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Home Automation using ESP-32 Development Board with Alexa Voice Assistant and Manual Switch

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Abstract: This project focuses on the development of a home automation system in Malaysia, a country with a growing economy and advanced infrastructure. The system utilizes a NodeMCU microcontroller and Alexa voice recognition to control and monitor various appliances within a home. The idea of this project lies in the increasing adoption and development of home automation systems in Malaysia, offering homeowners the convenience of remotely controlling and monitoring their appliances through computer or smartphone interfaces. The developed system provides multiple control options to users. Firstly, it enables appliance control through voice commands via Alexa, allowing users to control their devices hands-free. Secondly, the system includes a virtual button on the Alexa application interface, offering users an alternative control method. Lastly, a manual switch is provided to control appliances when Alexa is in offline mode, ensuring uninterrupted functionality. To enhance user experience and accessibility, the system integrates with the Alexa Amazon application, which is available on both Android and iOS platforms. This cross-platform compatibility allows users to monitor their appliances regardless of their preferred mobile operating system. The implementation of the system involves a combination of hardware and software components, including the NodeMCU microcontroller, relay, user interface, and other necessary elements. By integrating with Alexa and utilizing voice commands as the primary means of communication, the system offers user-friendly and efficient interaction between users and their appliances. This project shows the feasibility and advantages of using an ESP32 with Alexa integration and a manual switch for home automation, therefore contributing to the advancement of smart homes in Malaysia.

Keywords: Home Automation System, NodeMCU, Alexa Amazon

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1. Introduction

1.1 Background Study

Home automation systems have witnessed substantial growth in recent years due to the increasing popularity of smart gadgets and the Internet of Things (IoT). As smart devices become increasingly affordable and accessible, homeowners are increasingly embracing home automation systems. Developed by Amazon and driven by Artificial Intelligence (AI), the Alexa device empowers users to control their devices and execute various tasks through voice commands. In the domain of home automation, Alexa serves as a voice-controlled interface for managing and automating a wide array of devices and accessories within a household. This functionality is achieved through the integration of hardware and software components. The hardware includes a microphone capable of accepting voice commands from different directions, while a built-in speaker provides audible responses. The software component consists of cloud-based services that store, manage, and process voice data, facilitating the interpretation of user commands. The application of Alexa extends to controlling household appliances connected to a microcontroller, which serves as a communication device. This communication device utilizes Wi-Fi connectivity, eliminating the need for complex wiring throughout the home and allowing for convenient installation and setup. Wi-Fi connectivity also enables a wide range of device connections, ensuring the operation of the home automation system from any location, as long as the system and the controlling phone are linked to the network, even across different networks.

Moreover, the Alexa application offers the capability to generate automated routines triggered by specific events, such as arriving home, leaving home, or retiring for the night. For instance, a routine can be established to deactivate lights and secure doors upon leaving the residence in the morning. In this project, four 9V bulbs representing standard home lighting and two 5V fans are employed as illustrations of household appliances. Furthermore, the system incorporates manual switches to facilitate manual control of household appliances in instances where internet connectivity is lost [1].

1.2 Problem Statement

A home automation system represents an automated device that enables the automatic control of household appliances. Its purpose is to mitigate electricity wastage resulting from human forgetfulness, such as neglecting to turn off home devices, which can lead to increased wear and tear on appliances. Ultimately, this can result in appliance damage, necessitating costly repairs or replacements.

The fourth industrial revolution has seen the integration of modern technologies such as the IoT, AI, and automation. Industry 4.0 embodies the use of these technologies to construct smart houses that can be remotely controlled and monitored via networked devices. In the absence of automation, homeowners who leave for extended periods of time would be burdened with manually controlling home equipment and systems.

Within the realm of energy management, tracking and restricting energy consumption can prove challenging, potentially straining appliances and causing damage. Automated systems facilitate energy management, reducing the risk of appliance damage [2]. Moreover, daily tasks can be arduous for individuals with disabilities or the elderly, such as adjusting lighting or thermostats. A home automation system significantly simplifies these tasks [3].

1.3 Objectives

There are several objectives in this project to be achieved which are:

a. To investigate the IoT control system using ESP32 Development Board with Alexa Voice Assistant that uses a residential electrical system.

b. To develop a portable house appliances control system based on IoT, manual switch and voice recognition.

c. To validate the system and ensure the project's performance.

