer

The service layer is the control engine of the system architecture. This layer helps to maintain the bridge of interaction between hardware and application. There are four major components of this layer: Robotic infrastructure and Signal Processing System, Microcontroller and Actuator, Robotic Limb, and Sensor Functionality.

3.1.1.1 Robotic Infrastructure and Signal Processing System

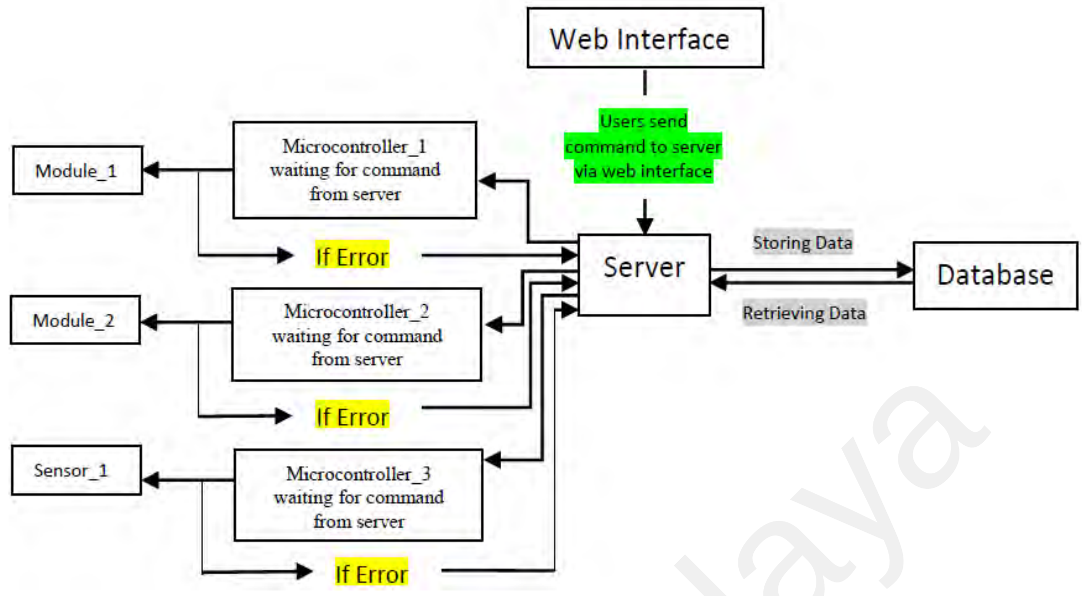

Figure 3.4: Overall System Diagram of the Robotic and Signal Processing System

The whole infrastructure of the signal processing system of the remote laboratory system is interrelated with the web interface, server, database, and microcontroller as illustrated in Figure 3.4. In essence, the physical modules are controlled by the user via a microcontroller governed by the server whose task is to follow the command triggered through web interface control panel buttons. According to this, a master-slave robotic system can be defined by controlling and manipulating the components remotely. In addition, data from sensors connected with Arduino is collected by the server and stored in the database which can be retrieved and displayed on the web interface. In case, if the data failed to retrieve by the system, it will report back to the server. Based on the error report server will trigger the function again.

3.1.1.2 Microcontroller and Actuator

The microcontroller is a module that plays a vital role between server and hardware instruments such as an actuator, and sensors. It contains a chipset to receive, manipulate and relay signals from either the server-side and/or the physical transducer based on the program designed into it. In this work, a series of 3 Arduino UNO (Figure 3.5) microcontrollers are used to perform different tasks. To ease in managing hardware remotely, each microcontroller will be connected to a specific sensor or actuator to perform a specific task. The task involves reading and writing data governed by the codes to control the timing, value, and frequency of the signals.

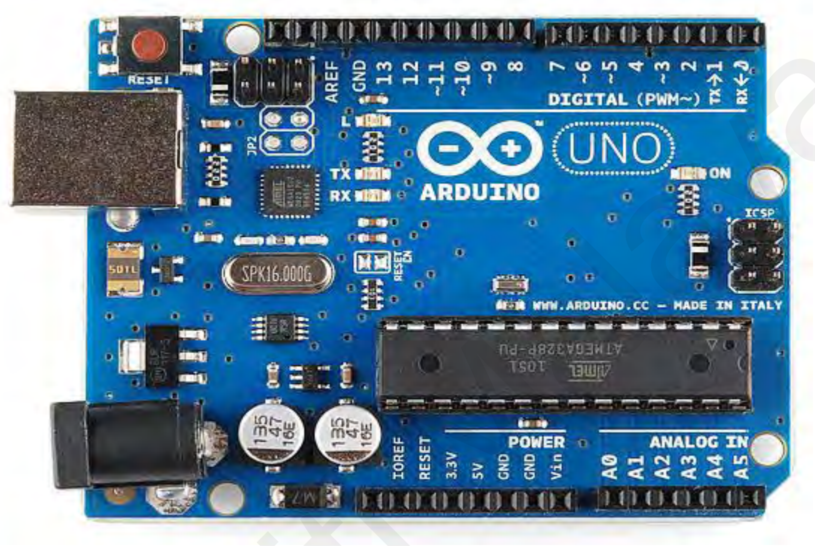

Figure 3.5: Arduino UNO (Microcontroller)

As mentioned earlier, to enable direct web communication between the user and microcontroller, a function was developed within the back-end of the web application that will communicate to the microcontroller through a pre-defined port. The function has been built with ASP.NET webform and C# code-behind. This function works in such a way that would synchronize the data to ensure successful transmission through the server, microcontroller, and actuators. It has a specific identifier or value written in the Arduino sketch which leads the microcontroller to perform a task, such as lights on or motor rotation. Each control button of the control panel on the web interface has a specific value to perform a specific task. The command moving to the microcontroller from the control button is illustrated in the block diagram as shown in Figure 3.6.

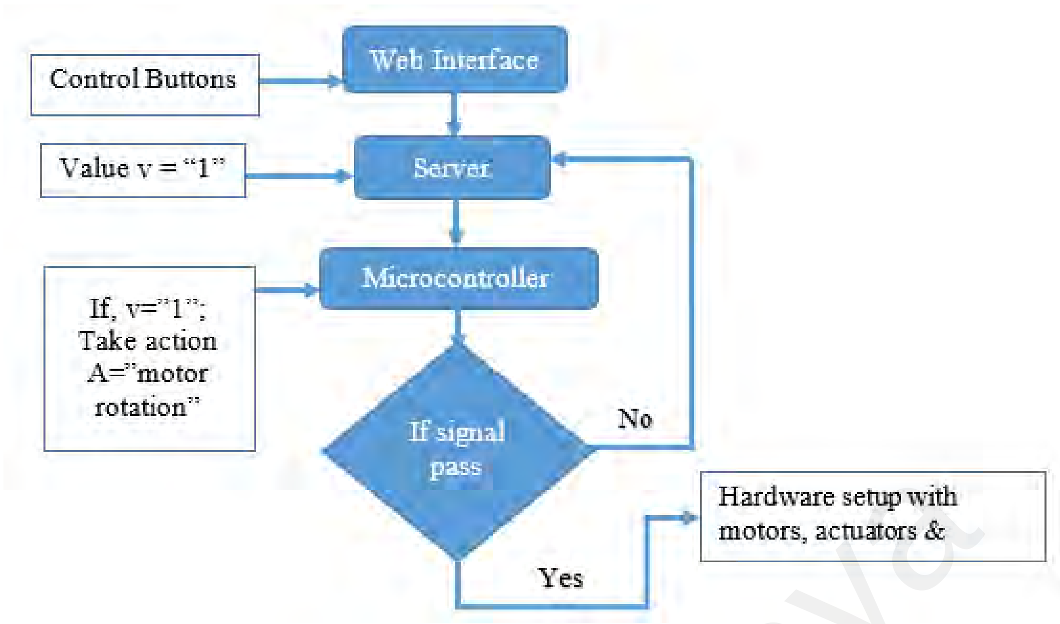

Figure 3.6: Data Transmission to the Microcontroller

The server can serve the facility on a wide area network (WAN) over the internet. In this project, the server is hosting the whole remote laboratory web application. It creates connectivity with web applications and microcontrollers. In this context, it takes the command from the user interface through the web application and passes it to the microcontroller to produce signals for remote actions. The example code in Figure 3.7 illustrates how the value passes to the microcontroller through the server by triggering control-panel buttons from GUI.

```
Protected void Button (object sender, EventArgs e) //Method
  {
     string LED = "value"; //assign value
     ardo.Open(); //open port
     ardo.Write(LED); //write to microcontroller
     ardo.Close(); // close port
  }
```

Figure 3.7: Example Code Behind of Button Trigger

3.1.1.3 Robotic Limb

The robot limb (Figure 3.8) is the main functional part of the "Vibration and Load Facility" system. This limb holds the electromechanical latching mechanism and "force" sensor. The purpose of this limb is to move the force sensor and the solenoid. The limb has to go up to sense the force from the load cell. Additionally, the limb has to go down to put the load and to touch the beam with the help of the solenoid and then release the solenoid to make the vibration. Therefore, the laser distance sensor can detect the deflection of the beam.

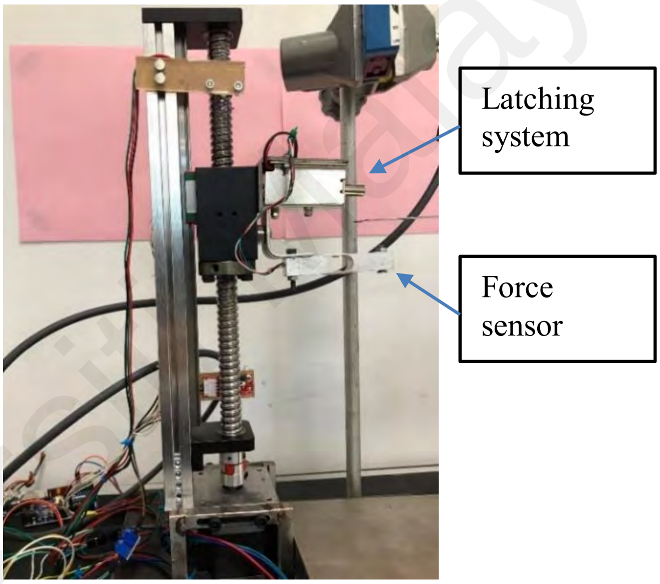

Figure 3.8: Robotic Limb

Building the robotic limb requires a bipolar stepper motor. The motor has its driver setup (Figure 3.9). The problem is this motor is configured with a carrier (Figure 3.10) and when it runs the driver is configured in a specific way. By this configuration when the motor rotates and if the limb reaches the limit of the carrier then the motor starts to rotate in reverse mode with the default speed.

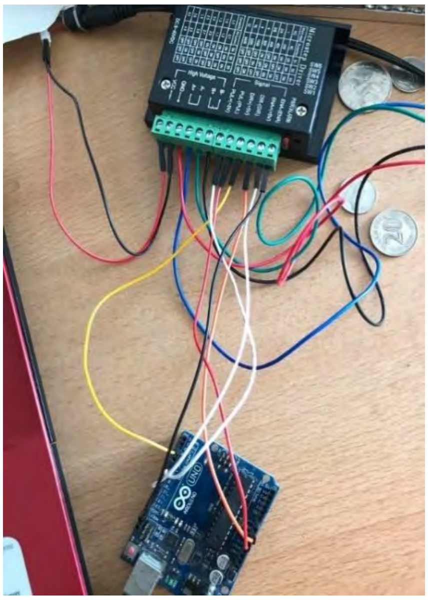

Figure 3.9: Bipolar Stepper Motor Driver with Arduino

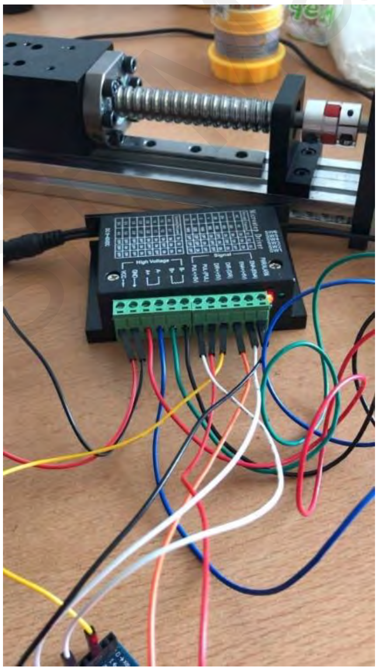

Figure 3.10: Bipolar Stepper Motor with Carrier

To overcome this issue a limit sensor is connected with the carrier as shown in Figure 3.11. Once the motor rotates and the limb reaches the limit sensor a signal would be sent to the motor to cease movement. Alternatively, the default functionality of the motor driver will allow the motor to operate in the opposite direction if the current motion reaches the limit.

