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Integrating IR4.0 Technology in Engineering Education: Robotic Arm Remote Lab

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Abstract : The education sector, in general, is constantly trying to integrate the current fourth industrial revolution known as Industry Revolution 4.0 (IR4.0) into its curriculum. In efforts to do that, this capstone project was assigned to a group of students doing their Bachelor's in Engineering to effectively create and design a virtual or remote lab that would further help students everywhere to be more engaged and involved in the learning process. In this regard, this paper introduces the initiative being carried out by the UOW Malaysia KDU University College (UOWMKDU) to implement IR 4.0 in various modules being taught, in terms of projects or assignments. Therefore, a remote lab was created based on the learning outcomes of a subject available in the module. The lab includes a robotic arm manipulated through an established interface developer Blynk, being simultaneously observed through a website built by a student in the School of Engineering, UOWMKDU. The movement of the robotic arm is viewed through the website by incorporating an inexpensive camera chip into the design. Also, this paper discusses the advantages of using those components, in-depth information regarding the components and their usage, and a detailed methodology that could be used as a guideline for future students interested in creating their robotic arm. It highlights the objectives of the lab, procedures, and challenges that were faced during the period of assembling the prototype and how those challenges were overcome to produce a well-functioning robotic arm.

Keywords : education sector; IR4.0; remote lab; robotic arm; virtual lab

1. Introduction

The problem which currently dominates intellectual debate is Industrial Revolution 4.0 (IR4.0). This fourth industrial revolution began at the World Economic Forum in 2016, where an announcement was made that the world had reached the inception of the fourth revolution in the industry. To describe the current revolution, these have used many different terms, including 'Fourth Revolution', 'Industry 4.0', Revolution 4.0', and 'Fourth Industry'. The Fourth Technological Revolution can be described as the latest and evolving alteration of human function, resulting from disturbing inventions and phenomena such as digital technology, the

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Internet of Things (IoT), augmented reality, and artificial intelligence (AI) .

The development of IR4.0 is a recent trend that directly affects many industries, including higher education institutions (IHL). Higher education is a significant sector that needs due attention because it is closely linked to the economic sector of the country. If the education system is not aligned or equipped to meet current trends, our country will stay behind and this will have lasting consequences for the country and the community. The Public Institute of Higher Education as one of the most relevant institutions has a strong duty to produce good human capital to meet the demands of people today more inclined to achieve the highly qualified human resources of the country.

Based on improvements in the country's education system as a result of its growth and success, universities have begun focusing in particular on the industrial requirements that will consume university education products. The change in IR4.0 implicitly complicated human life and characterized the competition aspect. Otherwise, graduates will not be able to meet the demands of modern times. Graduates will be unable to meet the requirements of the modern era without this preparation. Consequently, apart from the growing usage of intelligent computers, the use of digital technologies, information access, and the introduction of modern media has become a fact that cannot be disregarded. Therefore, IHL must be well prepared to leave the comfort zone and routine to meet the obstacles presented by IR4.0 .

In this modern period, formal education is becoming a benchmark for employing workers. As such, career possibilities are the standards for the worth of any education sector in the world of education. Education is also considered to be a long-term investment to meet the demand for trained workers in society . Any formal education loopholes might compromise a nation's education and human capital. Thus, education must be meticulously planned. IR4.0 is rapidly changing the globe, as well as the labor requirements. As a result, public universities have begun to customize their curricula to meet the demands of the firm.

For all the above-mentioned, Robotic Arm Remote Lab is introduced in this paper to improve the education system by implementing IR4.0 into the curriculum. This lab aims to provide an alternative solution to performing labs when the lab is unreachable due to distance. With that, it will help enhance the practical skills of students in adjusting a robotic arm to perform a particular task remotely. With the help of technology, distance will no longer be a problem in education. The details of the core work done by the group are presented in the following chapters.

2. Literature Review

A. Industrial Revolution

The first industrial revolution began in the 18th century with the use of steam power and the mechanization of production . The mechanized edition, which had generated threads on basic spinning wheels before, accomplished eight times the volume at the same time. The biggest advance in rising human productivity was its use for manufacturing purposes. The Second Industrial Revolution began with the invention of electricity and assembly line manufacturing in the 19th century . The notion of mass processing from a slaughterhouse in Chicago was picked up by Henry Ford between the years 1863 and 1947. The pigs were hanged from conveyor belts and each butcher undertook only a part of the process of butchering them. In the '70s, by partial automation using memory-programmable controllers and computers, the Third Technological Revolution started in the 20th century for the most part. The whole manufacturing chain is simplified with the advent of these innovations without human help. Robots that execute programmed sequences without human interference are known examples of this.

Industrial Revolution 4.0 (IR4.0) is currently being implemented in this day, where information and communication technologies are applied to the industry. Production systems that use computers are advanced with the use of network connection which will allow them to have a digital twin on the internet to speak to. This will allow interconnection between facilities that can assess each other's outputs. This intends to produce smart factories where everything is connected through a network making it almost autonomous. IR4.0 changed the manufacturing industry by digitizing it. IR4.0 involves 9 pillars which are The Internet of Things, Augmented Reality, Simulation, Additive Manufacturing, System Integration, Cloud Computing, Autonomous Systems, Cybersecurity, and Big Data Analytics.