1.4 Scope and Limitation

This project proposes developing and constructing a residential house appliances management system using IoT, Alexa device and manual switch. Therefore, the following is the scope project:

a. Using the ESP32 development board as this project's central processing unit, which can store coding for this hardware.

b. The platform of the IoT is based on the Amazon Alexa application used to monitor home appliances.

c. Another useful feature of this Alexa virtual button and voice assistant, which is good for the elderly.

d. This project comes with manual switches which can control home appliances manually without the internet.

e. The home appliance used in this project is four 9V bulbs as standard home lights and two 5V fans.

2. Materials and Methods

This section provides a comprehensive summary of the project's method and materials. All aspects of the work operations for each step will be covered in the data, including the block diagram, the software and hardware used, and a summary of the system flowchart.

2.1 Materials

The operation of a home automation system served as a basis for this project's design. As a result, the simulation of a home automation prototype was successfully developed. The relay used in this project acts as the main switch for household appliances, and the project's inputs include Alexa and manual switches. Alexa responds to voice commands to control several features on home appliances. Alexa also provides remote access capabilities which can use smartphone to control the home devices when away from home [4]. When the system is not connected to the internet and immediate control required, the manual switches can be helpful. The list of the components and software that used for this project are listed below:

Hardware:

- NodeMCU ESP32 DEVKIT V1
- 4 Channel 5 Volts Non-Latching Relay
- 2 Channel 5 Volts Non-Latching Relay
- DC 5V 2 Pin Fan
- DC 9V Light Bulb with Holder
- Blue LED
- 330-Ohm Resistor

Software:

- Alexa Amazon
- Arduino IDE
- AutoCAD

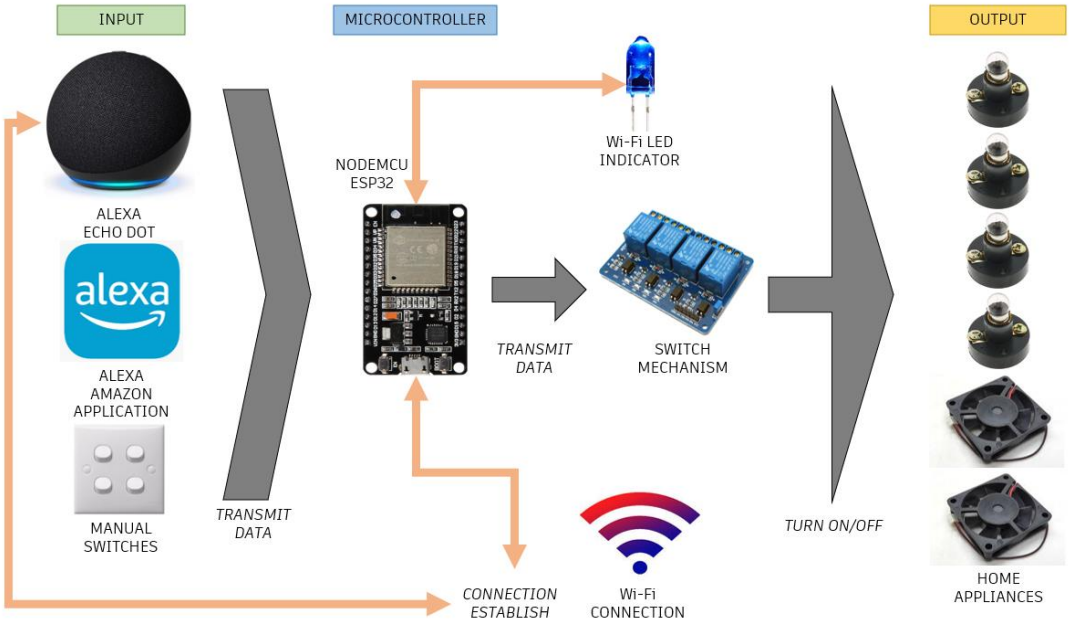

Figure 1: Block diagram of the system

The system depicted in Figure 1 is divided into three distinct sections, input, microcontroller serving as the central processing unit and output, which comprises the home appliances. The microcontroller acts as the brain of the system, responsible for analyzing all incoming data from the input sources. The IoT platform is one of the input sources, which includes a button and voice assistant provided by Alexa, as well as manual switches. These input sources transmit relevant signals to control the output section, which consists of household appliances. Notably, the relay assumes a vital role in this setup, functioning as an automatic switch that replaces conventional switches in the home when utilizing Alexa for control.

2.2 Methods

Figure 2 presents a system flowchart illustrating the control of home appliances through Alexa voice commands, switches from the Alexa Amazon application, and manual switches. The system initialization begins with the activation of the NodeMCU ESP32, which establishes a connection to a preconfigured Wi-Fi network. Subsequently, the NodeMCU establishes connectivity with the Alexa Application, accessible from any device equipped with the Alexa Amazon application, via the internet. This integration aligns the system with the Internet of Things (IoT) paradigm, characteristic of the fourth industrial revolution. The project incorporates two input channels, one from Alexa and another from the manual switch. Both inputs facilitate the control of home appliances.