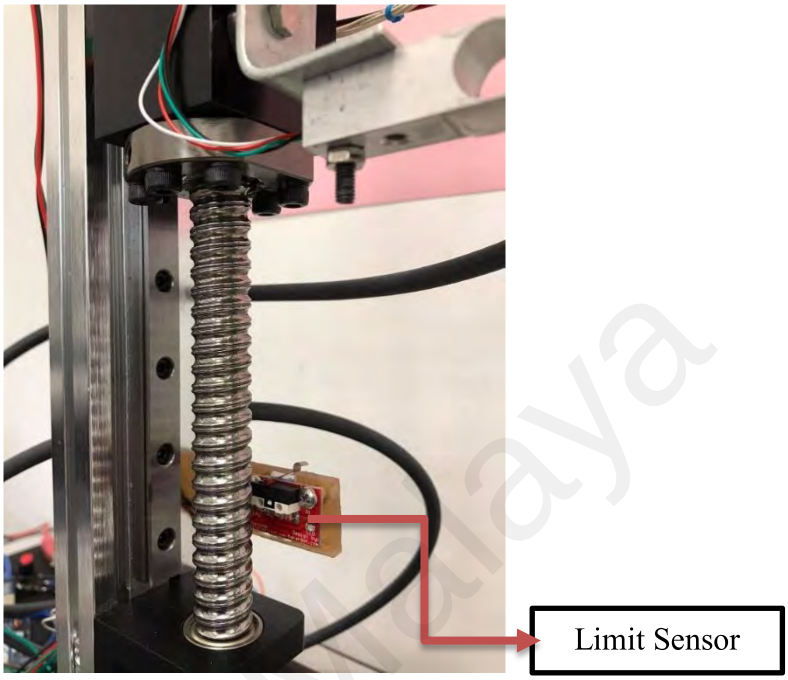

Figure 3.11: Limit Sensor with Motor Carrier

To read the limit sensor value, the Arduino sketch (Figure 3.12) is programmed and uploaded in the microcontroller in such a way that the signal to the motor pins can be manipulated based on that sensor data. At the very initial stage of the experiment, in the microcontroller, the code was developed in such a way that once it gets the value from remote interaction such as “a”, the motor will start rotating in one direction until it receives another command. According to this function, if a user presses the button from a web interface and the limb reaches the boundary of the motor carrier, then the control system will break down and the setup will start to run following the default function. To avoid this difficulty, the limit sensor was integrated, and in the code, within the command function another “if” statement for the sensor value-added. By this, if the limb touches the limit sensor the control command will go to the sensor code statement of the code loop of the microcontroller. For this reason, the motor will stop rotating automatically.

```
    if(val == 'a')
    {
      int sensorValue = analogRead(A0);
      int voltage = sensorValue * (5.0 / 1023.0);
      //Serial.println(voltage);
      if(voltage == 0)
        {
          //Serial.println("LOW");
          digitalWrite(solenoidPin,LOW);
          digitalWrite(dirPin,LOW);
          digitalWrite(stepPin,LOW);
          delayMicroseconds(2000);
          digitalWrite(stepPin,LOW);
          delayMicroseconds(2000);
        }
        else{
          digitalWrite(solenoidPin,HIGH);
          digitalWrite(dirPin,HIGH);
          digitalWrite(stepPin,LOW);
          delayMicroseconds(2000);
          digitalWrite(stepPin,HIGH);
          delayMicroseconds(2000);
        }
    }
    //if(val == 'b' || voltage == 0)
    if(val == 'b')
    {
```

Figure 3.12: Arduino Code to Control Bipolar Stepper Motor

3.1.1.4 Sensor Functionality

The server also plays a vital role in collecting data from the sensor. A windows form application (WFA) has been developed as Figure 3.13 to read and store sensor data from Arduino (microcontroller) connected with the server. This application connects Arduino with the sensor module by selecting a specific port number and storing data in the database table.

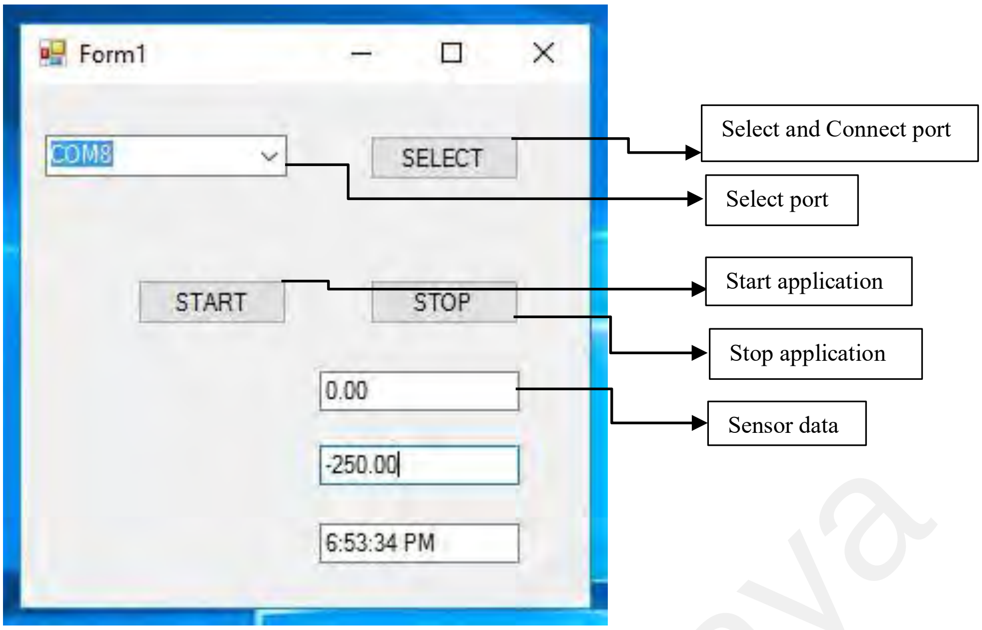

Figure 3.13: Windows form Application for Sensor Data

In this section, the study shows that when the interval is of signal from the sensor is less than 500 milliseconds, the application is not able to get proper data from the sensor. There is an over-head issue of data happening and most often the application shows false data. To overcome this issue a “hub” was created in the “cs” file to analyze the data. A method was developed which is called “Fi-Fo” – First-in-First-out. Following this method, a function was generated as shown in Figure 3.14 to avoid the overhead issue. This function will read the data accordingly as the data is sent from the sensor within any interval even as small as 1 millisecond.

To resolve the issue of false data, a filtration function was also developed as shown in Figure 3.15 in that “hub”. The function of the filtration allows to get all kinds of data but it will process the data and finally, the application will show proper data and also can store these filtered data.

```
public void SetLaserDistanceSensorData()
{
    LaserDistanceSensorData = new List<RealTimeVibrationSensorDataModel>();
    try
    {
        string result = string.Empty;
        bool valid = false;
        var resultExisting = SerialCom_LaserDistanceSensor.ReadExisting();
        var r = resultExisting.Split(
            new[] { "\r\n", "\r", "\n" },
            StringSplitOptions.None);
        result = GetValidDataLaserDistanceSensorData(r, true, false, "0", "5", out valid);
        if (!valid)
            return;
        decimal resultDecimal = Convert.ToDecimal(result);
        LaserDistanceSensorData.Add(new RealTimeVibrationSensorDataModel() { RCM = DateTime.Now, RTVSD_web = resultDecimal });
    }
    catch(Exception ex)
    {
        LaserDistanceSensorData.Add(new RealTimeVibrationSensorDataModel() { Msg = ex.Message });
    }
}
```

Figure 3.14: Data Reading Method to Avoid the Overhead Issue

```
public string GetValidDataLaserDistanceSensorData(string[] r, bool isDecimal, bool isInt, string minValue, string maxValue, out bool valid)
{
    valid = false;
    string result = string.Empty;
    Regex reg = new Regex(@"^\d*\.\d+$");

    for (int i = 0; i < r.Length - 1; i++)
    {
        if (string.IsNullOrEmpty(result))
        {
            try
            {
                result = Convert.ToString(r[(r.Length - 1) - i]);
            }
            catch (Exception ex)
            {

            }
            valid = false;
        }
        else if (isDecimal && !reg.IsMatch(result) && string.Compare(result, minValue) >= 0 && string.Compare(result, maxValue) <= 0)
        {
            try
            {
                result = Convert.ToString(r[(r.Length - 1) - i]);
            }
            catch (Exception ex)
            {

            }
            valid = false;
        }
        else
        {
            valid = true;
```

Figure 3.15: Data Filtration Method

3.1.2 Application Layer

The application layer is the front-end unit of the system architecture. This layer helps to maintain the interaction with the users and the facility. There are four major components of this layer: User Authentication System, System Feedback Mechanism, Virtual Assistance, and Dedicated Web-Based User Interface.

3.1.2.1 User Authentication System

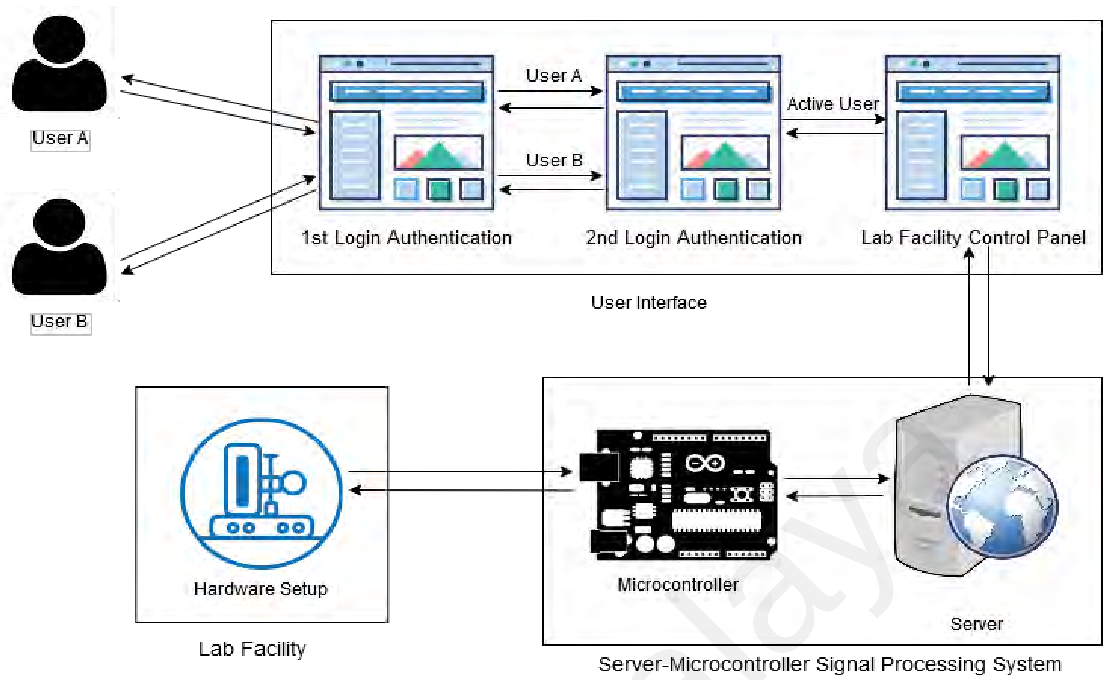

Figure 3.16: Remote Laboratory Management System

The online procedure of the proposed system is shown in Figure 3.16. The web portal provides a secure login and authentication function for its users. This login system enables the proposed system to restrict it from unauthorized access. It also involves registration procedures for the unregistered users which are administrated by the system administrator for the verification process. According to the system, there is two-phase login authentication functionality developed to avoid interruption of usability of remote lab facilities for students. In this process, students need to specify and click on the lab facility or experiment setup of the facility on the web page. This will redirect to the first login page. Subsequently, to enter the main control panel or functional page of that facility students need to login through the second authentication phase. At the same time, queuing students who want to use the same lab facility or experiment setup, will be unable to login to the main control or functional page of that facility. If the facility is occupied by an active user in that case, those queuing students who try to login to the main control page will be redirected to the first login authentication page through the system. In this phase, these students can follow the activity of the current or active user from the viewing section of the first space of the login authentication system as shown in Figure 3.17 in the lab as a passive user.

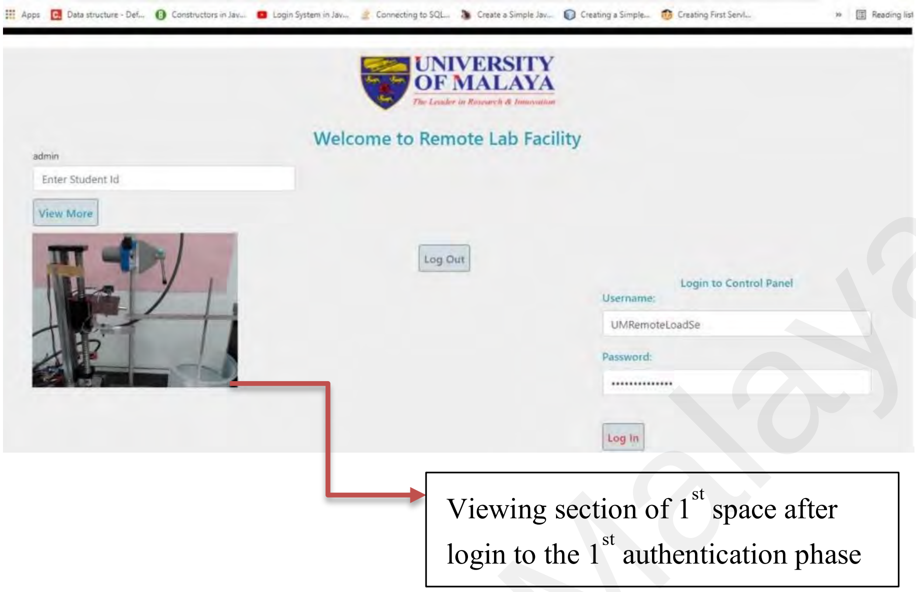

Figure 3.17: 1st Space after Login to 1st Authentication Phase

3.1.2.2 System Feedback Mechanism

Each remote lab facility has its system and functions to do a different type of work. Users or students may get confused to operate the system for specific tasks. For example in "Vibration and Load Facility", there is a function that the user needs to specify "interval time" for sensor data. In that case, the user may put the interval which might not be helpful to complete the task. Hence, the system will notify the user to use the proper interval or suggest taking assistance from the virtual assistant system according to the user's performance (Figure 3.18). The response may vary depending on the facility or the experiment setup. As in this "Vibration and Load Facility", the user should not take a long time to complete the task. If the user takes more than 20 minutes system will notify by sending a pop-up message as shown in Figure 3.19 to take assistance from the chatbot function.