B. Remote & Virtual Labs

Virtual laboratories can be considered as replicas or imitations of real-life experiments which are carried out using simulation on a computer. Accessibility, availability, safety, and observability are some of the general benefits of virtual and remote laboratories. Remote laboratories are of great use when it comes to distance-learning courses which mainly develop professional skills, conceptual knowledge, and understanding in students. According to one of the papers, most educational institutions prefer virtual laboratories used in the first stages of learning to build confidence in students, then make use of remote laboratories in later stages of learning to achieve learning outcomes of module courses .

Previous research has shown that virtual and remote laboratories produce higher achievement in learning outcomes and higher transfer of learning compared to hands-on laboratories . It is of great importance to focus on the mental activities of students when using these laboratories, some of which may include their motivation, collaboration, and feedback. The students were more enthusiastic to learn about the current technologies available for the automation of manufacturing systems. Interest increased amongst students due to the ability for them to visualize the behavior of productive systems when using the virtual lab and remote lab.

Although remote laboratories are deemed less efficient than hands-on laboratories, they provide a greater experience of working geographically with students and allow for better compensation of any problems that may arise from equipment failures. Authenticity, inquiry, collaboration, and technology are all considered to be important features when operating laboratories . Through the synthesis, planning, making of decisions, and transforming of data, students develop a greater cognitive engagement and higher-level learning strategies. Motivational challenges because the complexity and difficulty of the experimental course must also be exploited .

Students can learn new modules without having to worry about experimental setup, while researchers can try out new ideas on testbeds previously used by other researchers/focus groups hence producing fast, reliable comparisons of a variety of solutions. In most cases, remote laboratories prove to be a sufficient and effective trade-off between needs for real experiments and the shortage of time and resources. With minimal effort, several different experiments can be carried out thus reducing expenses and reducing the time taken to complete the experiments .

C. Robotics and Automation

Industrial Networks is a program that allows students the opportunity to develop methodical solutions related to the installation and design of industrial networks surrounded by process automation. It requires an analysis of the representative models, devices, protocols, topologies, and planning systems included in industrial communication networks to gain a further understanding of what occurs between these networks. It is largely rooted in the architecture and automation of the plants and industrial procedures from a distance, their Programmable Logic Controllers (PLC), and their transmission methods . Integrated Manufacturing Systems enables students to identify different technologies that are found in an integrated manufacturing system. Some important technologies used in process automation include Human Machine Interface (HMI), industrial communication buses, and PLC .

The first implementation of a virtual lab (VL) was done through the design and construction of a PLC simulator. More its environment rather than the PLC itself. Of this implementation, various problems arose but were subsequently solved. Some of these included the availability of equipment for each student to use, low training, and accessibility for students to practice and learn through trial and error as the errors in programming did not impact the physical devices. Lastly, the evaluation of results needed to be done efficiently as the feedback times of the system were instantaneous. Several Virtual Reality Machines (VRM) were developed to facilitate this .

The main constituents found in a remote lab (RL) are prototypes of the process, a PLC, video cameras, and a PC server. In this application, features such as process dynamics will take a primary role in the overall performance of the control system. It will validate that the control actions are carried out successfully and adequately within the automatic system including feedback meaning closed-loop systems, but especially without feedback which is open-loop systems. A remote laboratory with this kind of equipment has a reduced cost of implementation and operation .

3. Methodology

In this chapter, the details of developing the remote lab are shown where the main task of the robotic arm is to pick and place an object from one place to another. The user can manipulate the robotic arm by giving specific commands to control the motion. The robotic arm contains servo motors that allow the arm to move in the desired direction. A microcontroller is used to give commands to the motors of the robotic arm where the commands will be given through the user interface on the app, Blynk. The robotic arm control is done through the Internet to the wifi module connected to the robotic arm. The signal provided to the robotic arm can simply be transmitted over the Internet and the user can then access the robot anywhere and anytime as long as there is an Internet connection. In addition, this project provides a webpage to monitor the robotic arm. This webpage allows the user to observe how the robot is moving while controlling the robot's operation through the app. For security purposes, access can be restricted from the webpage for specific students only while the controller is given to students performing the lab to ensure only one student controls a robotic arm every time. By doing so, the admin would be able to track the user easily too.

A. Software Application

Arduino Integrated Development Environment (IDE) provides a text editor for writing code and messages. It contains a set of toolbars and menus with the basic feature icons. It is connected with the hardware to import and interface the programs into it. The sketch is the term for a program used by Arduino. It is the unit of code on which an Arduino Board is run.

B. Hardware Integration

In this section, the hardware design and the reason behind each decision made for the project will be discussed. This involves the design concepts, material and component selection as well as the software chosen for the completion of the project.

1) Robotic Arm

In this project, acrylic plastic was chosen as the material to build the robotic arm. Acrylic plastic is light and strong; therefore, the SGR 90 servo motor can rotate the robotic arm. As the prototype has electrical components as well, acrylic plastic acted as an insulator material to avoid current shock. The robot arm contains 5 servo motors which indicate that the robot has five degrees of freedom. There are three wires in the servo motors that act as power and signal control of the servo motors. The servo motor acts as the motor for rotating and shifting the robot arm. The five servo motors are linked to the NodeMCU ESP8266. It is used to transmit the signal to control the rotation of the servo motor. The signals are sent to the robotic arm via the internet and thus can be accessed from anywhere as long as there is an internet connection. The action of the robot is visible through the website. Hence, by combining the website and robotic arm controller, the user can monitor the robot and control the robot's motion.