Analogous to the truth table concept of an "OR gate," the manual switch and Alexa button exhibit three distinct conditions. Firstly, when the Alexa button is pressed while the manual switch button is in the off position, the device turns on. Conversely, in the second condition, when the manual switch button is pressed while the Alexa button is in the off position, the device also turns on. The third condition arises when both switches are turned on simultaneously, resulting in the activation of the device. However, if one switch is turned off while the other remains on, the load is deactivated, even if one switch remains in the on state.

Upon receiving the command signals from the Alexa button and the manual switch, the ESP32 microcontroller initiates the analysis of the data. Subsequently, the microcontroller transmits the resulting signal to the relay, which serves as the primary switch in this project. The relay functions as a replacement for the conventional switch in the household, providing easy control through direct smartphone interaction. Importantly, the normal switch in the house retains its regular functionality and can be used as usual alongside the relay-based control system.

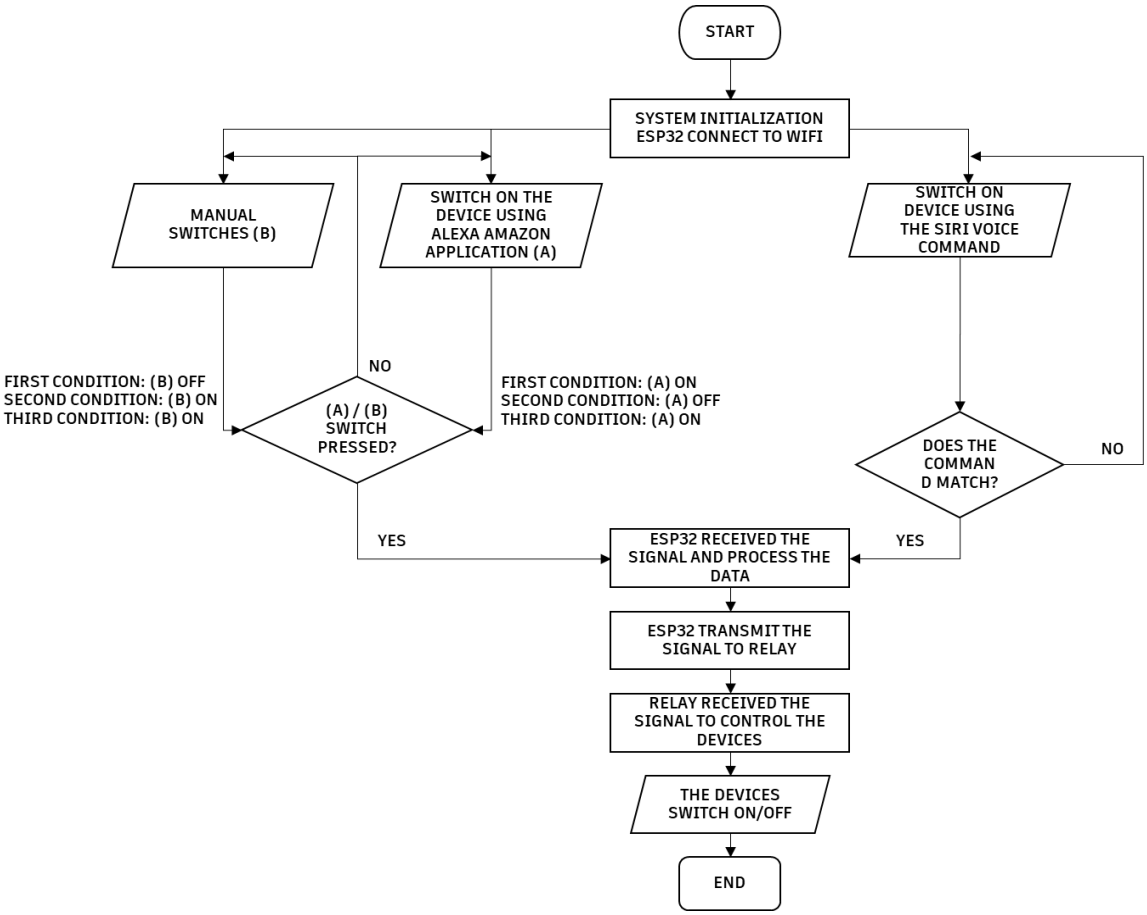

Figure 2: Flowchart of the control system

3. Results and Discussion

This section centers on the analysis and discussion of the findings derived from multiple experiments conducted to address the project's objectives. The primary aim of the project is to develop a system that empowers users to control household appliances through voice commands, while also allowing for manual control via switches when the system is offline or disconnected from the internet. The effectiveness of the Home Automation system utilizing ESP32 with Alexa and manual switches was assessed and discussed through a comprehensive examination of the obtained test results. The presentation of the findings encompasses the utilization of tables and graphs, facilitating easy comprehension and interpretation of the data.