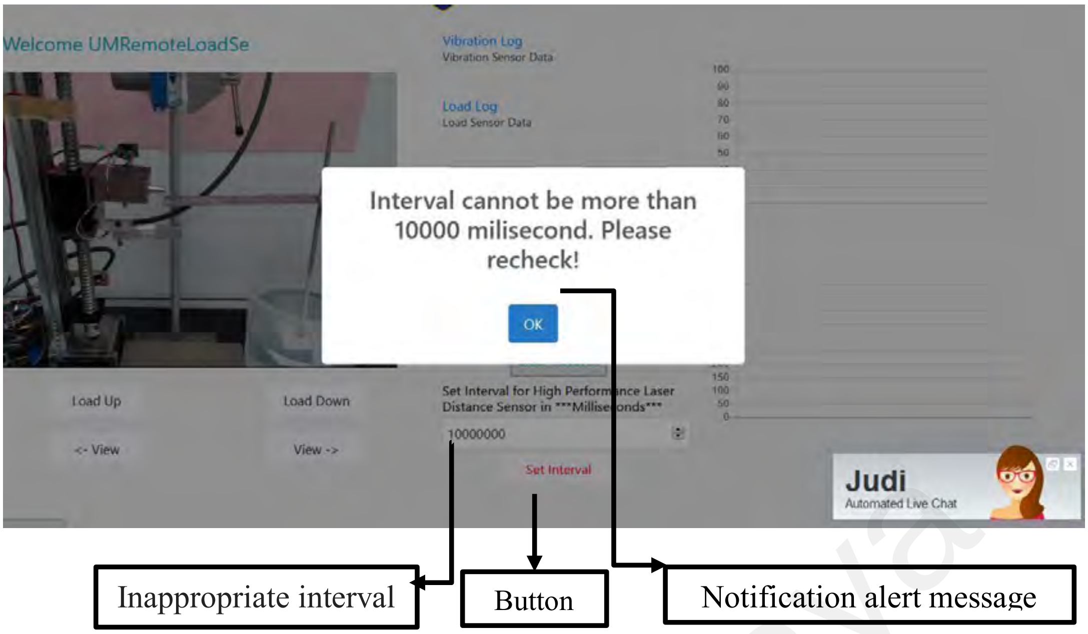

Figure 3.18: Direct Feedback from System

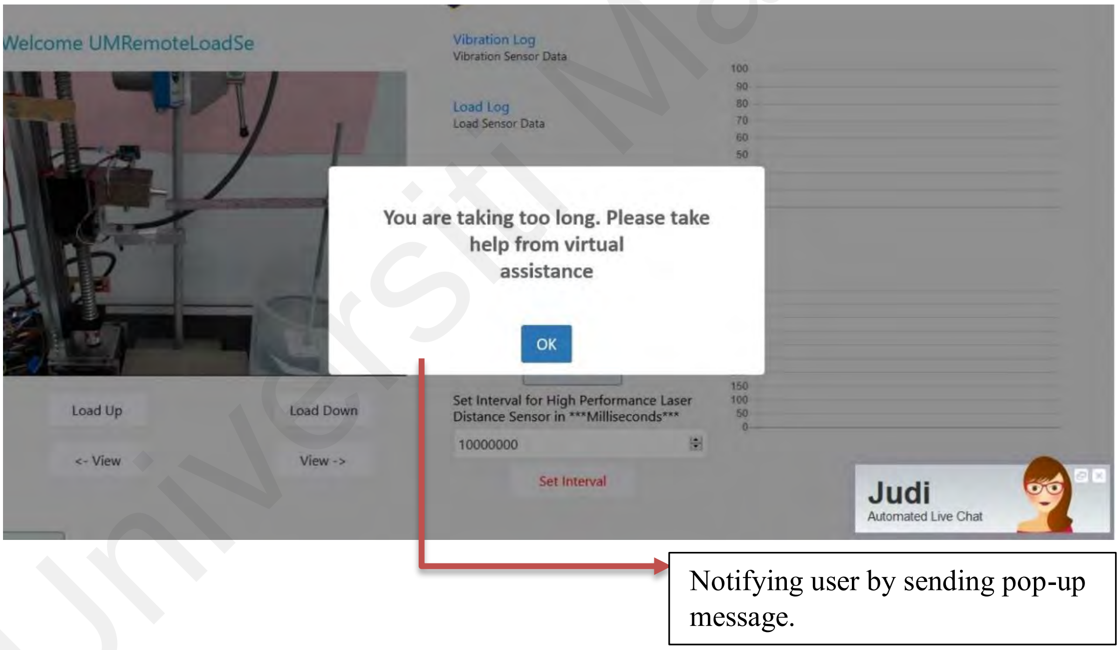

Figure 3.19: Pop-up Message to Notify User

To do so, scripts (Figure 3.20) were developed to make the system give instant feedback to the user in a smart way. As the application must interact with the user directly, the scripts must be developed in the front-end of the application. To achieve this, an “Ajax” function was used in the front-end. Inside the Ajax function, there is “Java Script”, which can interpret once the button “Set Interval” as Figure 3.18 triggered directly from the front-end of the application. According to the script, the function will call the backend method called “Method_interval” as shown in Figure 3.20 to send the value to back-end server-side code. Otherwise, if the interval value is not appropriate, the application will send an alert to the user.

Figure 3.20: Automatically Sending Alert Function to the User

3.1.2.3 Virtual Assistant

A virtual assistant like “Chatbot” may assist the user following their query. This virtual assistance works following a basic knowledge base query (Figure 3.21).

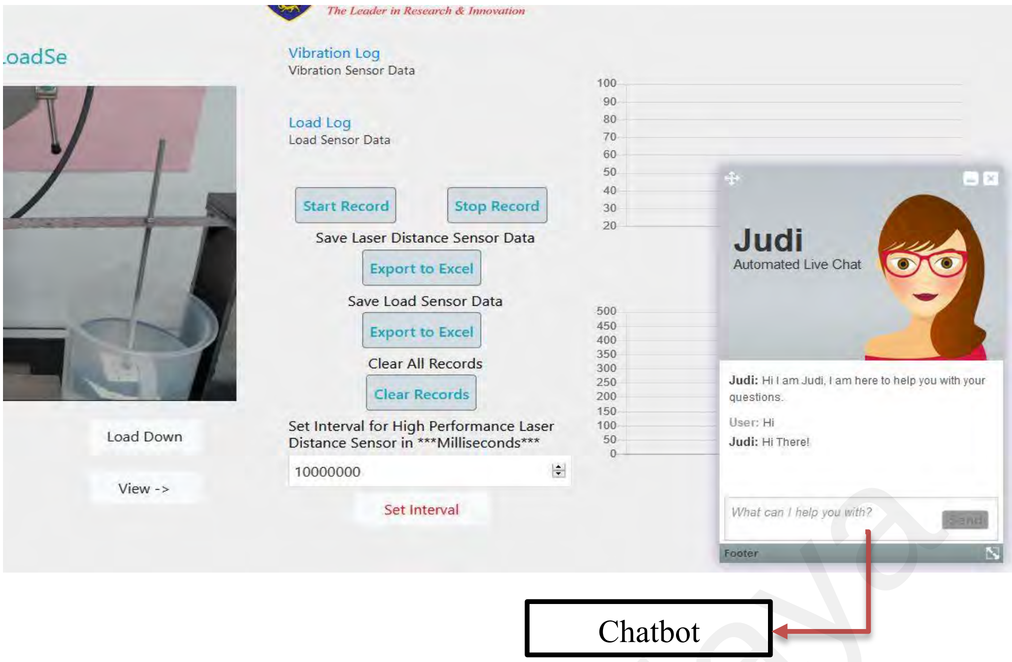

Figure 3.21: Virtual Assistant - "Judi"

Another advanced function was developed and integrated which is a virtual assistant in this system. The purpose of this virtual assistance is to serve the user by answering them based on their basic query. But in this manner, this virtual assistant is unable to help the user with advanced solutions of that specific lab facility. To develop this knowledge base "chatbot", a software called "Syn Bot Studio" was used. "Syn Bot Studio" is the environment where it is possible to develop a knowledge-base "Bot's" basic interactions as shown in Figure 3.22.

Figure 3.22: Chatbot Knowledge-Based Code

The following part is to integrate this function in ASP.Net web application. The idea is to deploy a chatbot on a website. In this case, the chatbot function will not be connected to any online bot API services. The function is directly hosted inside of the web application itself (Figure 3.23). To achieve this NuGet package which is "Syn.Bot.Channels" needs to be installed in the application. However, the issue is all knowledge-based project file exported from "Syn Bot Studio" is suffixed with the ".siml" extension, which is not accessible by ASP.Net environment. The file needs to save as with the ".txt" or "JSON" extension which can be used whenever the function is called from the front-end.

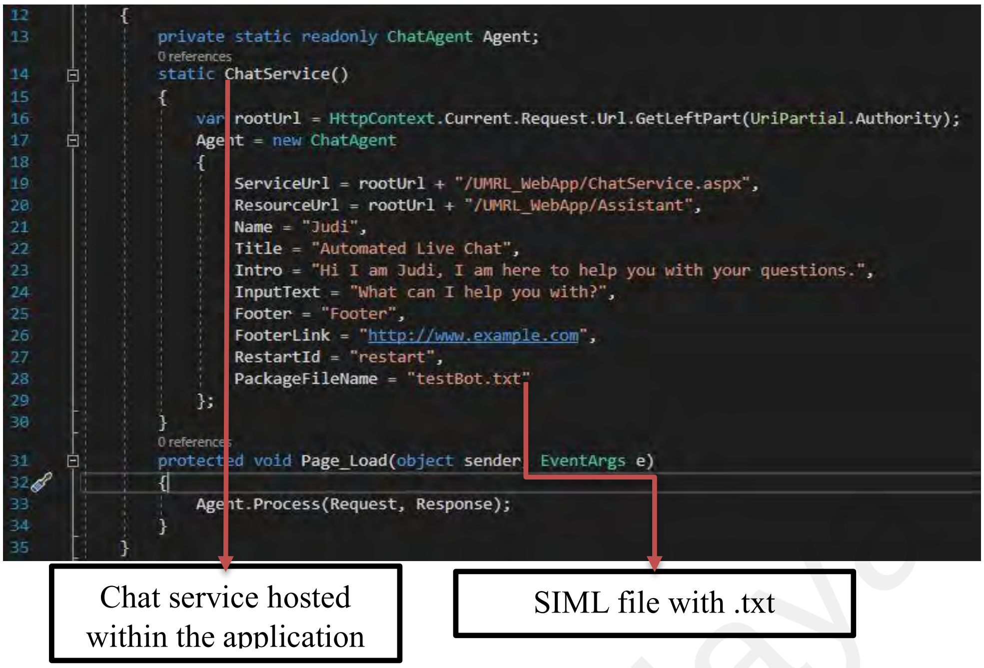

Figure 3.23: Chatbot Function Hosted in Web Application

3.1.2.4 Dedicated Web-Based User Interface

This module serves as a communication bridge between the user and the lab facility. According to Figure 3.24, the user interface (UI) is the client-side of the web application which is deployed in a server. However, students can perform a sequence of lab exercises within the experimental setup remotely through this UI. For example:

I. Controlling actuators and motors to run instruments.
II. Controlling visual devices to observe and monitor the experimental setup.
III. Perform measurement and collect data from sensors.

This module contains three major components, including, control buttons, viewing section, and sensor data chart. Each of these components will be explained briefly in the following section.

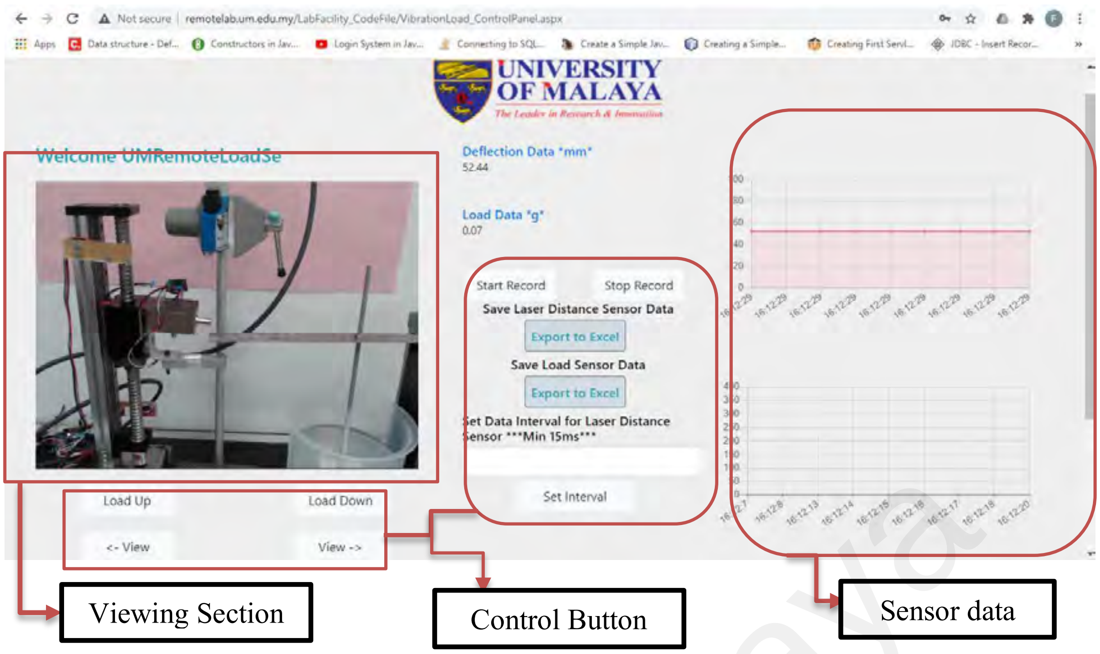

Figure 3.24: Remote Laboratory Web-based User Interface

The functionality of UI Components:

I. Control Button - as shown in Figure 3.25, users interact with the remote infrastructure via a series of control buttons that manipulate the corresponding action. These actions depend on the function triggered by a specific button. Such as motor rotation, and camera movement. Different experiment setup has different control panel based on the facility of an experiment. The functionality behind buttons has been explained briefly in the "Microcontroller and Actuator" section 3.1.1.2.

II. Viewing Section – a large portion of the interface as in Figure 3.25 is dedicated to providing the video stream focused on lab experiment setup. The view can be adjusted within the 180degree horizontal movement of a camera module. This would enable the user to acquire a realistic view that emulates the actual presence in the lab.

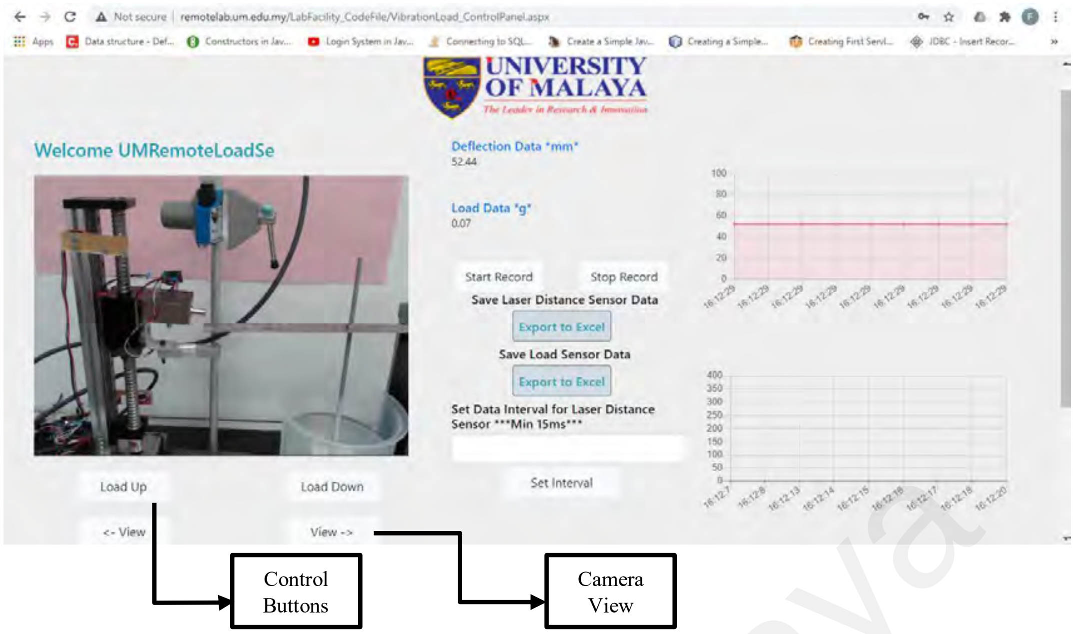

Figure 3.25: Controls Panel and Camera View

III. Sensor data chart - another function within the web interface involves the sensor data logging system (Figure 3.26) which generates the essential output from the experiment to conduct further analysis and interpretation. Also, the logging system allows students to capture and save the sensor data for further implementation. Each data will have value, time, and date signatures to ease tracing the history. This feature is highly convenient for the user who wishes to conduct the analysis later after the experiment.