The connection of five servo motors and the NodeMCU ESP8266 was verified through Fritzing before being implemented to the robotic arm as shown in Fig. 1. By doing so, the risk of servo motors and NodeMCU ESP8266 being burnt out can be reduced. These motors will not consume more power therefore the 5V DC supply is enough to drive them. The actual connection is shown in Fig. 2.

The MB102 Solderless Breadboard Power Supply Module was used as a power supply in this robot arm to provide a separate power supply to the servo motor. Two output voltages can be used simultaneously for

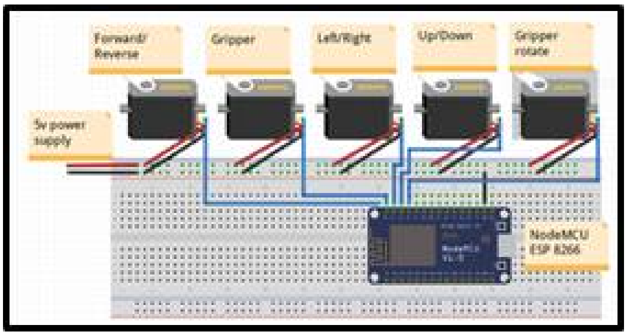

Fig. 1 : Connection of the servo motors and NodeMCU ESP8266 in Fritzing

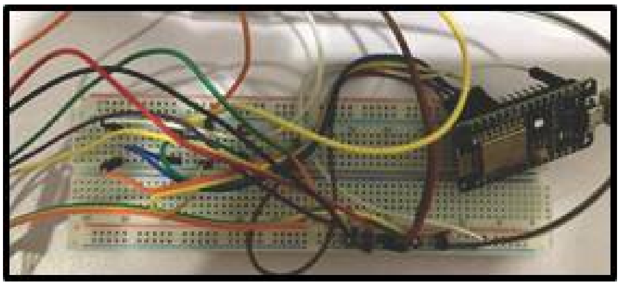

Fig. 2 : Connection of the servo motors and NodeMCU ESP8266

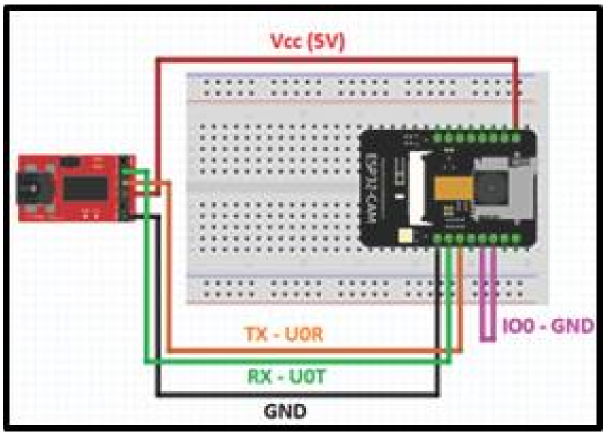

Fig. 3 : The connection of ESP-32 Cam to FTDI in Fritzing

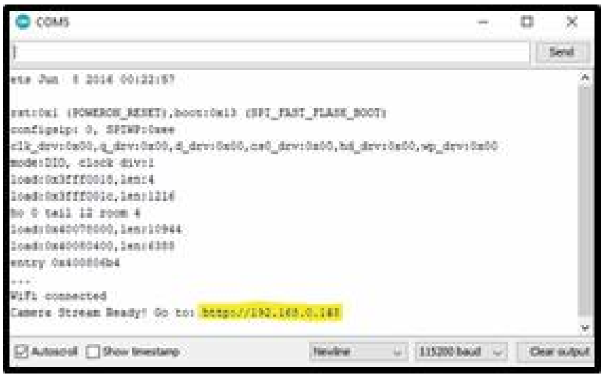

Fig. 4 : Example of IP address from the Serial Monitor of Arduino IDE

the project. This MB102 module can be plugged into the breadboard directly without any soldering needed. With a separate power supply, the robot arm will operate more smoothly, and the power supply would not be affected by the NODEMCU ESP8266. The power supply is controlled so that it does not exceed the requirements of 5V of Arduino.

2) ESP-32 cam

The ESP-32 Cam is used as the camera for the project because it is one of the cheapest IoT cameras available in the market. The ESP-32 Cam will contribute to one of the main purposes of the website, which is viewing the robotic arm. To upload the code into the camera, FTDI is needed because it can be used as a medium connecting the camera to the laptop. Fig. 3. shows the connection of the ESP-32 cam with the FTDI. After uploading the codes, the IP address of the camera will be created after running the codes where it can be obtained from the Serial Monitor as shown in Fig. 4.