3.1 Project Layout and Application

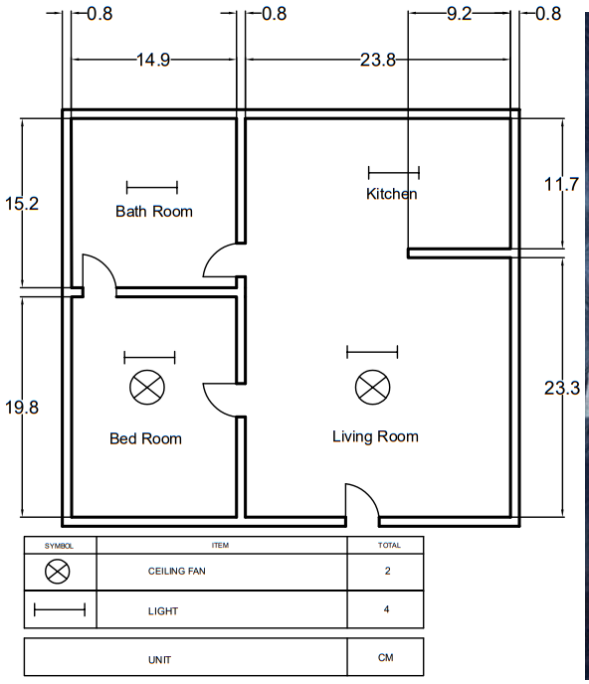

Figure 3: House Floor plan drawing

Figure 4: Hardware project design

Figure 3 illustrates drawings created using AutoCAD software, which includes precise measurements of the prototype's size. The measurements are denoted in centimeters. The legend accompanying the drawings represents various home electrical appliances, including four lights distributed across different areas, namely the living room, bedroom, bathroom, and kitchen. Additionally, two fans are positioned in the living room and the bedroom. It is important to note that each measurement provided is an approximation. Figure 4 shows a completed prototype home. The accompanying board has a circuit box that houses the entire project's circuit as well as a manual switch.