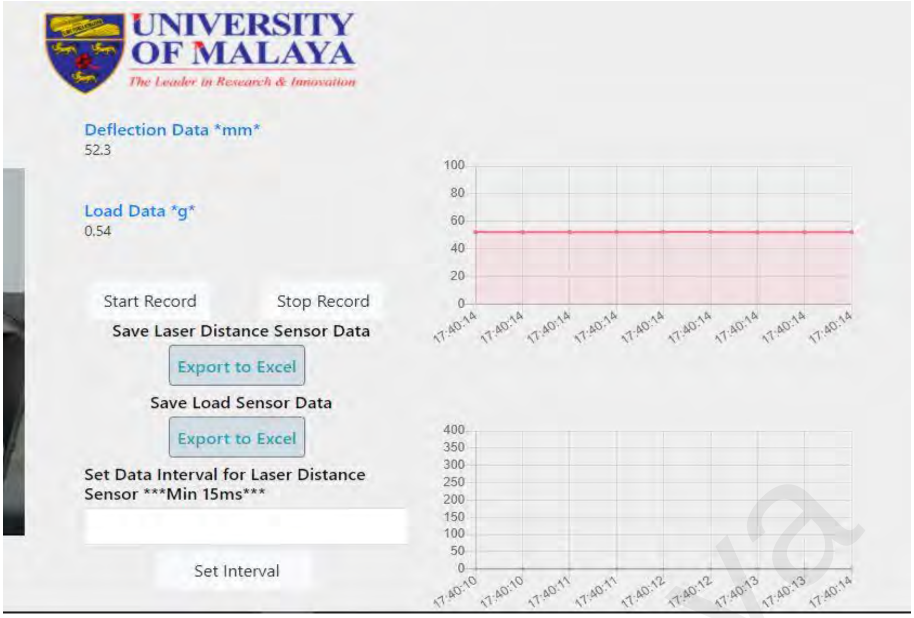

Figure 3.26: Sensor Data Log and Sensor Data Graph

To visualize the remote robotic lab a Windows Presentation Foundation (WPF) application was developed as shown in Figure 3.27 for live video streaming and broadcasting. This application can detect and list down all connected USB camera modules. From the list, a selected module can do the video streaming. In this study, the hardest part is to broadcast the video taken by a USB camera. To achieve this, a protocol was added to set WAN IP and Port No by which the application can broadcast video stream.

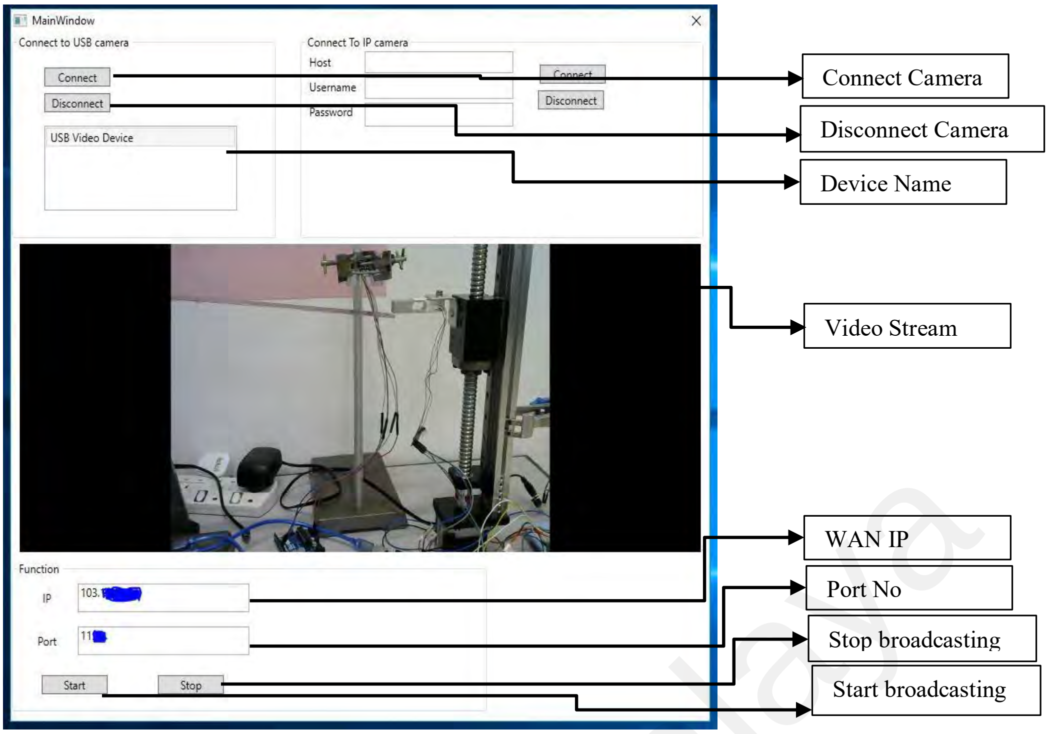

Figure 3.27: WPF Application for Broadcasting Video Stream

3.1.3 Data Layer

The data layer serves to control the data management process of system architecture. This layer also helps to store and manage data, user credentials, and user accessibility. There is one major component of this layer, which is the Database Management System.

3.1.3.1 Database Management System

The database is a program to perform a set of data arrangements that can be accessed, managed, and updated systematically (Mapanga & Kadebu, 2013). It also helps to create a log file for data and can provide support for remote connectivity. Within the current system, the database module performs an important task to store information (such as sensor data, and student information) from the remote infrastructure to organize that information accurately and effectively. Several database functions have been developed which can be executed based on subsequent query requests through the server. These data can be stored and accessed as required by the Database Management System (DBMS) as per query. For example, Figure 3.28 shows a code to retrieve student information from the DBMS system and Figure 3.29 shows a database table “student information table” based on the query.

```
protected void Button1(object sender, EventArgs e) //Method
    {
        con.Open();//Database connection open
        string query = "select* from Db_Tbl where Name='"
+TextBox1.Text + "' andPswd='" + TextBox2.Text + "'";
//Query to select data from table
        SqlCommandcmd = new SqlCommand(query, con);
        // string output = cmd.ExecuteScalar().ToString();
        SqlDataAdapter da = new SqlDataAdapter(cmd);  //Load
records from database
        DataTable dt = new DataTable();
        da.Fill(dt);
        cmd.ExecuteNonQuery();
        con.Close();  //Close database connection
        if (dt.Rows.Count> 0);
    }
```

Figure 3.28: Example Code for DBMS (Student Information Retrieval)

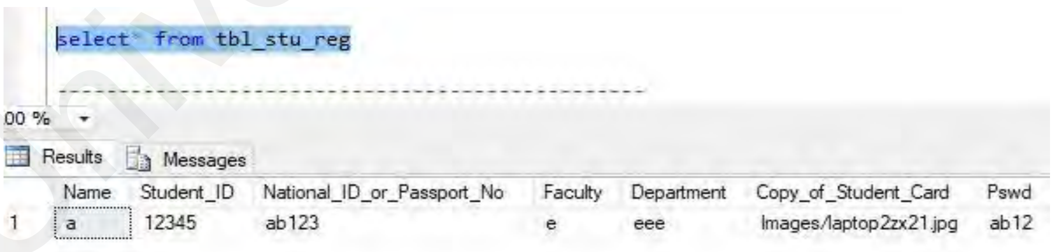

Figure 3.29: Student Information Table

3.2 Experiment Setup of Vibration and Load Facility

Figure 3.30 shows the complete set-up to demonstrate the current remote laboratory system. It consists of the physical hardware and controllers which receive the command

and send signals between the user and the lab facility. The experiment "Vibration and Load Facility" entails determining the spring coefficient and the vibration response of a beam under external excitation by measuring and analyzing its deflection. Users have to access the facility remotely to get the deflection, load, and vibration value from the experiment by controlling sensors with the help of robotic equipment through online. In principle, the instruction from the user will be translated into a series of voltage signals which will be sent to the microcontroller to operate all motors, sensors, and other modules. To demonstrate the data logging process, a load sensor and laser distance sensor were incorporated within the setup. A USB camera was connected to the server computer and can be activated internally by the client when accessing the user account to view the facility and movements in the laboratory.

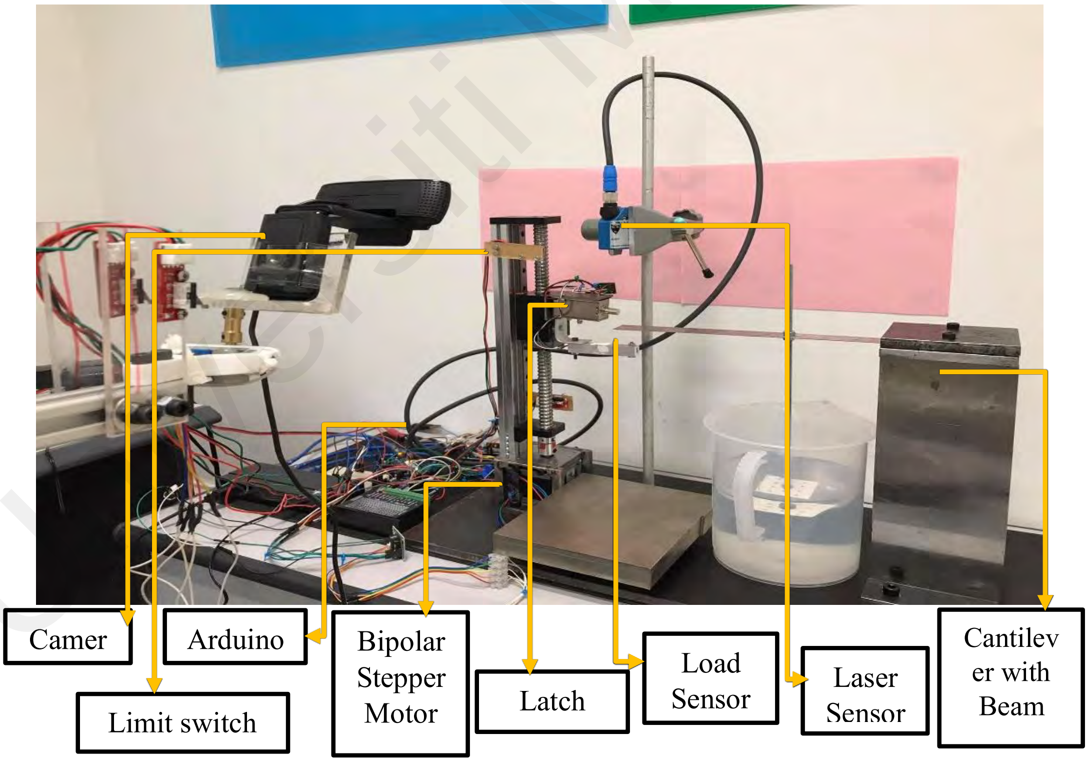

Figure 3.30: Complete Setup for One Facility of Remote Robotic Laboratory

Figure 3.31 shows different angles of the camera view indicating the dynamic viewing space that the user may experience while experimenting. The ability to move the motors and sensors allows the user to conduct self-experiment on understanding the basic concept of the topic such as measuring and analyzing the deflection of a beam as well as getting the vibration response of the beam under external excitation. The fact that to do the self-experiment and for conducting such type of experiments via online, users can concurrently look for internet sources while conducting the experiment would help them to improve the learning process and boost their ability and interest to conduct further reasoning in the path to complete the experiment.

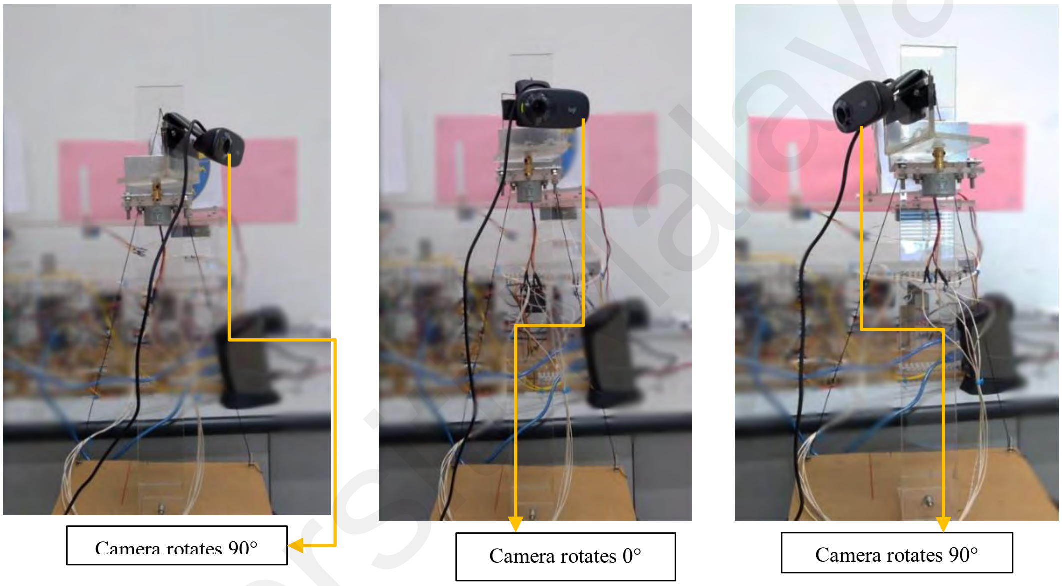

Figure 3.31: Camera Rotation for Flexible Viewing

CHAPTER 4: RESULTS

The study will evaluate the system, by validating and comparing the performance and enhancement of the web-based remote laboratory model with traditional remote laboratory experiments. This chapter will highlight and describe all findings following the objective of the research. The performance and output data of remote experiments using remote robotic lab facility has been analyzed based on the experimental equitation and elaborated in sub-section 4.1.1, 4.2.1, 4.3.1, and 4.3.2. Also, an assessment has been conducted to review the usability based on the user perspective that is discussed in sub-section 4.3.3. The following analysis of the system will help us to determine the efficiency of data transfer rate and accuracy level of real data.