C.Control system development

1) Block diagram

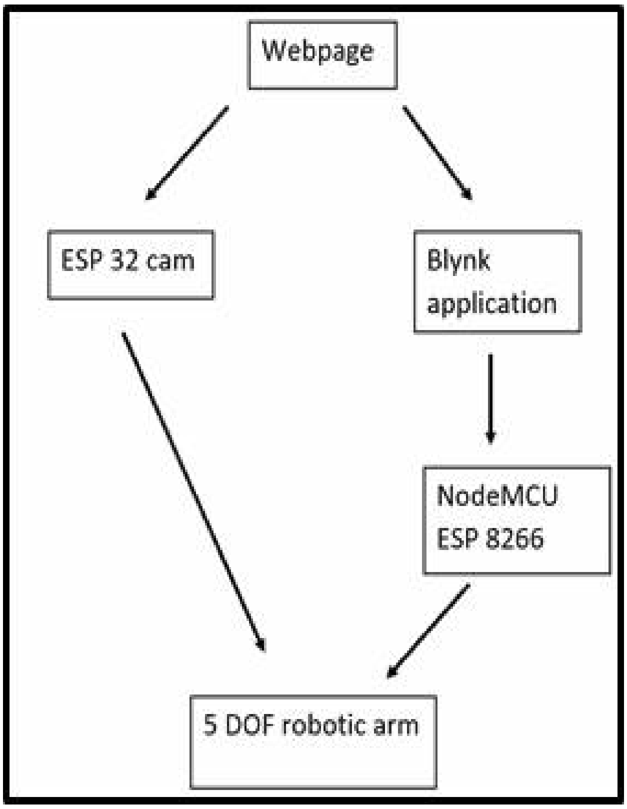

Fig. 5 : Block Diagram of IoT Robot Arm

The block diagram above describes the overall concept of the project, in which a webpage would provide lab details and be used to monitor the 5 DOF robotic arm, while the Blynk application is used to control the arm's movement. Therefore, to perform the lab, the user must have access to internet connection while having a smartphone for the Blynk application and a desktop/laptop is recommended to access the webpage.

2) Blynk controller

The project used the Blynk application as a platform to control the robotic arm. The reason for using the Blynk application in this project is because Blynk application is a well-established interface developer. It allows users to create an interface quickly for controlling hardware projects from Android and IOS devices. To upload the code, the NodeMCU library needs to be installed in the Arduino IDE. The NodeMCU can be installed using the built-in library manager available in Arduino IDE.

```
#include <BlynkSimpleEsp8266.h>
#include <Servo.h>

char auth[] = "WAUx08caWjv49bkmKVyrw2BACs6nAvEx";  //Paste Auth Token Here

// Your WiFi credentials.
// Set password to "" for open networks.

char ssid[] = "iPhone"; //Enter Wifi User Name
char pass[] = "issac59515753"; //Enter Wifi Password


Servo servo;
Servo servo1;
Servo servo2;
Servo servo3;
Servo servo4;

BLYNK_WRITE(V3)
{
  servo.write(param.asInt());
}

BLYNK_WRITE(V0)
{
  servo1.write(param.asInt());
}

BLYNK_WRITE(V1)
{
  servo2.write(param.asInt());
}

BLYNK_WRITE(V2)
{
  servo3.write(param.asInt());
}
BLYNK_WRITE(V4)
{
  servo4.write(param.asInt());
}

void setup()
{
  // Debug console
  Serial.begin(9600);

  Blynk.begin(auth, ssid, pass);

|
  servo.attach(D0);
  servo1.attach(D1);
  servo2.attach(D2);
  servo3.attach(D3);
  servo4.attach(D4);
}

void loop()
{
  Blynk.run();
}
```