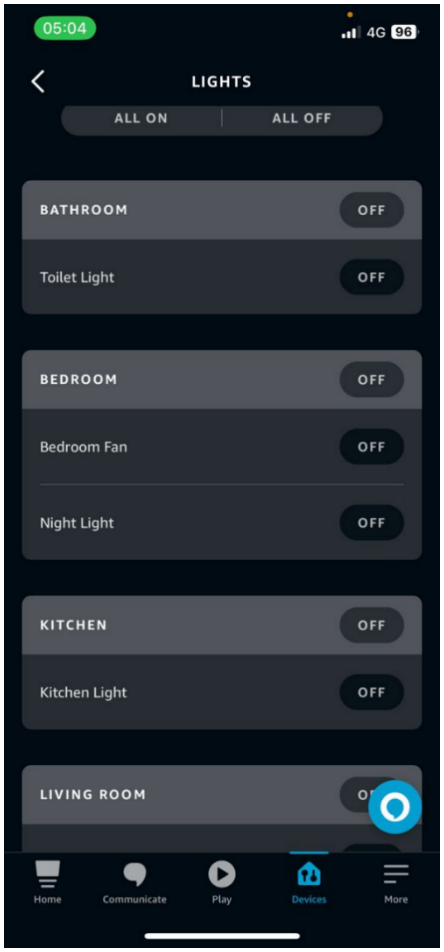

Figure 5: Alexa's virtual button interface

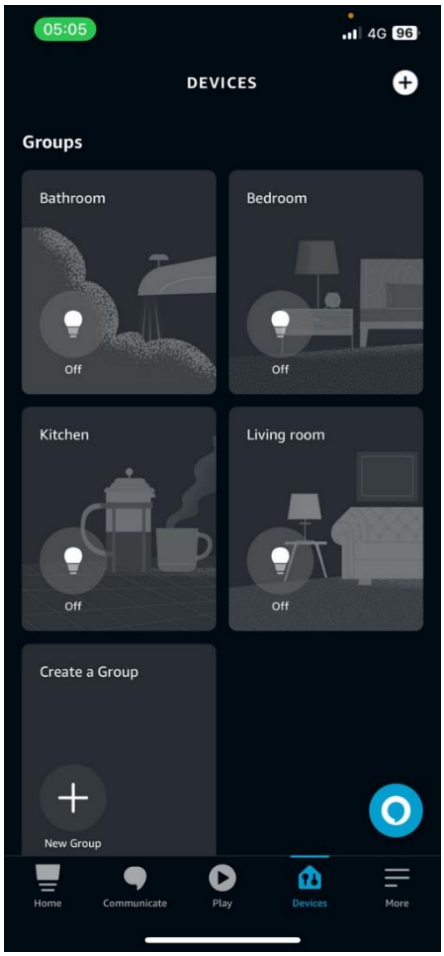

Figure 6: Alexa's group interface

Figure 5 presents the user interface of the Alexa Amazon application, which serves as the central control hub for the home automation system. Users can manage specific devices linked to the NodeMCU microcontroller through this interface. This comprehensive control enables users to manipulate each device according to their preferences and requirements. On the other hand, Figure 6 showcases the grouping functionality within the application. Groups allow users to control multiple loads simultaneously. For instance, if a group consists of two loads, activating the group command will simultaneously turn on both loads. This grouping feature provides users with enhanced convenience and efficiency in managing multiple devices within their home automation system.

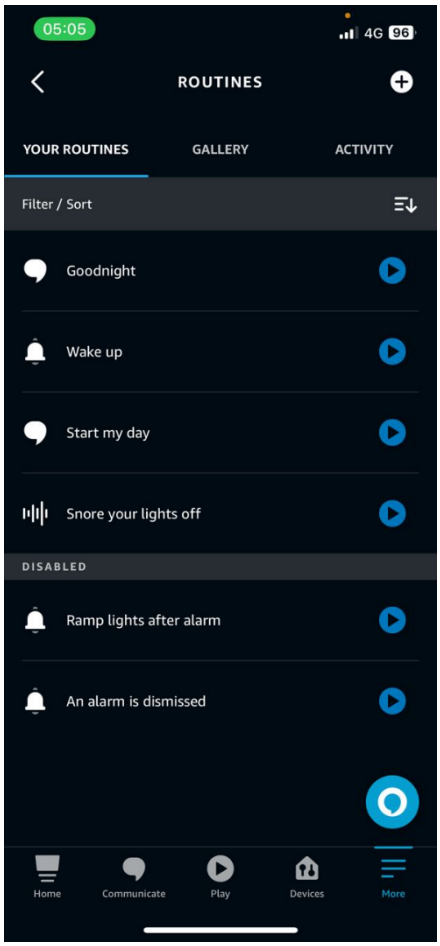

Figure 7: Alexa's routines interface

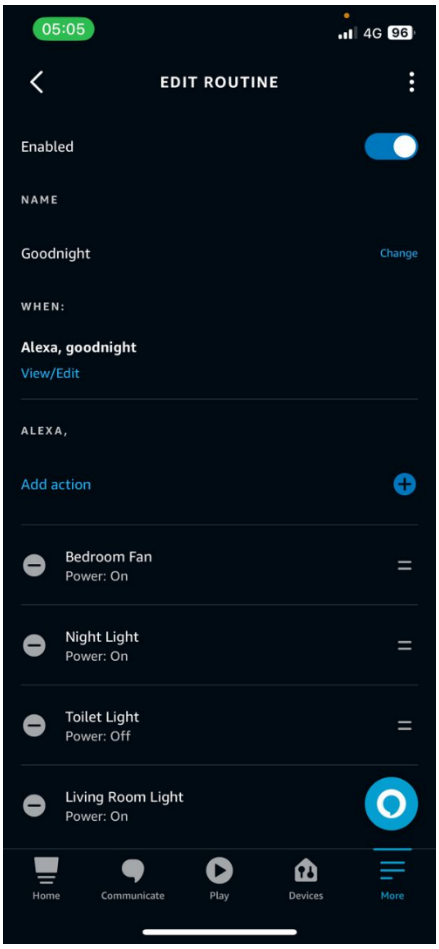

Figure 8: Alexa's routine set up interface

Figure 7 and Figure 8 depict the configuration of routines within the home automation system, based on specific user preferences. One such routine example is the "wake-up" routine, which consists of a series of automated commands. By setting the wake-up routine for 6 am, the system can initiate a sequence of actions such as activating the alarm, turning on the lights, and subsequently turning off the fan to ensure a peaceful waking up from sleep. The execution of these commands occurs sequentially according to the specific settings established by the user. These routines enhance user convenience and streamline daily tasks by automating a series of actions based on predetermined schedules or triggers.

