

Design and Implementation of an IOT-Based Voice-Controlled Home Automation System Using Esp8266 And Alexa

**Alhassan Abdullahi Ndasheshi,
Mohammed Aliyu Abdullahi,
&**

Mohammed Ahmed Abubakar.
Department of Computer Engineering,
School of Industrial Engineering,
College of Engineering,
Kaduna Polytechnic, Kaduna-Nigeria

ABSTRACT

The increasing demand for energy-efficient and remotely accessible home automation systems has led to the advancement of IoT-based smart home solutions. This paper presents a smart home automation system capable of remotely automating appliance operations and making autonomous decisions. The aim of the work is to deal with the problem associated with the challenges elderly and physically challenged individuals are facing while struggling with manual tasks for adjusting lights or appliances. The circuit is designed in such a way that the system can turn ON and OFF the appliances from any location as long as network signal is available at both ends. ESP8266 NodeMCU is incorporated in the circuit. The ESP8266 is to control the relay module to switch ON/OFF the bulbs and fan. A relay module interface board is also incorporated to allow us to control various appliances in homes. In this work, the relay module used is a 4-channel relay in a single module, each of the relays powers one appliance. Results obtained from the tests conducted with the prototype in my office and users at Institution administrative block, Library, and HND-1 and HND-2 Classes of the Department of Computer Engineering Kaduna Polytechnic, Kaduna show that appliances can be controlled from any location as long as network signal is available at both ends, while

results with the prototype placed outside the network coverage show that the system is in-active.

Index Terms: Home Automation, System, Alexa, Application, NodeMCU

1.0 INTRODUCTION

In today's era of technological advancements, the concept of smart homes has gained immense popularity. The evolution of smart home technologies in recent years has helped move homes from being conventional to being smart internet connected homes. A house that has technologies like wireless and wired networks, intelligent system and actuators are known as "Smart home" (Stojkoska & Trivodaliev, 2017). A smart home (SH) is an environment where heterogeneous and electronic devices are connected together to deliver smart services to individuals. A smart home (SH) is also the integration of technology that enables users to achieve a better quality of living. An SH is a voice assistant for the remote control of all home appliances. It helps to improve comfort, convenience, and energy management. An SH aids elderly and disabled people by providing them a safe and secure environment. SH

automation systems have gradually become all-purpose portable controllers that provide convenience to people in their daily routines (Waheb et al., 2017). Smart home appliances are internet-connected devices that can be monitored and controlled remotely via mobile apps or voice assistants. They boost energy efficiency and improve home security by allowing automation like turning off forgotten appliances or syncing with off-peak energy rates. The main part of the home automation system based on IoT is the microcontroller. A node microcontroller unit (NodeMCU) Wi-Fi-based controller board is used as a microcontroller. The NodeMCU is an open source platform for IoT applications and is used as the main microcontroller in this work. This node microcontroller unit receives commands given by users via smartphones to perform specific tasks (Mattoo and Kumar, 2019).

Smart home automation refers to the use of technology to control and automate various functions in a home, such as lighting, heating, air conditioning, and security (Vyawhare et al., 2023). Smart home automation systems are becoming popular in recent years as the rapid development in the Internet of things (IoT) technologies makes interconnections and remote control of appliances much easier. They enable users to conveniently control and monitor their home appliances. In addition, they enhance efficient energy use and minimize energy losses (Muhammad et al., 2023). At present, majority of homes have some of the “smartness” because various devices have built-in sensors or electronic appliance controllers (Christantonis, 2019). Devices within an SH system can be linked with one another and reached through an access point (AP) to monitor home conditions and control home appliances (Popli et al., 2019). For instance, lights, thermostats, TVs, door locks, cameras, washing machines, and refrigerators can be

monitored and controlled via an all-in-one SH automation system. Such a system becomes an IoT-based automation system when it is provided with access to the Internet (Woodford, 2018).

The smart home appliances follow the working principle of automation. The system uses electronic devices to control and operate the complete working process in order to reduce the involvement of human to the minimum level (Cho, 2025). Home automation using NodeMCU8266 is a modern and innovative project that utilizes the latest advancements in technology to enable the remote control of various home appliances and devices through the internet. The NodeMCU8266 is a highly capable and popular Wi-Fi-enabled microcontroller unit, which enables seamless communication between the user and the connected appliances. Voice control has become increasingly popular in recent years due to its ease of use and convenience. Home automation is implemented in many ways but using voice module is the latest Technology. With voice commands, users can easily turn on/off lights, fans, air conditioners, and other appliances from the comfort of their couch, bed, or even while they're away from home (Bhaskar et al., 2023).