Fig. 6 : Coding for the NodeMCU ESP8266

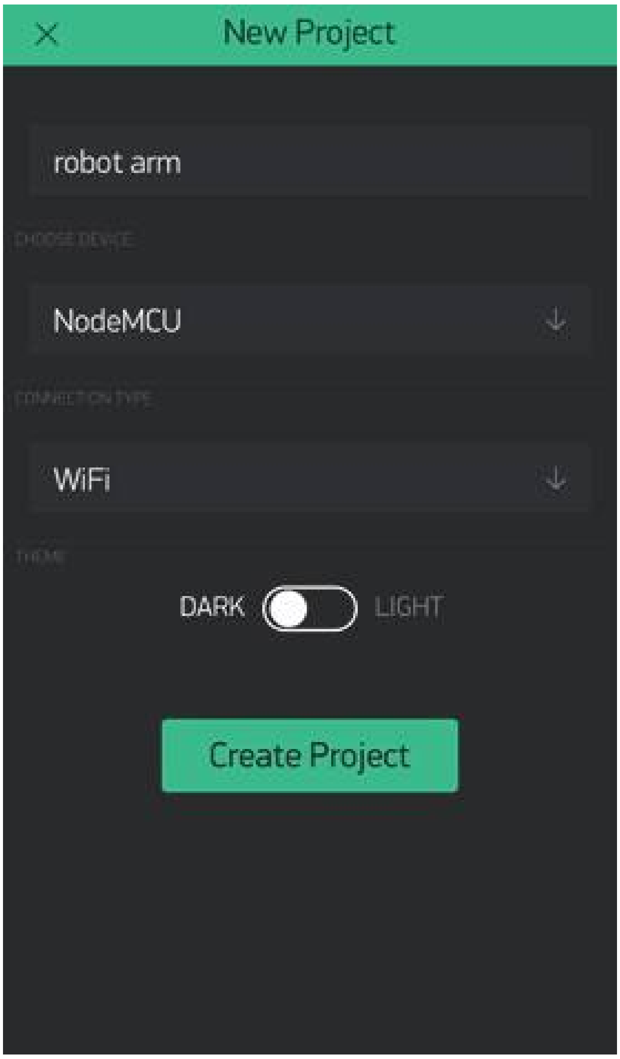

Fig. 7 : New project setting in Blynk application

The Blynk application is required to be set up to control the robotic arm. First of all, an authorization code (auth token) will be sent through email after signing up for the application. The token can then be directly copied into the codes as shown in Fig. 6. After logging in to the Blynk app, a new project was created and it is named as robot arm. In the "New Project" setting, the NodeMCU was selected as a device and the connection type is WIFI.

Besides that, an application is needed to be created in Blynk which will allow it to act as a controller for the robotic arm. Since the robotic arm is controlled by 5 servo motors, it is required to add 5 sliders in the controller. The slider settings are shown in the table below. The slider value is fine-tuned to achieve the desired angle and movement for the robotic arm.

Table 1 : The setting of the slider in Blynk

Slider name	Output	Slider value (angle)
Gripper	V0	0-180
Left/right	V1	0-180
Up/down	V2	30-150
Forward/reverse	V3	10-90
Gripper rotate	V4	0-180

The controls were then shared with other users using a QR code. The app provides 2000 Energy for new users which were used to "buy" the sliders for designing the controller and the sharing of the

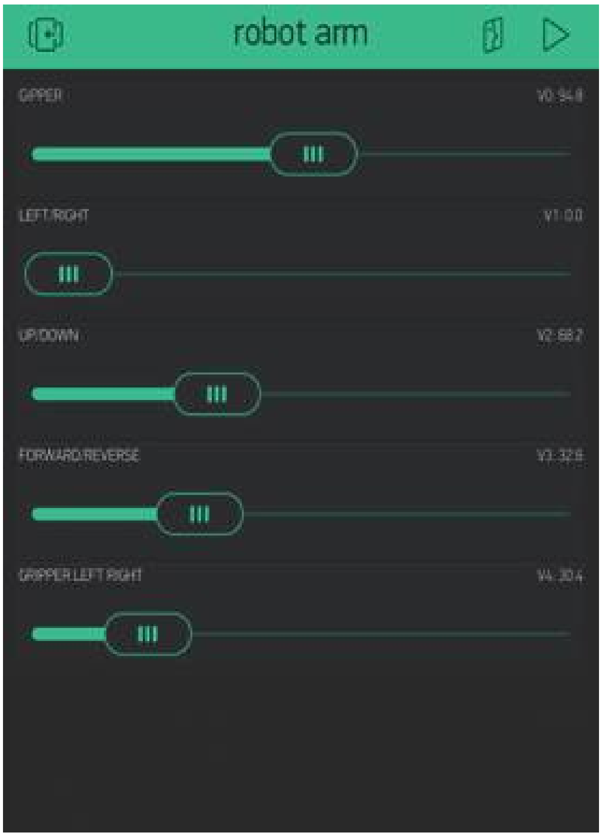

Fig. 8 : Robot arm control in Blynk

controller. Therefore, if extra Energy is needed to add more features, such as an emergency stop button, the user has to spend money to buy the Energy. This application was used since mobile phones are used in the IoT in the industry to access and control devices such as CCTV, August smart lock, SCADA apps which will give the students a better experience of how things run in the industry.

1) Webpage

In this project, the main purpose of the webpage is to monitor the robotic arm as well as provide a platform that consists of all the necessary information of the lab. This webpage allows the user to observe how the robot is moving and controlling the robot's operation through Blynk. The google site was chosen to be used as the website builder because:

- Easy to design and manipulate
- Able to achieve the requirements where the website will be used as the lab cover as well as the monitor while controlling the robot arm
- Able to restrict the users accessing the website based on the student email (no Log-in feature required)
- Admin can manage and analyze the website easily

The website developed has 3 main pages which include the Home page, the Labs page, and the Schedule page as shown in Fig. 9. The Home page is used to provide a brief idea for the user about the project therefore, it includes a simple introduction of the team, the topic given and the lab decided to be done. On top of that, the project objectives are also included on this page to give more details to the user regarding the project.

Fig. 9: Home page of the website

The lab page was used to list the available virtual and remote labs which in this case was Robotic Arm Remote Lab. Students would be able to check the availability using the Schedule page and they would have to make a booking with their respective lecturers or admin depending on the system of the school. After a student has booked a slot, the admin of the webpage would have to update the availability of the labs. It does not require much technical knowledge to change, manage and manipulate the content of the website. Thus, using Google Site significantly reduces the maintenance cost of the website and it is sustainable.

The most important page on the website is the subpage in the Labs page - Robotic Arm Remote Lab. Details of the labs such as the overview, user guide, and lab procedures are included on this page. After the student successfully books a slot, access will be given to the student. On top of that, the host of the controller needs to be online for the shared controller to be used. This also helps to make sure that the student can only access the controller during the given time slot and not any other period.