3.2 System Process Flow

The concept of the OR gate proves to be highly relevant and suitable for this project, as it facilitates the integration of signals from manual switches and Alexa for controlling home appliances. The implementation of the OR gate within the system significantly enhances the functionality and versatility of the home automation project. By combining signals from multiple sources, such as manual switches and voice commands through Alexa, the OR gate enables a comprehensive control mechanism. This mechanism ensures that the appropriate actions are triggered to operate home appliances effectively. The incorporation of the OR gate concept within the project contributes to the convenience and seamless operation of the home automation system, as it facilitates a diverse range of control options by integrating signals from different input sources.

Table 1: The truth table of how the system works

Step	Alexa	Manual Switch	Output
0	0	0	0
1	1	0	1
2	0	1	1
3	1	1	1

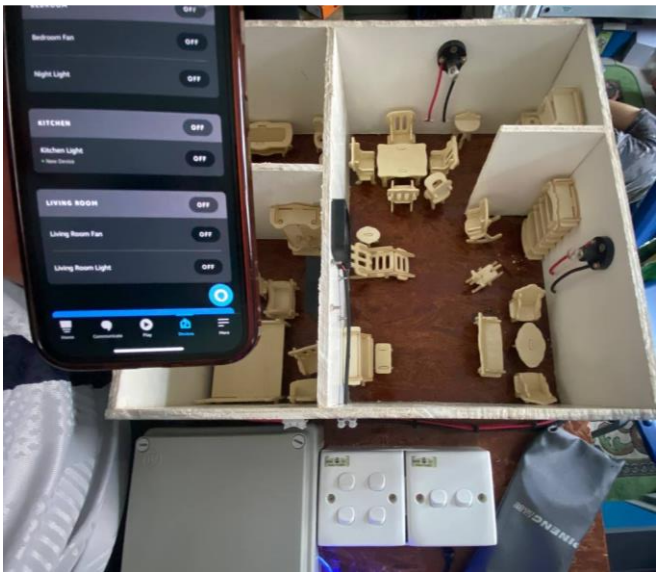

Figure 9: Example of step 0 from the truth table, both the manual switch and Alexa are set to off

Figure 9 exemplifies the initial step, denoted as step 0, as outlined in Table 1. In this scenario, both the manual switch and Alexa are set to the off position, resulting in the loads being in an off condition. This representation illustrates the starting point of the system, where both control inputs indicate the absence of a command to activate the loads.

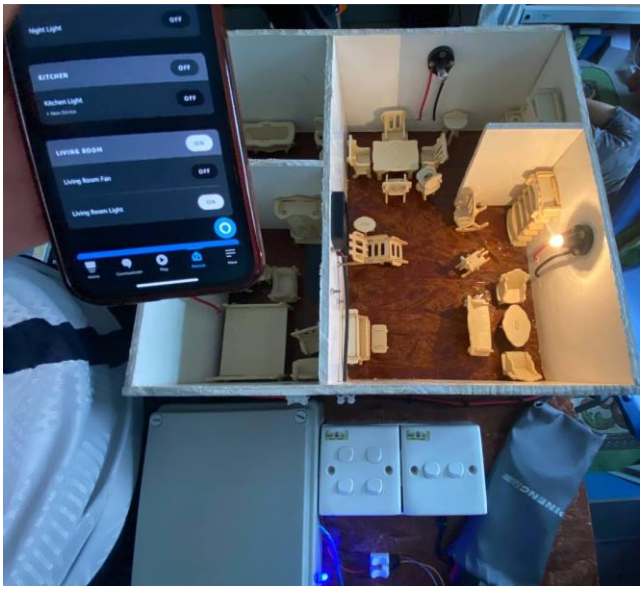

Figure 10: Alexa was switched on as an example of step 1 from the truth table while the manual switch was in the off position

Figure 10 demonstrates an example of step one, as indicated in Table 1, within the truth table framework. In this particular instance, the load is turned on despite the manual switch being in the off position. The activation of the load is attributed to the Alexa switch being switched on, which overrides the status of the manual switch. This shows the system's behavior, where the presence of a command from Alexa supersedes the manual switch status, resulting in the load being activated.