4.1 System Architecture

According to objective 1, to design an architecture of a remote robotic laboratory for engineering experiments. The following objective connects the corresponding research question; 1) what kind of architecture can be implemented to build a remote robotic lab? Accordingly, the research question will be answered in the following subsections by explaining the design of the proposed system architecture of a remote robotic laboratory facility.

4.1.1 Layered Architecture

Based on the requirement of the experiment there is a high demand for a short interval data acquisition system. According to the very scratch level of this experiment, the system was designed with a single-layered architecture. However, the architecture was not strong enough to handle simultaneously high-speed data acquisition process, robotic interaction, and front-end functionality of the user interface. In this case, the huge traffic of high-speed data even with 500 milliseconds was unable to be maintained and false data were apparent by the system as shown in Figure 4.1, as a result of massing all functionality into one layer. Also, the system got stuck in taking any command from the user interface, therefore the system stops responding to hardware.

	ID	RCM	RTVSD_web	Msg
2	0	27-03-21 17:23	51.94	
3	0	27-03-21 17:23	51.97	
4	0	27-03-21 17:23	0.23	
5	0	27-03-21 17:23	51354	
6	0	27-03-21 17:23	2$9	
7	0	27-03-21 17:23	52$53	
8	0	27-03-21 17:23	52.25	
9	0	27-03-21 17:23	5.2553	
10	0	27-03-21 17:23	52.25	
11	0	27-03-21 17:23	###25	
12	0	27-03-21 17:23	.	
13	0	27-03-21 17:23	0.2	
14	0	27-03-21 17:23	0.23	
15	0	27-03-21 17:23	0	
16	0	27-03-21 17:23	0	
17	0	27-03-21 17:23	52&	
18	0	27-03-21 17:23	5&	
19	0	27-03-21 17:23	0.3	
20	0	27-03-21 17:23	52.15	
21	0	27-03-21 17:23	##5#	
22	0	27-03-21 17:23	0.2	

Figure 4.1: False Data from the System with Single Layered Architecture

In response to this issue, there was a necessity to diversify the system structure into three main divisions as service, application, and data. In this manner, the system architecture is designed to three-layered architecture including with service layer, application layer, and data layer for the efficiency of system performance. According to the three-layered architecture, each of the components can run simultaneously without any glitch. After implementation of the layered architecture, the output data with the same interval with 500 milliseconds of the experiment as shown in Figure 4.2 was quite countable and visible. Also, the performance of the system interaction and data acquisition process was pretty much near as expected.

	ID	RCM	RTVSD_	Msg
2	0	5/31/2021 19:18	53.19	
3	0	5/31/2021 19:18	53.25	
4	0	5/31/2021 19:18	53.25	
5	0	5/31/2021 19:18	53.34	
6	0	5/31/2021 19:18	53.2	
7	0	5/31/2021 19:18	53.34	
8	0	5/31/2021 19:18	53.23	
9	0	5/31/2021 19:18	53.34	
10	0	5/31/2021 19:18	53.22	
11	0	5/31/2021 19:18	53.25	
12	0	5/31/2021 19:18	53.44	
13	0	5/31/2021 19:18	53.25	
14	0	5/31/2021 19:18	53.15	
15	0	5/31/2021 19:18	53.15	
16	0	5/31/2021 19:18	53.34	
17	0	5/31/2021 19:18	53.25	
18	0	5/31/2021 19:18	53.15	
19	0	5/31/2021 19:18	53.25	
20	0	5/31/2021 19:18	53.17	
21	0	5/31/2021 19:18	53.25	
22	0	5/31/2021 19:18	53.1	

Figure 4.2: Countable Data from the System with Three Layered Architecture

4.2 Remote Robotic Lab Facility

Research objective 2, to develop a robotic laboratory system that incorporates hardware and software specifications for real-time remote access. There is one research question that correlates with the second objective; 2) what are the requirements based on facility, experimental setup, hardware, and software features to develop a remote robotic lab system? Concurrently, the question will be answered by demonstrating the requirements to conduct such type of laboratory experiment remotely and validating the experimental result of vibration and load facility.

4.2.1 Conducting Remote Experiment on Deflection and Vibration Response of Beam

The main requirement of the facility is to measure and analyze the deflection of a beam as well as get the vibration response of the beam under external excitation. To establish such a system, high-speed data sampling is highly critical and the fact that this task must be accomplished remotely via web application makes it even more challenging. On this note, all hardware components were integrated with the web application in such a way that can handle very specific and short interval sensor data while experimenting remotely.

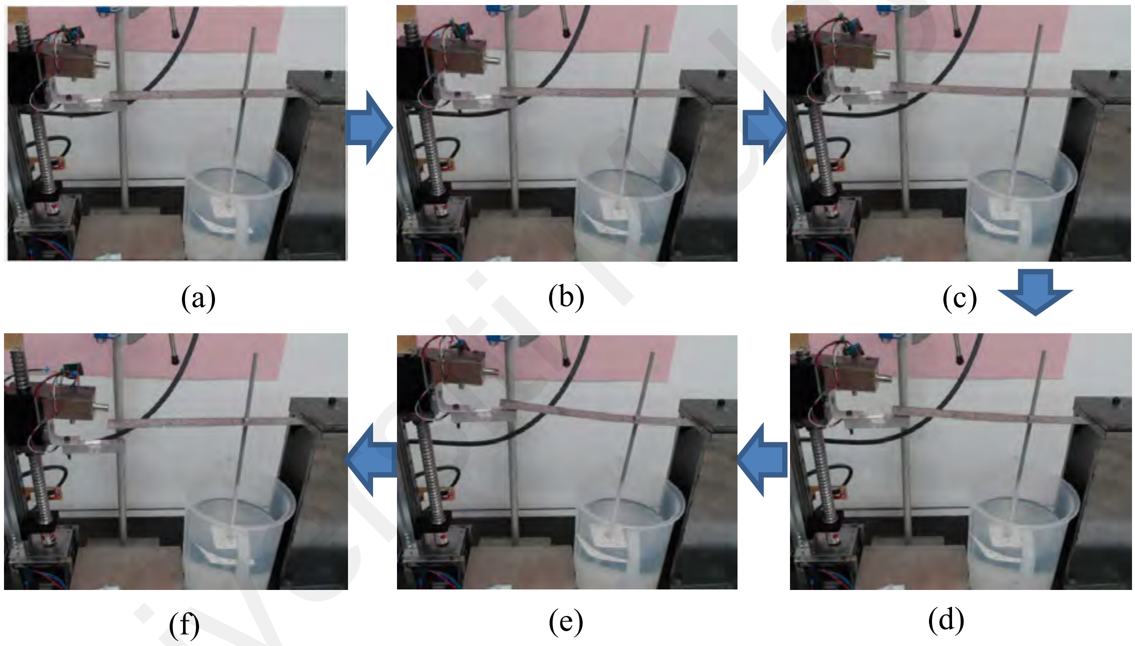

Figure 4.3: Sequence for Conducting Deflection Experiment

The sequence for experimenting is given in Figure 4.3. In essence, the experiment consists of two phases, both require exciting the beam using the force sensor while measuring the deflection and oscillation responses with time. To measure the force on the beam, the laser distance sensor time interval is set to 500ms. A “Load Up” button on the GUI is pressed until the load sensor barely touches the beam i.e. (Figure 4.3 a). The “Start Record” button is then pressed to start recording the data. Next, the “Load Up” button is pressed stepwise (i.e. Press-hold-release) so the deflection occurs gradually as shown in Figure 4.3 (b) – (e). On each step, let the reading stabilize about 3-5seconds before taking another step. Upon reaching the maximum height indicated by the limit switch, a “Stop Record” button is pressed. Finally, the slider can be brought down to its neutral position by (Figure 4.3 f) pressing the “Load Down” button. The recorded data can be exported to Microsoft Excel for further presentation and analysis.

To perform excitation on the beam, the laser distance data interval is first set to 30ms. Starting from the natural position as given in Figure 4.3 (a), The electromechanical latch mounted on the slider (Figure 4.4) is brought to touch the beam and further driven vertically down until the beam disengages, generating an oscillatory motion that is the pick-up by the laser distance sensor. The motion is displayed in real-time using the graph function created on the GUI. The graph will respond according to the beam movement. Since the load sensor is not used during this sequence, the value remains idle. In the case of data presentation and analysis, the record button can be used to stamp and store the data followed by exporting them into Excel.

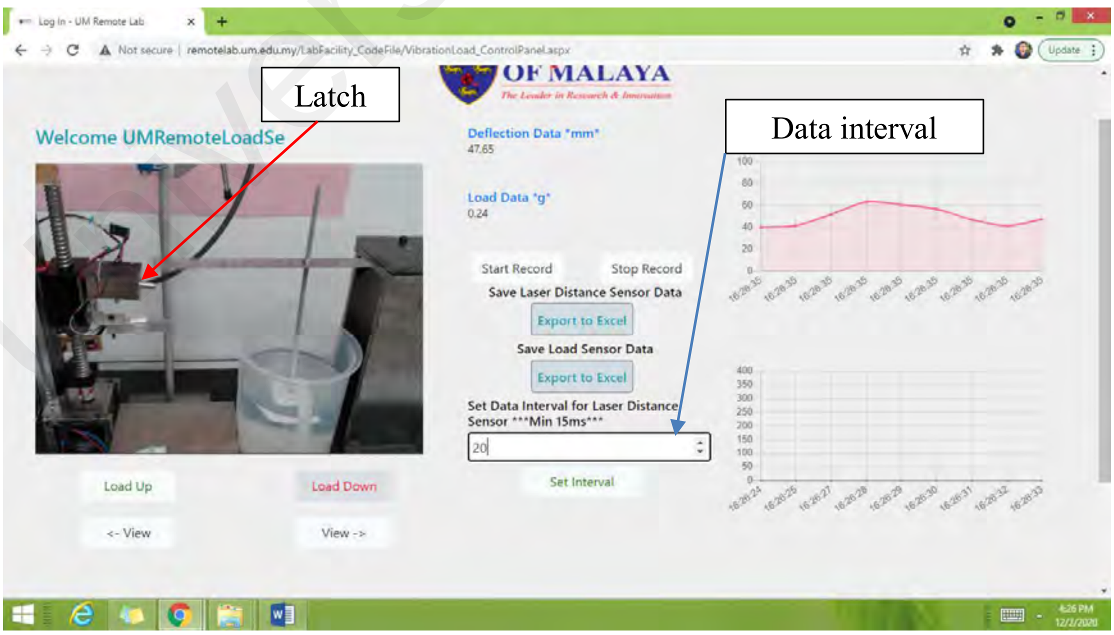

Figure 4.4: Vibration Measurement under Remote Operation

4.3 Evaluation Method

Research objective 3 stands to evaluate the remote lab architecture, system performance, and user assessments based on the Technology Acceptance Model (TAM). On this note, there persists one corresponding research question; How to evaluate the effectiveness of the proposed system? To answer this question, an analysis of the system has been done and is presented in sections 4.3.1 and 4.3.2 respectively. Further, the effectiveness of the remote robotic laboratory is also evaluated in section 4.3.3 based on the user assessment survey.

4.3.1 System Data Analysis

E13

	ID	RCM	RTVSD_	Msg
2	0	5/31/2021 19:11	52.25	
3	0	5/31/2021 19:11	52.34	
4	0	5/31/2021 19:11	52.2	
5	0	5/31/2021 19:11	52.25	
6	0	5/31/2021 19:11	52.25	
7	0	5/31/2021 19:11	52.34	
8	0	5/31/2021 19:11	52.44	
9	0	5/31/2021 19:11	52.15	
10	0	5/31/2021 19:11	52.25	
11	0	5/31/2021 19:11	52.34	

Figure 4.5: Recorded Data for 10 Seconds with 1000ms Interval

According to figure 4.5, there are 10 data available that was received by the system from the laser deflection sensor. The data was recorded for 10 seconds duration while the experiment was live. At that moment the interval was set as 1000 milliseconds for each reading from a sensor. To get the proper and complete set of execution data, an extreme level of speed of data acquisition is required, which is 1 millisecond. Different levels of intervals were set to validate the performance and accuracy of the data set received from the system. The interval set was split into 20 slots from 1000 to 1 millisecond. Each of the intervals recorded a different set of data with the targeted duration of 1000 milliseconds that is counted and regulated with the help of a stopwatch. Based on the recorded data a table has been created to evaluate the accuracy level of the data acquisition system.

Table 4.1: Recorded Data Analysis Table from the Facility

Interval (millisecond)	Theory		Practical			Compare to the theoretical data practical data is satisfactory
	Duration (seconds)	Number of data (theory)	Duration (According to system Stopwatch)	Number of recorded data (System)	Number of theoretical data according system stopwatch	
1000	10	10	10.7	10	11	Yes
900	10	11.12	10.81	12	12	Yes
800	10	12.5	10.40	13	13	Yes
700	10	14.28	10.56	15	15	Yes
600	10	16.66	10.62	17	18	Yes
500	10	20	10.50	21	21	Yes
400	10	25	10.40	26	26	Yes
300	10	33.33	10.51	35	35	Yes
200	10	50	10.60	53	53	Yes
100	10	100	10.10	101	101	Yes
90	10	111.12	10.35	115	115	Yes
80	10	125	10.16	127	127	Yes
70	10	142.85	10.15	145	145	Yes
60	10	166.76	10.32	172	172	Yes
50	10	200	10.15	203	203	Yes
40	10	250	10.12	253	253	Yes
30	10	333.34	10.29	343	343	Yes
20	10	500	10.17	344	509	No
10	10	1000	10.33	646	1033	No
1	10	10000	10.49	713	10490	No

According to Table 4.1, there are four variables to calculate and compare the accuracy level of data: Interval, Theory, Practical, and Comparison with theoretical and practical data. There are two major components of theory and practical. One of the components is the duration and another one is the number of data. According to the theory, the duration of data collection for calculation is 10 seconds. And if the interval value is 1000 milliseconds then the number of output data will be 10 according to the equation. In the practical scenario, while conducting the experiment remotely, data need to be recorded to collect the deflection data of sensor and beam. This recording duration should be 10 seconds. However, while counting this duration on the stopwatch, this duration may differ a bit due to clicking on the stop recording button. Therefore the actual number of data obtained both under theoretical and within the system can be calculated based on the actual time duration gained during the experiment. The efficiency of the system performance is comparable based on theoretical data and runtime practical data of the "Vibration and Load Facility" experiment. The output of the theoretical value is calculated based on the specific value of equation components.