4) Animation

On the website, a demonstration of how the robotic remote lab should turn out was included when carrying out the lab experiment provided in the lab cover. The demonstration of the lab is an animation of the robot arm's movements when picking and placing the weights on a platform.

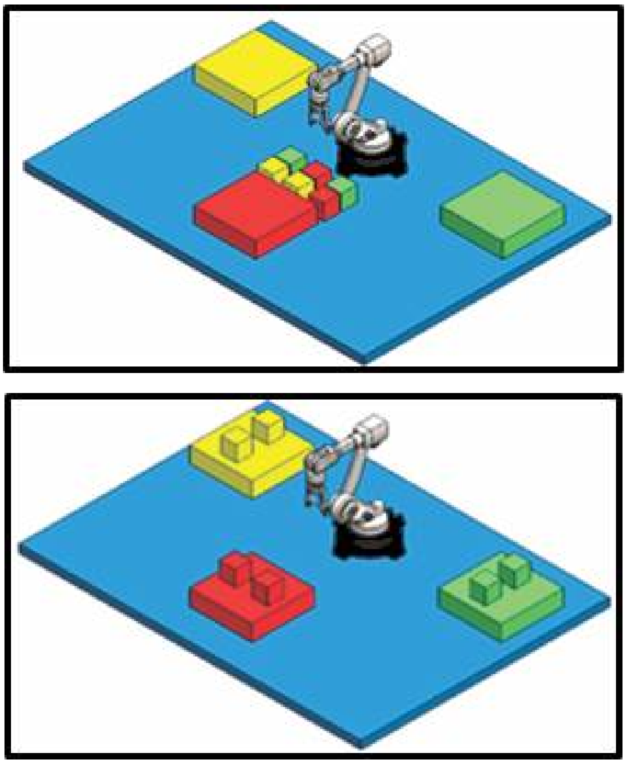

Fig. 10: Screenshot of the demo for lab (Exercise) at the beginning (top) and end (bottom)

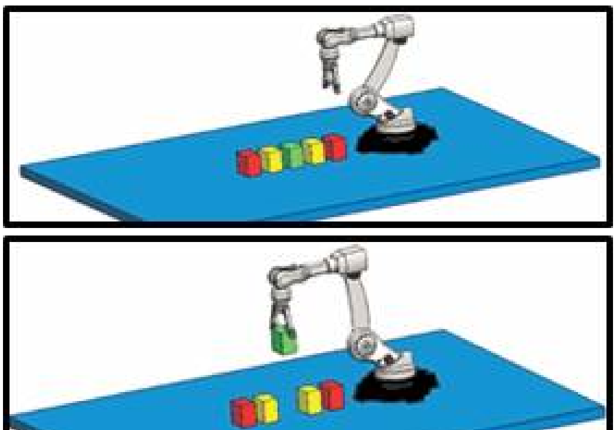

Fig. 11. Screenshot of a demo for lab (Part A) setup and picking up one of the weights

SOLIDWORKS is used to design and create the animation as it would be more conducive for the task to be completed. Each component was designed separately and then assembled accordingly to form the final design of the robot arm model. Once the full 3D drawing is completed, SOLIDWORKS is used to create the animation of the robotic arm showing its functionality in the virtual remote lab.

D. Overall Prototype

In this section, the presentations of the complete model and embodiments of the prototype will be shown including the assemblies and parts. The parts of the robotic arm are shown in Fig.12 which includes the acrylic parts, motors as well as bolts and nuts.

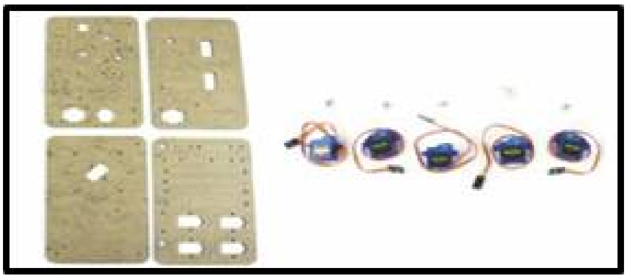

Fig. 12. Parts of the robotic arm

The parts of the robotic arm can be separated into three main sections which include the base of the robotic arm, the arm itself, and the gripper. Each part is assembled accordingly to the servo motors using the bolts and nuts. The overall final prototype of the robotic arm is shown in Fig.13.

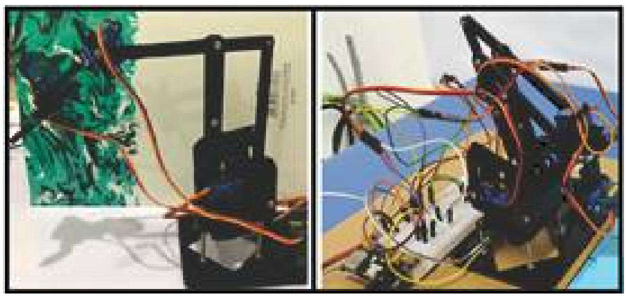

Fig. 13. The assembled robot body with the base (left) and the full assembly 5 DOF robotic arm along with the circuit (right)

4. Finding and Analysis

A. Robotic Arm

The initial plan was to use a 4DOF robotic arm but there were issues regarding the gripper and servo motors. This was solved by replacing the gripper and using a 5DOF robotic arm for the gripper.