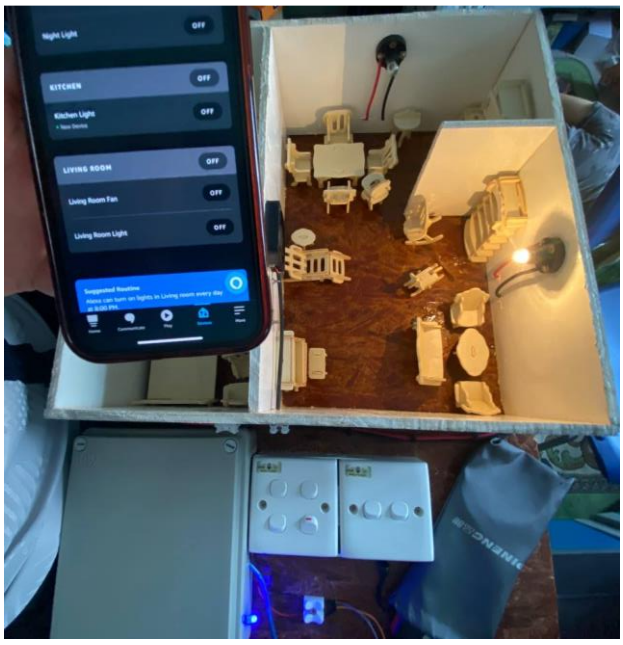

Figure 11: Manual switch was switched on as an example of step 2 from the truth table while the Alexa was in the off position

Figure 11 presents an instance where the light in the living room is turned on using the manual switch, while the Alexa switch remains in the off position. This scenario corresponds to step 2 in Table 1, reflecting the OR gate concept. In this situation, the manual switch's activation serves as the triggering factor, independently controlling the light regardless of the Alexa switch status. This aligns with the OR gate functionality, where a signal from any of the input sources in this case, the manual switch is sufficient to initiate the desired action, overriding the state of other inputs. Thus, the example in Figure 11 illustrates the effective application of the OR gate concept within the system.

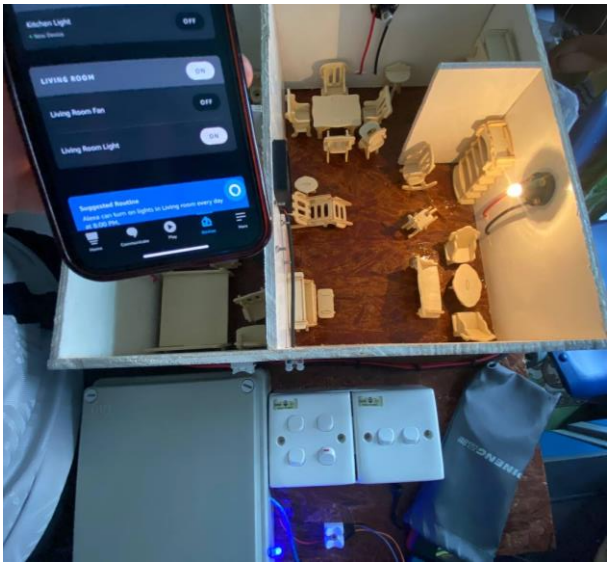

Figure 12: As step 3 of the truth table, the light is turned on and both the manual switch and Alexa are in the on position

Figure 12 corresponds to step 3, as described in Table 1, wherein both the manual switch and the Alexa switch are turned on. This configuration results in the load being in the on condition. The simultaneous activation of both input sources triggers the desired action, illustrating the combined effect of the manual switch and the Alexa switch. This representation aligns with the system's behavior, as outlined in the truth table, whereby the OR gate concept allows for the activation of the load when either or both input switches are in the on position. Consequently, Figure 12 serves as an illustrative example, showcasing the successful operation of the system when both the manual switch and the Alexa switch are engaged.

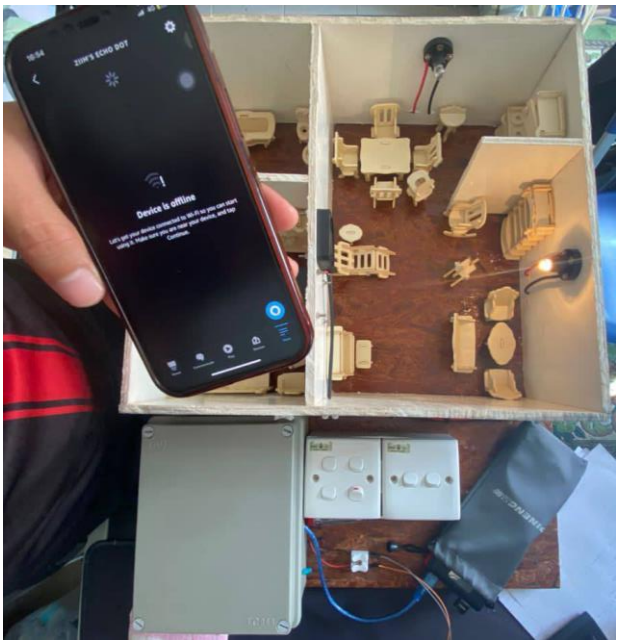

Figure 13: Example of controlling home appliances manually without internet

Figure 13 depicts the testing of the circuit utilizing a manual switch while operating in an offline mode. During the disconnection, the blue LED indicator is turned off, the lack of an internet connection and making the Alexa Amazon application inaccessible. In this state, the functionality of the system is restricted, and solely the manual switches can be utilized to operate the home devices. The testing procedure demonstrates the system's capability to function independently using manual control in the absence of an internet connection, ensuring continued operation and control over the home appliances until network connectivity is restored.