The equation is:

$$\frac{N \times 1s}{I} = data\ for\ 1\ S$$

Here, N = Number of Data

$1s$ = 1000 milliseconds

I = Interval

Now, if the interval is 900 ms

And duration is 10 seconds

Then output data for 1 second will be = $\frac{N \times 1s}{I}$

$= \frac{1 \times 1000ms}{900}$

= 1.112 data per second

So, for 10 seconds output data will be = $1.112 \times 10 = 11.12$ data

Alternatively, the output of practical value is based on real-time data recorded from the system while experimenting. According to the run time report of recorded data of row no. 4 from the bottom of Table 4.1, it shows that the number of output data from the system with 30 milliseconds and 10.29 seconds duration can satisfy the equation. Following Table 4.1, it is also found that from the bottom row no. 1, 2, and 3 where the interval is less than 30 milliseconds there are significant differences between a theoretical number of output data and a practical number of output data from the system. According to the equation theoretically, if the interval is 1 millisecond and duration is 10.49 seconds then the expected number of output data should be 10,490. Hence the number of output data is 713 which is quite less than the expected number of output data.

4.3.2 System Response Based on Bandwidth

In this experiment, the robotic limb will be activated to move the carrier from the bottom limit switch to the top limit switch. The time ~~is~~ taken for the carrier to travel from the bottom to the top and vice versa will be captured both from the web and from the actual site. Different internet speeds will be used to gauge the capability of the setup to respond under different bandwidths. The experiment was conducted with all the connected devices in active mode to ensure a similar level of experimental condition. The experiment is illustrated in the following Figure 4.6.

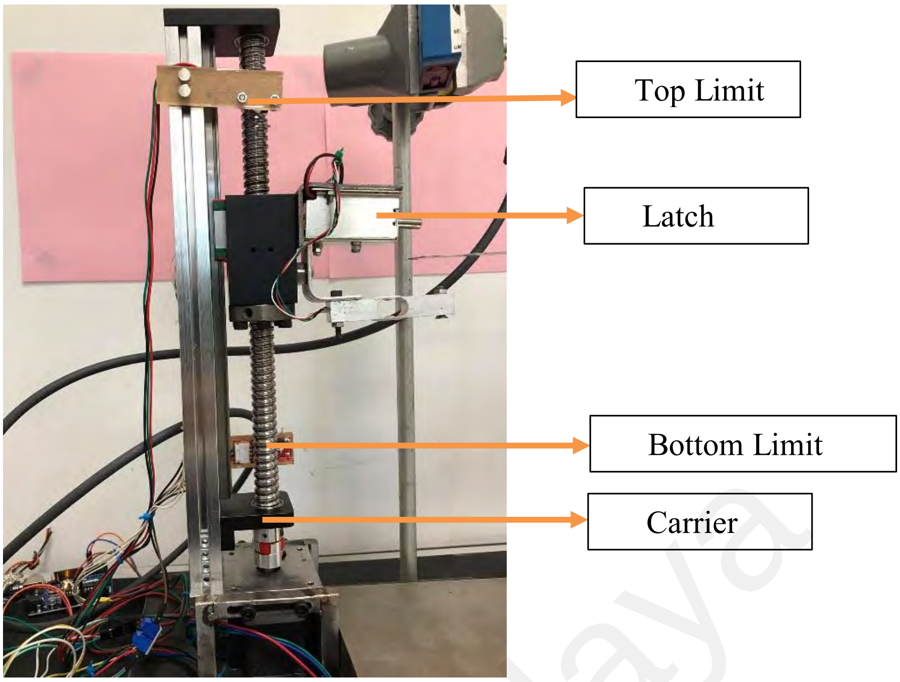

Figure 4.6: Delay Response of Movement of the Robotic Limb

Following this method, the experiment was conducted under 5 different bandwidths including with Ethernet 75 Mbps, Wi-Fi 40 Mbps, 4G 23 Mbps, 3G 7 Mbps, and 3G tethering 1-5.7 Mbps. The movement of the carrier of the robotic limb was run by three times with each bandwidth to get the average and response delay. The time was regulated and counted with the help of two different stopwatches from both ends of the web application interface side and hardware setup side. All data has been collected and documented in Table 4.2. There are six major variables in the table. Variables are - Bandwidth category, Bandwidth speed, Stopwatch time from the application side, Stopwatch time from the hardware side, Average and Delay. System response time also depends on the bandwidth quality. With low bandwidth, the system takes a longer time to respond than the average bandwidth. According to the data of Table 4.2 if the bandwidth is about 1 to 5 Mbps then hardware and application side response time can be delayed near about 76.21 seconds.

Table 4.2: Response Time with Different Bandwidth

Bandwidth	Bandwidth (Mbps)	Stopwatch time from application side			Average	Stopwatch time from hardware side			Average	Delay
		1st read	2nd	3rd		1st read	2nd	3rd		
Ethernet	75	19.67	19.55	19.63	19.62	19.60	19.47	19.53	19.53	.09
Wi-Fi	40	19.87	19.51	19.63	19.67	19.35	19.18	19.16	19.23	.44
4G	23	20.38	19.95	19.72	20.02	19.23	19.44	19.37	19.34	.68
3G	7	19.80	19.50	19.70	19.67	19.30	19.16	19.49	19.32	.35
3g tethering with pc	1 - 5.7	3:06:03	34.73	1:05:87	95.55	19.30	19.29	19.43	19.34	76.21

4.3.3 Assessment Based on User Perspective

To investigate the usability and efficiency of the proposed remote laboratory management system, an assessment procedure was executed and performed on students of the Universiti Malaya. A prototype has been built to experiment remotely through an online system which is developed in Asp.Net, C#, and MS SQL and hosted on the local server of the university. The assessment aims to make the prototype available for participants to experience the system by registering individual user id.

A. Participants

A total of 30 respondents participated in the above-mentioned assessment. The final-year student from the engineering faculty was selected as participants. The aim to work with engineering students was because of the belief that they are practically advanced in doing lab exercises. This assessment intends to evaluate how easily and comfortably these students can do lab exercises remotely by using our proposed system. Among the 30 invited students, 6 groups were created by 5 random students in each to attend a separate session.

B. Material

In this experiment, the participants were requested to use the online system to experience the remote laboratory facility through our developed prototype. Students were asked to take control over vibration and load experiment setup remotely via the website. The process aims to make a real environment for students to do research work remotely. It is expected that this facility can bring the students more freedom to do lab work without their physical presence in the laboratory. Once students have completed the task with a limited time, they were given a questionnaire form to complete. This involves identifying their acceptability to the proposed remote laboratory management system. The query is composed of 14 questions as shown in Table 4.3.

Table 4.3: Question based on Technology Acceptance Model (TAM)

Participants' Perceptions of Ease of Use
Q-01. Doing laboratory work remotely through the system is easy for me. Q-02. It would find easy for me to get the system to do what I want to do in lab. Q-03. My understanding level on the subject matter between the manual and remotely operated procedures is clear. Q-04. The intelligent interaction of system is helpful and easy to develop my skill. Q-05. The overall process of performing experiment under remote condition is flexible. Q-06. Interact with the system is easy for Me.
Participants' Perceptions of Usefulness
Q-07. The process of obtaining the required raw data is useful. Q-08. Using remote laboratory system encourages me to explore more on the related subject. Q-09. Using the system in my e-learning would improve my productivity. Q-10. Using this system doing laboratory exercises would enhance my effectiveness. Q-11. The usefulness of remote laboratory management system is very high based on the current context of the world. Q-12. I would recommend to others to use this facility.
Behavioral Intention
Participants' Perceptions of based on Time and Space flexibility
Q-13. The remote experiment would benefit me in terms of time and space flexibility in performing the experiment.
Participants' Perceptions of enriching knowledge with the scope of experiment
Q-14. Doing lab exercises through remote lab system is much easier. Q-15. Collecting data via remote lab system is easy to solve problems.
Participants' Perceptions on Viewing system of experiment setup
Q-16. Camera control and visualization aid for remote interaction are very helpful to do lab work remotely.

Among these 16 questions, the top 12 questions were adapted followed by the Technology Acceptance Model (TAM) proposed by Davis (Davis, 1989). This TAM model is used to describe how enthusiastically a user gets across the cold face of the application before they embrace and use it (Morris & Dillon, 1997), which has already been used in various studies (Capra, Marchionini, Oh, Stutzman, & Zhang, 2007). The degree to which a person considers the particular system would be flawless to use is evaluated by the ease of use. Usefulness is defined by the degree to which a person expects the implementation of a particular program to improve the efficiency of his / her task. In this study, Q1-Q6 questions pose a real impression of the participants about the ease of use of the proposed method when using remote laboratory facilities. Similarly, Q7-Q12 questions analyze the participants' understanding of the usefulness of the proposed architecture. The participant completes a Google survey form for all statements using the 4-point Likert scale with values ranging from (1) strongly agree, (2) agree, (3) disagree, and (4) unsure. Q13 is helpful to evaluate the flexibility of time and space regarding remote lab facilities based on participants' perceptions. Q-14 and Q-15 indicate the users' perception of enriching knowledge with the scope of the experiment. And Q-16 emphasizes flexibility viewing and interacting system of remote experiment setup based on participants' perception.

C. Procedure

The assessment was executed in six different sessions. Each session is a part of subsequent groups. Each session starts by asking the participants for 30 minutes to take charge of the setup of experiments through the remote laboratory management system. The single restraint placed on the participants throughout the session was to set the proper interval for the laser sensor to get the vibration ratio and put a load on the load cell using the proposed system. Participants were asked to share their experience by responding to a set of questionnaires on Google's survey form after completing the session. All the following groups issued the same set of objectives and questionnaires. Once the first group concluded their session, other groups successively performed the rest of the sessions.

There are two phases of the whole assessment. In the first phase, students get the experience of our proposed system by doing lab work remotely. Then in the second phase students share their opinion based on experience. After that, additional data collected were associated with student feedback on the efficiency of the proposed facility.

CHAPTER 5: DISCUSSION

This chapter will explore the findings and their implications for the research objectives and theories. The experimental findings according to chapter 4 are studied to respond to the research questions posed in Chapter 1. Furthermore, the significance of the findings from both an academic and real-world perspective is highlighted as part of the research's strengths.

5.1 System Architecture

The outcomes of the analysis that was presented in section 4.1 will be discussed in this part to accomplish the Research Objective 1 of this study. Objective 1 is to identify an architecture of a remote robotic laboratory. There is one corresponding research question that relates to the objective; 1) what kind of architecture can be implemented to build a remote robotic lab?

5.1.1 Three-Layered Architecture

A laboratory exercise has been followed to implement the Remote Robotic Lab system. In this case, the exercise is related to mechanical engineering and that is about getting the vibration response of the beam under external excitation. The reason behind this is that there are highly sensitive physical movements that can be conducted remotely with the help of robotic functionality and a high-speed data acquisition process with millisecond intervals which is controlled by the system. At the very primary stage of this experiment, there was one layered architecture in system design. All components of the system were integrated into a single layer. According to the web page, there was a function to connect with the microcontroller. Following that function each time a request comes from the client-side, it needs to trigger the microcontroller port to send the command. The process was very manual and was unable to handle high-speed data transection with 10 milliseconds or 50 milliseconds. For this reason, the three-layered architecture has been implemented. There is a signal processing unit "SignalR" that is connected with the service layer of the architecture. This unit works as a data processing hub and is responsible for high-speed live data transactions from the sensor to the system. Also, the corresponding live chart relies on this functionality. According to the design, the system works in a way that can broadcast live data to the front-end interface with the help of the application layer.

The fact that, specifically in this research, three layered architecture is more reliable based on the performance consistency. The concept and benefit of layered architecture were also as highlighted by Domínguez, Prada, Morán, Antonio, et al. (2012). He indicated that the distinctive feature of layered architecture containing the Physical layer, Server layer, and Client layer for remote laboratory systems allows easier management and reusability. A similar type of experiment was encountered in a comparative study conducted by Ak, Topuz, Altikardeş, et al. (2018) on the investigation of the performance of remote laboratory infrastructure. Such four-layered architecture has been used to establish the remote laboratory system. Ak, Topuz, Altikardeş, et al. (2018) reported that the results demonstrated a satisfactory and good quality of the EDUMEC Project educational materials, pilot training, and mechatronic remote laboratory infrastructure. The comparison also presented that the layered architecture is the best performing mechanism for remote robotic laboratory systems.

To answer research question 1, the integration of three-layered architecture as shown in Figure 5.1 makes the system much more stable, efficient and structured to maintain the requirements of the remote robotic lab infrastructure. As the system design is capable to handle high-speed data acquisition processes and remote robotic movement, the architecture also can be implemented to conduct other engineering and science-related laboratory experiments.

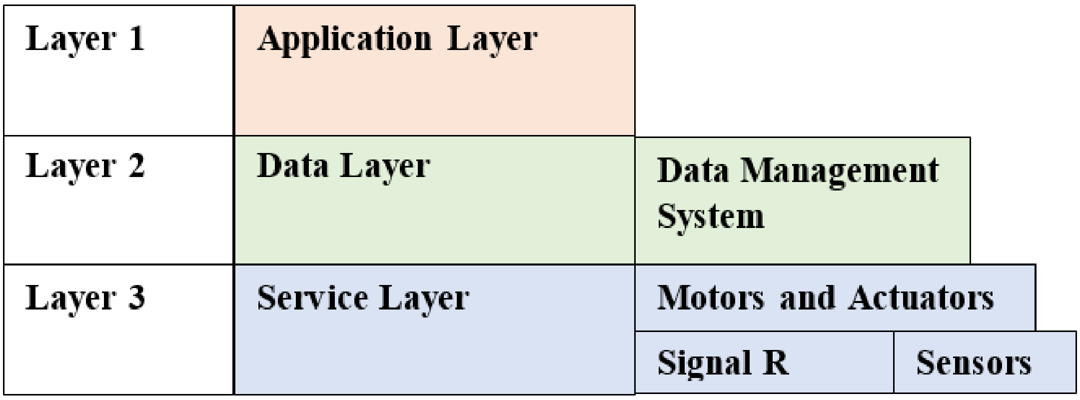

Figure 5.1: Three Layered Architecture of Remote Robotic Laboratory System

5.2 Remote Robotic Lab Facility

This section will go through the findings of the analysis that were reported in section 4.2 to address the Research Objective 2 of this study. For research objective 2 (i.e. to develop a robotic laboratory system that incorporates hardware and software specifications for real-time remote access), there is one corresponding research question that reflects the objective that is; 2) what are the requirements based on facility, experimental setup, hardware, and software features to develop a remote robotic lab system?