During the testing process, there were times when a signal was given from Blynk, but the servo motor did not respond to it. This might be due to the internet connection causing the controller to be in an offline status, thus the signal provided to the microcontroller is unstable. The internet connection also affected the speed of the signal transfer. This means that when the latency was high, the lab was not performed smoothly.

The robotic arm seemed to vibrate even when no signals were being sent through Blynk. This vibration occurred due to the peak current of the power supply being unable to handle the large torque. Therefore, the power supply needed to be increased until it was sufficient to drive five servo motors.

Two capacitors with values of 2200μF and 220μF are inserted into the servo motors' connection. The capacitors were connected parallel with the power supply to servo motors. This is to solve the problem where the power is insufficient to support all five servo motors which result in the shaking of the robotic arm at certain angles. After inserting the capacitors, the current capacity is sufficient to supply five servo motors. The second improvement done to the robotic arm is using two gears to control the angle of the gripper to open and close. With gear control, the gripper can grip an object more efficiently since it can provide more angles.

Building a platform for the robotic arm allowed the user to perform their lab activity in a safer environment. The platform ensures that the user is controlling the robotic arm under the safety region while protecting the robotic arm because it avoids the robotic arm from going over to its maximum operation. It is similar to the safety line marking in the industry.

B. Camera

The initial setting for the camera shows lots of latency at the image which is quite normal for a low-cost IoT camera and if the internet connection is bad. From the reference found (ESP32-CAM Troubleshooting Guide: Most Common Problems Fixed, n.d.), some improvements have been made to reduce the latency of the image. The frame size of the image can be reduced to reduce file size. Using a standalone power supply can also improve the problem. Another method found which is quite useful is to upload the sketch (codes) into the camera again before using it. Overall, the setting of the camera can be changed to suit the condition.

C. Previous papers

Since there were no calculations and simulations involved while developing the prototype, the comparison with a pre-existing project which was similar to the prototype would be discussed and analyzed in this section.

Based on the previous paper found, the robotic arm was controlled using a Raspberry Pi microcontroller, and the programming language used is Python 2.7, JavaScript, and Node-RED (Ishak et al., 2018). The robotic arm is a 4 DOF robot and the joints that enable the movement of the robotic arm are represented by RC servo motors. The frame of the robot is made from lightweight aluminum. The 4 MG996R servo motors were used for the movement of the robotic arm as shown in the figure below.

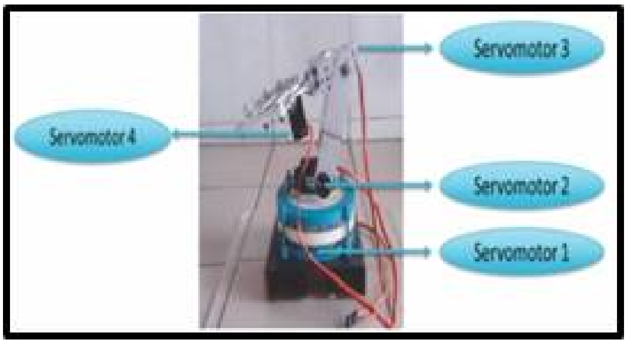

Fig. 14 : The robotic arm of the previous paper

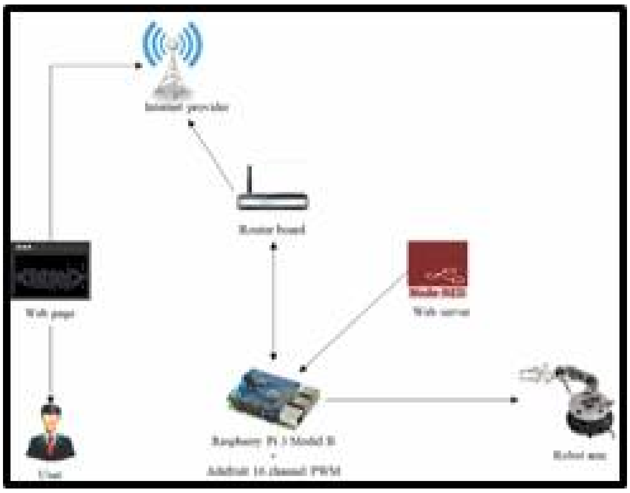

Fig. 15 : Block diagram of the robotic arm system design from a previous paper

The robotic arm system design requires the user to use an internet-connected computer to access the webserver using a Node-Red platform. The web server interacts with Raspberry Pi which is followed by a PWM servo motor drive to manipulate the robotic arm.

As a comparison, this robotic arm system from the previous paper is more expensive and has less degree of freedom compared to the existing prototype for Robotic Arm Remote Lab. Although the Robotic Arm Remote Lab was not able to pick up heavyweights, the objective of the lab was achieved. In addition, the Robotic Arm Remote Lab allows users to monitor the robotic arm from the web page and control the robotic arm from the Blynk application which is user-friendly and more interesting for the users.