3.3 Data Analysis

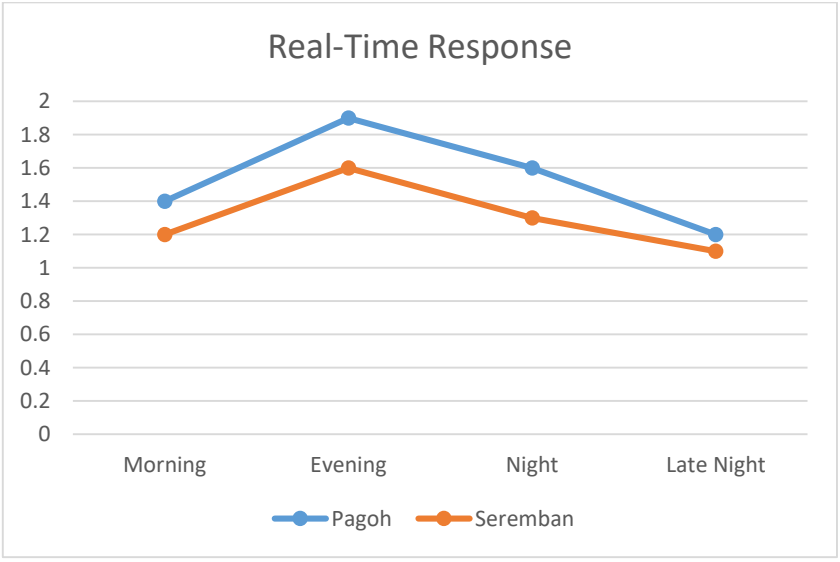

Figure 14: Graph of Alexa's time response to the voice commands

Table 2: The time response of Alexa in four times

TIME	PAGOH (s)	SEREMBAN (s)
Morning	1.4	1.2
Evening	1.9	1.6
Night	1.6	1.3
Late Night	1.2	1.1

Figure 14 illustrates a graph showing how Alexa responds to user commands coming from Pagoh and Seremban, two different locations. The test is conducted four times, in the morning, evening, night and midnight. The network coverage in these two locations is different. Since Seremban is a main city with better network connectivity than Pagoh, Alexa's real-time response at Seremban is greater than Pagoh's while using the same hotspot from the same mobile phone. However, it is also dependent on a variety of different factors such as network connectivity, server load, and how complex the command is. In this test, only the simple command to switch on the living room light is used. The highest available signal at Pagoh is 4G with two or three bars, whereas the best signal in Seremban is 5G with a full bar.

Based on Table 2, response times are often faster in the morning since there is generally less network traffic. Due to the increased user activity during the evening hours, the response time is a little bit longer than it is during the morning and night. Due to the lower network traffic and time response that is nearly similar to the morning, the time response decreases from evening to night. In the late night, when people are sleeping and there is the least amount of activity, responses are performed more quickly. It's vital to keep in mind that this reaction may change depending on uncontrollable circumstances. Additionally, improvements in reaction times over time could be brought about by infrastructure and technological developments.

4. Conclusion

In conclusion, home automation and Alexa voice assistants can greatly enhance the convenience, security, and comfort of a home. It also can be particularly beneficial for handicapped or elderly individuals allowing them to control various systems in the home remotely and increasing their independence and safety. With the integration of home automation systems and virtual assistants, users can control various aspects of home devices with just their voice, making it more convenient and user-friendly. Additionally, automating the appliances and systems in the house can prevent damage and prolong the life of the appliances. One of the ways to implement a home automation system is by using ESP32, a low cost, low power microcontroller that is well suited for IoT applications and can be programmed using the Arduino programming language and others. ESP32-based IoT control systems are easy to interface with other devices, including sensors and actuators, using the available input and output pins, and can communicate with other devices in the home and with IoT platforms to allow for remote monitoring and control. Before making a choice, it's important to analyze the possible advantages and disadvantages of a home automation system and consider the specific needs and preferences of the household.

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