5.2.1 Analyzing Deflection and Vibration Response Data of Beam

Figure 5.2 and 5.3 shows the sample graph generated by the system under the deflection experiment described in section 4.2.1.

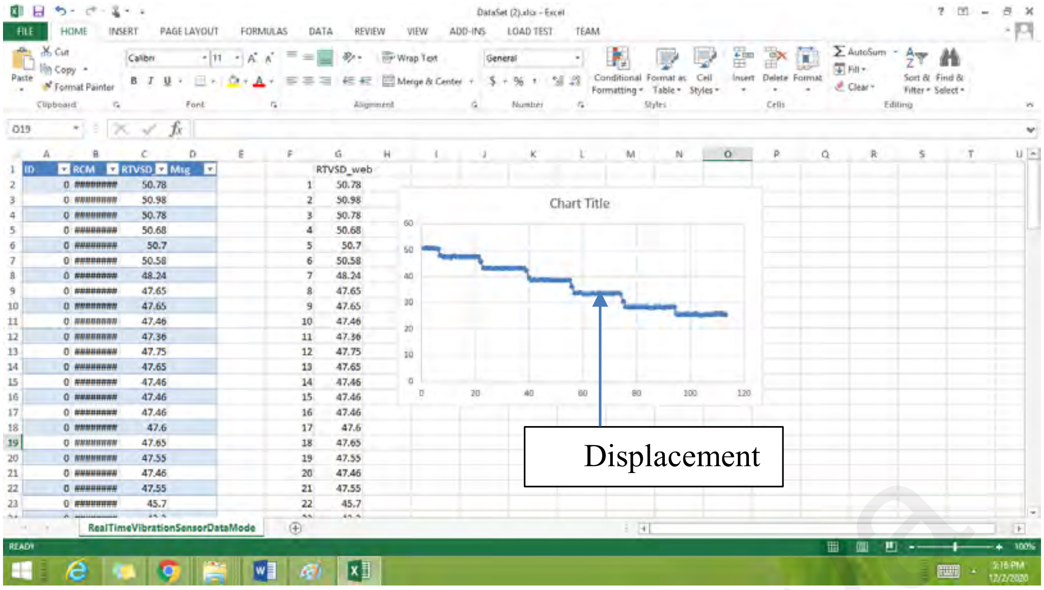

Figure 5.2: Recorded Data for Displacement in Excel under Deflection Experiment

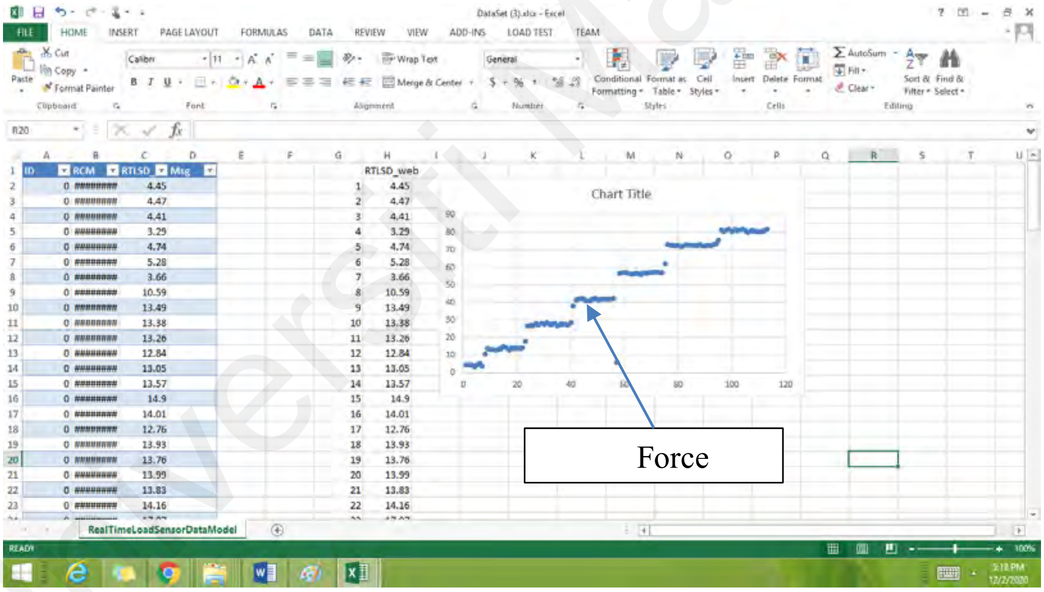

Figure 5.3: Recorded Data for Force in Excel under Deflection Experiment

The results indicate that data of both parameters were successfully recorded and displayed by the system. The consistency in the plots displayed at constant intervals suggests the absence of data loss or data misrepresentation, indicating the reliability of the algorithm to sample and decode the bits. The much smoother plots for displacement result in comparison to the Force was due to the accuracy of the sensor to provide consistent signals to the controller. However the standard deviation of the reading fall in acceptable accuracy (i.e. <10%) between the step which provides a strong indicator for conducting further analysis.

Similarly, the result of beam oscillation recorded and plotted in Excel for the vibration experiment is shown in Figure 5.4. It is interesting to note that the decayed oscillation was captured without any apparent loss of data which can distort the cyclic motion of the beam, thus compromising further analysis. The result confirms the ability of the web application system to provide a fast and accurate response in real-time which is the key factor in realizing the remote laboratory concept.

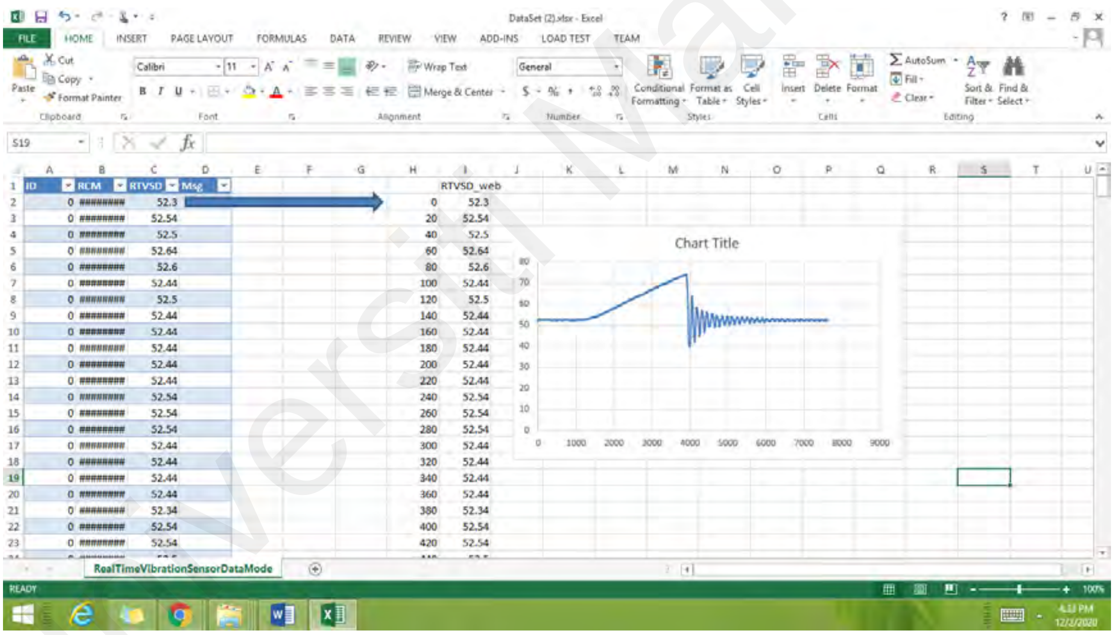

Figure 5.4: Recorded Displacement Data for Beam Oscillation in Excel under Vibration Experiment

5.3 Evaluation Method

This section will discuss the results of the analysis that were presented in section 4.3 to answer Research Objective 3 of the research. As research objective 3 is to validate the remote lab architecture, system performance, and user assessments based on the Technology Acceptance Model (TAM). There is one corresponding research question (research question 3 of the study) that correlates with the objective that is; How to evaluate the effectiveness of the proposed system?

5.3.1 Required Performance Based on the Facility

In accordance with the reading of sensor data with different intervals from the experimental facility, a data set has been recorded followed by the establishment of Table 4.1 in section 4.3.1. According to the variables of the table an equation was used to validate the performance of the data capturing ratio. There are two major variables to calculate the number of recorded data namely duration and time interval. The variables are contained with the number of output data of deflection laser sensor from an experiment with specific interval and duration. Based on the interval from 1 to 1000 milliseconds and the output number of real data there is a slight difference between the graph of theoretical data as shown in Figure 5.5. According to the graph when the interval is 30 milliseconds, practically the number of output data is 343 which is the same as the theoretical value based on the duration obtained via the experiment (i.e. 10.29s). The graph indicates that up to this interval the data generated by the system matches with the theoretical value which suggests the ability of the system to operate at a high sampling rate.

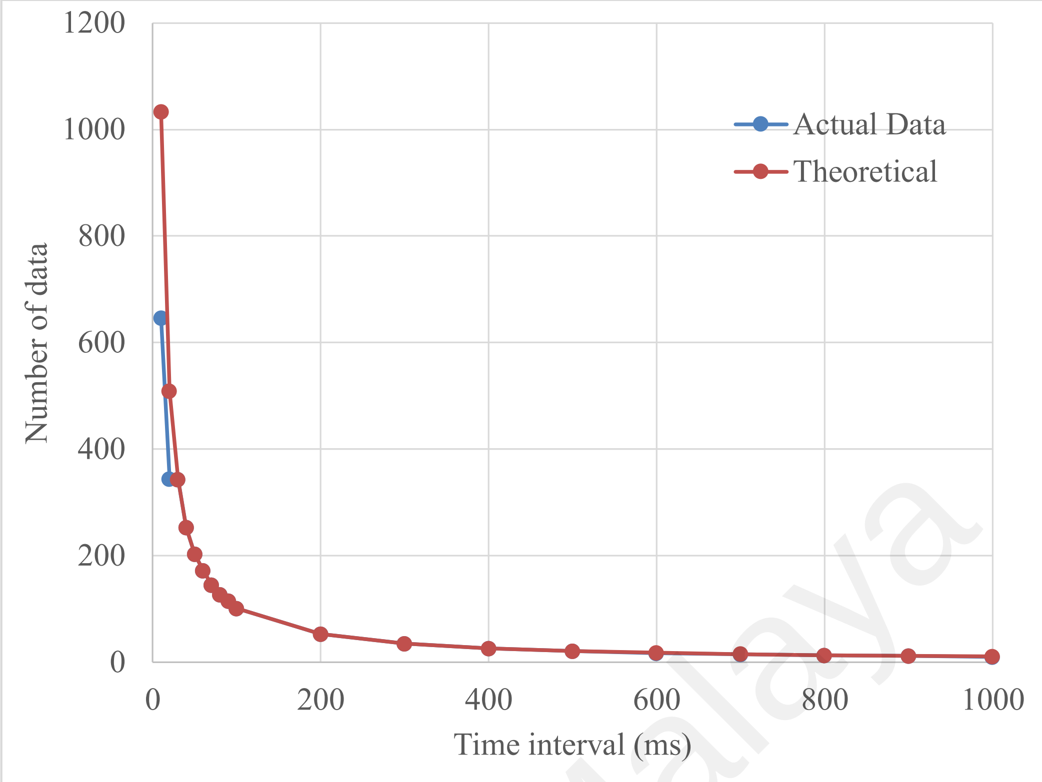

Figure 5.5: Theoretical Data Graph with the Number of Output Data

In contrast, according to data Table 4.1 from section 4.3.1, it was found that with the interval of 20 milliseconds and 10.17 seconds duration, run-time output data of the system was unable to comply with the following equation. The expected output number of data with the variable of 20ms and 10.17s duration should be 508. Whereas, the output number of recorded data is 344 which is less than the expected value within a specific interval and duration. The same goes for all below intervals of 20 milliseconds as 10 and 1 milliseconds cannot satisfy the expected number of output data. Following this issue, the investigation found that there is a limitation in the Asp.Net platform. The timer resolution is given by the system heartbeat. This is typically by defaults to 64 beats/s which is 15.625ms. This is the reason system is unable to deliver the expected number of output data when the interval is 20 milliseconds or less than that. Also, According to the findings from most of the previous work on remote laboratory systems the consistency of interval functionality is not very flexible. Moreover, in a few cases, the study shows that the interval of each data reading or signal processing system for experimental setup depends on third-party tools or hardware. It is also found that the process of experiment data collection with interval functionality is inconsistent following the findings by Bisták, Halás, and Huba (2017) which indicates that the experiment output data are through Matlab scripted channel. Bisták, Halás, and Huba (2017) reported that experimental data are received and visualized continually using the block channel of corresponding client-side functionality.

5.3.2 Hardware Impact Response Based on Internet Speed

As a result of this study, it is obvious that the system requires high bandwidth of internet for hardware to work and respond efficiently. According to the findings by Bisták, Halás, and Huba (2017), it is suggested that additional parameters related to internet connection and server settings are needed to be in an acceptable range to conduct the lab experiments remotely. Domínguez, Prada, Morán et al (2012) reported that AJAX ~~is~~ interrelated client-side method provides uninterruptable interaction over internet. Rodríguez, Arqués, Nuñez et al (1989) mentioned that with LabVIEW web server, experiments can be accessed with internet connection easily. In this concern, an experiment was executed to find out the minimum bandwidth that can run such type of facility. According to section 4.3.2, Table 4.2 an index was documented with different bandwidths and delay response time of hardware. The study shows that minimum bandwidth of 7 Mbps is capable to run the "Vibration and Load Sensor" facility. Following the findings, it is highly recommended that to run the hardware infrastructure smoothly minimum bandwidth is required 7.5 Mbps, and more than that.