To compare the pick and place operation, the model from the previous paper allows users to operate only by clicking on the button "Pick and Place" available on the websites as shown in the figure below. On the other hand, the system fixes the pick and place operation as shown hence not much can be manipulated. While the Robotic Arm Remote Lab requires the user to download the Blynk application and scan the QR code from the confirmation email then only he/she can control the robotic arm.

Fig. 16 : The web page from a previous paper

There is one similar problem that both projects faced which is the time delay through a network. The time delay problem that occurs in the Robotic Arm Remote Lab is when the camera displays the movement of the robotic arm on the web page where there is some latency shown. The previous paper faced the time delay issue on the angle of each joint display on the web page. Both projects use Internet Protocol (IP) to access the web page and camera therefore, the time delay issue can be due to the internet connection problem. With the introduction of 5G in more and more places, said the problem should not arise soon. A summary of the comparison can be seen in the table below.

Table 2 : Comparison of the prototype with pre-existing model

Factor	Robotic Arm Remote Lab	Previous Paper
Material	Acrylic plastic	Aluminum
DOF	5	4
Micro-processor	NodeMCU ESP8266 + ESP 32 cam	Raspberry Pi
Programming language	C programming	Python 2.7, JavaScript and Node-Red
Actuator	SG 90 servo motor	MG996R servo motor
Controller	Web page + *Blynk*	Web page
Angle rotate	0-180 degree	0-180 degree
Display	Camera display + Angle from *Blynk*	The angle of each joint display
Demo	Yes (Animation)	No
Problem	Time delay	Time delay

Overall, the current prototype is a low-cost prototype done for illustration purposes. Some of the possible future works are as below if there were no time and budget limit.

(a) Webpage

(b) Camera

(c) Robotic Arm

As mentioned earlier, the google site was chosen to be used due to its conveniences and ability to achieve all minimum requirements of the lab. However, if there were more time and budget given, a better webpage could be done to enhance the performance and provide better service for the users of the lab. For example, the current webpage does not have a login page since it is under the user can only access the webpage using the same domain as the school. However, if the webpage has a login page, it can then be used not only for the students from the same school but also for outsiders for research purposes.

On the other hand, the camera used for the current prototype is a low-cost camera with lesser complexity where the quality of the image is not very ideal where its highest resolution is 1600 x 1200 pixels. Some other common camera module such as the Raspberry Pi camera module has a resolution of up to 2592 x 1944 pixels but the price is also much higher as compared to the current camera module. Therefore, the appropriate module can be chosen based on the requirements and the budget given.

As for the robotic arm, a pre-existing model is used and modified due to the time frame given. For a better prototype, a robotic arm can be done from scratch to suit the requirements more. The angle of rotation, for example, can be increased as well as the DOF of the robotic arm. With that, the robotic arm would be able to perform the movement with higher complexity hence improving the overall performance of the lab.

5. Conclusion

The objective of this project was to design a virtual lab based on the title 'Robotic Automation Virtual Lab' and to achieve this, a Robotic Arm Remote Lab was created which focused on the learning outcomes of a subject available in the module, ECTE471 - Robotics and Flexible Automation.

After careful consideration, it was decided that the Blynk app meets the requirements and Google Sites was used to design the website. The website allows students to check the availability of the lab and provides the link to get video streams of the robot along with a demonstration of what is expected of them. Whereas the Blynk application is used to move the robotic arm according to the instructions provided in the lab while observing the change in the degree of movement. The website and the robotic arm are connected by a camera chip which was used to provide a live feed of the robotic arm, students can then perform their labs based on the tasks assigned to them.

As expected, certain issues were encountered during the assembly of the robot. The initial plan was to use a 4DOF robot instead of a 5DOF robot. However, the prototype did not respond to the various commands and the gripper was not reading any of the commands. Therefore, a servo motor was added and the gripper was replaced which solved the problem. There were issues regarding the camera module as well, mostly concerning the connections and these issues were resolved well ahead of time.

After putting together the camera chip and the robot it was observed that the robot sometimes does not read the inputs sent from the Blynk app. Upon inspection of the prototype, it was discovered that there were some connection issues. This issue could have occurred due to the slow internet connection leading to a slower rate at which data is transmitted. After which the prototype was able to pick and place objects and move freely as per the instructions provided to it, the students can see how a robotic arm is manipulated and they can do it themselves remotely which was the goal of the project. In addition, there were certain problems with regards to the ESP32 cam and its connection to the Arduino but they were all settled in due time. The robotic arm was able to maneuver according to the path decided by the user and this was observed from the website.

With that, this remote lab can align with IR 4.0 because it provides an option to transform the conventional way of experimenting from carrying out physical labs to allowing students to conduct experimental procedures online. This is done so by integrating some of the pillars of IR4.0 into the lab such as IoT, System Integration, and Autonomous Systems. Through remote access, students will have the opportunity to perform labs that used to be physically unreachable to them. Hence, engineering education can be improved as the distance is no longer a barrier.

Therefore, it is safe to assume that the project was successful as the aims and objectives of the project and lab were achieved. This is said so because the education system can be improved by implementing IR4.0 into the curriculum where this lab enhances the practical skills of students in adjusting a robotic arm to perform a particular task that can be done remotely. Although the best way of performing a lab is still through physical experimenting, remote labs provide an alternative solution to bring labs closer to students with the help of technology.

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