5.3.3 Effectiveness Based on the User Perspective

An assessment was performed following the TAM questionnaire model to analyze the students' perception of the remote laboratory management system. To recall, a survey was conducted to evaluate the ease of use and the effectiveness of the proposed system.

Ease of Use

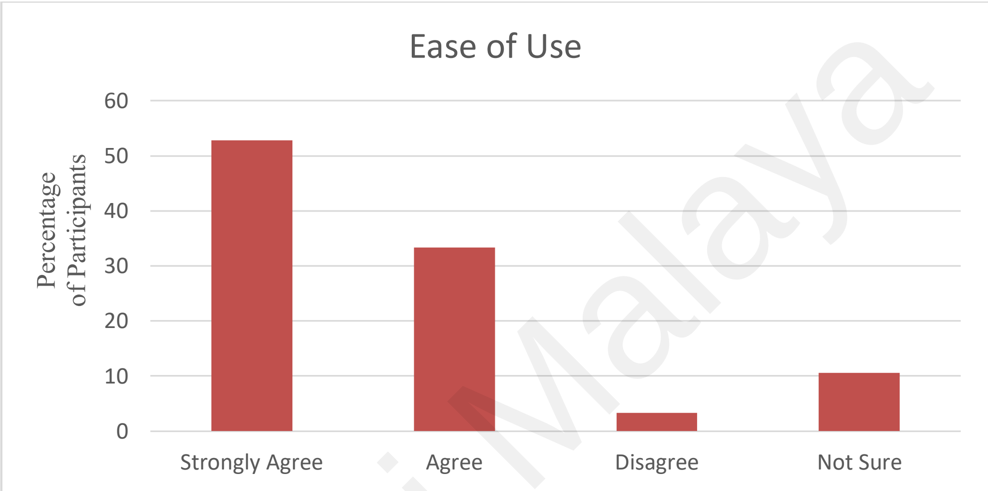

Figure 5.6: Students' Perceptions on the Ease of Use of the Facility

Usefulness

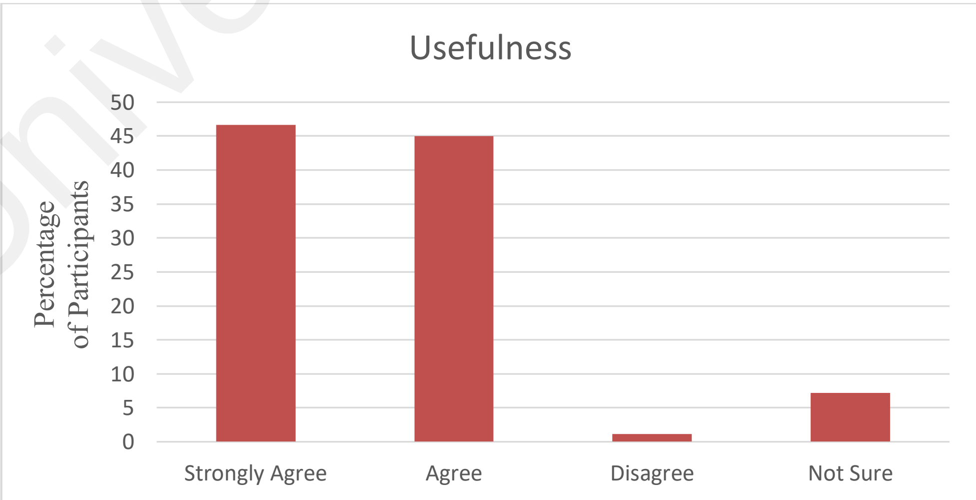

Figure 5.7: Students' Perceptions of Usefulness of the Facility

From this study, we found the acceptance ratio based on the students' perception of ease of use was determined. The results indicated that 52.77% of students strongly agree and 33.33% of students agree with the perception that the proposed system is easy to use (Figure 5.6). Very few students (3.33%) found that the remote procedure is not sufficiently ease to conduct laboratory exercise. Also, According to the survey, 10.55% of students stated that they are not very sure about the proposed system and how easy it could be to conduct lab experiments remotely.

Another section of this survey emphasizes the usefulness of the proposed system. In this context, 91.66% of students (46.66% strongly agree and 45% agree) found the system is useful to do laboratory experiments remotely (Figure 5.7). Following the survey results, it also appears that 1.11% of students do not agree with the usefulness of remote laboratory systems. While 7.22% of students are not sure how useful the proposed system could be according to the current situation of a pandemic.

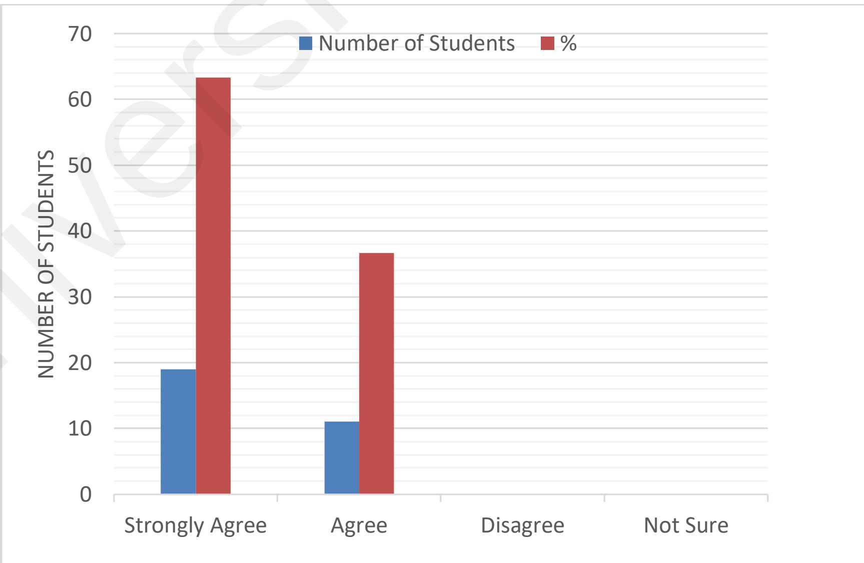

Figure 5.8: Level of Positive Impact in Time and Space Consumption for the Remote Facility

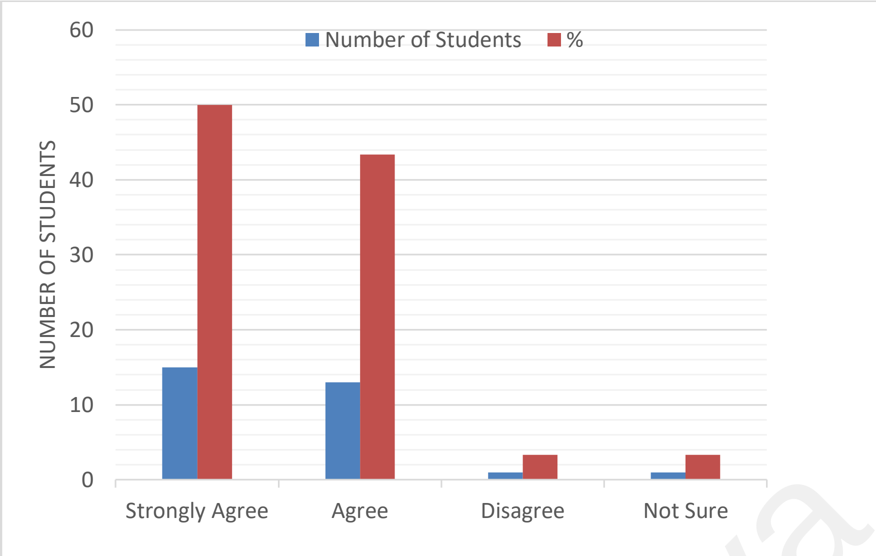

Figure 5.9: Level of Increment in Motivation Towards Enriching Knowledge Using the Remote Facility

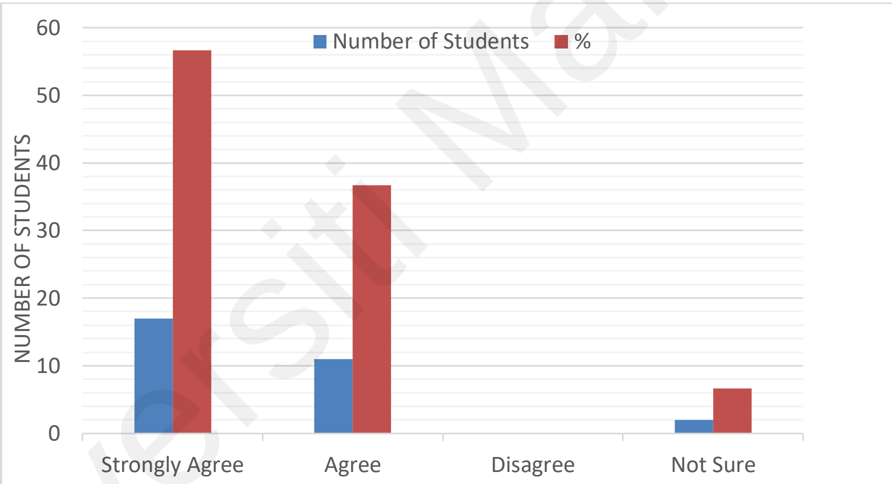

Figure 5.10: Level of Positive Impact on Camera Positioning System to Navigate the Remote Experiment

According to the survey result which is conducted in this study (elaborated in section 4.3), 63.33% (Figure 5.8) of respondents strongly agreed that this concept would promote time and space flexibility which brings convenience to the user.

In addition, most of the participants (around 93.33%) thought (i.e. strongly agree and agree) that conducting the lab via the web interface would motivate them to learn topics outside the scope of the experiments, particularly in the aspect of knowledge gathering and sharing as shown in Figure 5.9. On this note, only a few of the students were found not being motivated by the lab via the web interface, which is 3.33% disagree and 3.33% not sure respectively.

To resemble the user's presence in the laboratory, a live video stream of remote laboratory facilities plays a crucial role. It allows more freedom to navigate and explore the facility during the laboratory exercise phase. In this study, more than 93% (Figure 5.10) of participants agreed with the level of flexibility and positive impact on the camera system to navigate the experiment setup. The above results provide a welcoming perception of the expected impact of implementing remote labs towards nurturing the user to engage in multidisciplinary learning.

CHAPTER 6: CONCLUSION

This chapter provides the synopsis of the prior chapters, emphasizing what has already been explained and discussed, aspects of the research that were not explored, and suggestions for future areas that can be pursued.

6.1 Aims of the Study and Achievements

The study aims to establish a fully functional remote robotic laboratory system to conduct lab experiments remotely. At this aim, a new architecture has been designed and implemented successfully by converting a laboratory exercise of the mechanical engineering course. The achievement of the establishment of this facility is that students can feel their presence in the lab without being physically present. The concept involves the use of a server system to govern user accessibility and communication with the lab which allows systematic lab operation.

According to the study, objective one is about the architecture of the system that correlates with research question one. The corresponding research question is, what kind of architecture can be implemented to build a remote robotic lab? Referring to the run-time results and performance of the remote robotic laboratory facility, it is found that three-layered architecture is the most effective model to conduct laboratory experiments efficiently over online. In order to address research objective 2 which is about system specification to develop a robotic laboratory for real-time remote access, which relates with the research question 2. The corresponding research question that relates to objective 2 is about requirements based on facility, experimental setup to develop a remote robotic lab system. Following objective two, the efficiency of the system and accuracy level of the high-speed data acquisition process has been analyzed thoroughly. According to satisfying results of the analysis, the study enforced that three-layered architecture is highly compatible to conduct laboratory experiments remotely. The service layer, application layer, and data layer are the key layers of system architecture. The service layer helps to manage all connectivity and signal processing from hardware level to application level. The application layer enables the user functionality and web interface. The web interface module is responsible to maintain the communication and bridged by the server to synchronized data format and conversion to the microcontroller. A database layer was also incorporated, allowing the user to save and retrieve data through online upon their necessity. Also, to satisfy the objective 3 and research question 3 which is about evaluating the performance of the system, the output result data of the remote experiment was justified with the real experimental results data. Not only that a survey was conducted with the students of the University of Malay to obtain evaluation based on user perspective by using the remote lab facility. The survey results revealed that students were very positive regarding the effectiveness of remote laboratory management systems. They feel free to do their lab exercise whenever they want and at any place where internet connectivity is available. In terms of flexibility and efficiency, the proposed remote laboratory management system is able to eliminate time, space, and resource complexity.

6.2 Limitations

Within the establishment of this facility, there is one big challenge which can be considered as the cost. As this is a remote robotic lab system, two aspects need a certain degree of investment. One of these is to convert and build a hands-on traditional physical lab into a remote robotic lab. Another one is to make things work remotely. For that, it requires a dedicated server and dedicated WAN connection.

There is another big challenge that can be considered as a limitation which is the platform of ASP.Net webform. The current web application is developed on the ASP.Net webform system. ASP.Net webform is not very compatible with such type of data and signal processing system. For this reason, a few additional logic and functions have been developed to get high-frequency data efficiently and smoothly. Therefore, a deep investigation found that the ASP.Net web form system is not capable to handle high-frequency data transition, while the ASP.Net core can handle huge and high-frequency data without the integration of additional functionality.

For the time being another issue that needs to be considered is that only one user can be active at a time in a remote robotic facility. Other users may remain as passive users while there is already one active user in the facility. Passive users can follow up on the activity of a current user. To overcome this limitation there is a need to build communication and collaboration functions that allow the students participating in the session to switch roles between passive and active during the session to enlarge the flexibility of usefulness.

6.3 Future work

The next step of this research is to improve the viewing aid mechanism to enable the user to gain complete freedom from multi-direction navigation that closely replicates the user's physical presence in the laboratory as well as making the communication interface more user-friendly. In conclusion, the proposed research has demonstrated the viability of transforming the existing manual experimental facility into a "Remote Robotic Lab" scheme that allows the client to experiment with remote management protocol by using online communication technology. Following this infrastructure more experiments can be incorporated and hands-on lab facilities can be converted to the remote robotic system. The success of this project will ensure that the national aspiration in embracing Industry 4.0 within the society which also includes transforming the education field into an internet-oriented learning platform can be accomplished to meet the global trend. This effort has also laid the groundwork for setting up and implementing a smart campus under a remote laboratory program.

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