The trend of smart homes is rapidly expanding with the advancement of technology and the Internet of Things (IoT). A smart home (SH) is an Internet of Things (IoT) application that allows users to control and monitor home appliances in real time over the Internet. An intelligent home automation system provides an easy and convenient way to control and monitor various devices and appliances within the household (Lucerol et al., 2025). In the modern world, smart devices, such as smartphones, smart televisions (TVs), smart washing machines, smart refrigerators, and smart sensors, have become

involved in every aspect of people's daily lives (Waheb et al., 2017). Such smart devices are capable of communicating and interacting with one another to form a smart environment (Jabbar et al., 2018). With the widespread introduction of electricity into homes and the rapid advancement of information technology, a new era of controlling home appliances has started by using mobile devices with short-range communication interfaces, such as Bluetooth and ZigBee (Varghese et al., 2019), and by Wi-Fi networks and GSM modules (Anandhavalli et al., 2015).

As the system is an IoT-Based, the Internet of Things (IoT) is a system that allows devices to be connected and remotely monitored across the Internet. In the last years, the IoT concept has had a strong evolution, being currently used in various domains such as smart homes, telemedicine, industrial environments, etc. (Cristina et al., 2021). Internet-of-things (IoT) is the most trending and important topic in recent times. The concept of IoT makes it possible for devices to communicate with each other and share resources while using the Internet as a wireless medium. The Internet of Things (IoT) is revolutionizing several industries by allowing physical devices to be connected to the digital world. As reported by Nagayo et al. (2024), in healthcare, IoT enables smart medical devices, remote patient monitoring, and real-time health data collection. This enhances patient care and increases operational efficiency. In agriculture (Muthmainnah et al., 2024; Maslan et al., 2025), IoT supports precision farming through smart sensors that track soil moisture, weather, and crop health. This helps farmers use resources more efficiently and boosts productivity. IoT enhances wireless communication (Katariya et al., 2024) by enabling fast and seamless data exchange between devices through advanced networks like 5G. This technology supports smart cities and industrial

automation. The IoT is impacting many aspects of daily living.

Leveraging the Internet of Things (IoT) technology, various household devices such as lights, thermostats, and security systems are interconnected and controllable through voice commands facilitated by Alexa. Smart devices equipped with IoT capabilities are interconnected via a local network or cloud platform, enabling seamless communication and data exchange. The integration with Alexa added a layer of intelligence, allowing users to interact with their smart home ecosystem effortlessly using natural language commands (Seetharamudu et al., 2024). The findings of this research contribute to the growing field of IoT-based smart home systems, offering a practical solution for enhancing home safety, energy efficiency, and automation. The cornerstone of Alexa Assistant-controlled home automation lies in the concept of the Internet of Things (IoT). IoT facilitates the interconnection of various objects, such as smartphones, personal computers, and tablets, with the internet. This connectivity fosters novel forms of communication between objects themselves as well as between objects and individuals.

In the context of Internet of Things (IoT) and Machine-to-Machine (M2M) communications, home automation systems can be controlled and monitored remotely through a network connection. One of the key benefits of IoT-enabled home automation is the ability to control and monitor a wide range of devices and systems from a single, centralized location, such as a smartphone or tablet. Another advantage of IoT-enabled home automation is the ability to remotely monitor and control devices, even when one is away from home. This can be useful for controlling energy consumption and ensuring the safety and security of the home. (Vyawahare et al., 2023). With the IoT technology, the "smart

home," also known as "house automation," aims to make domestic tasks more convenient, safe, and cost-effective (Muhammad et al., 2023). According to the World Economic Forum's State of the Connected World 2020 report, IoT is playing a vital role in enabling smart homes, which are becoming increasingly popular as more people adopt digital technologies to automate and control their home environments. The report highlights that the global IoT market is projected to grow at a compound annual growth rate (CAGR) of 26.9% between 2020 and 2025, driven by the widespread adoption of smart home devices and other IoT applications (Lucerol et al., 2025).

Generally, IoT is a relatively new development, which enables existing homes to have strong computing and communication capabilities with the rapid development of the Internet and communication technologies. IoT can be utilized to improve the existing home automation systems by introducing a main control over the Internet. IoT can create new innovation concepts that can be used for the development of SHs to provide intelligence, comfort, safety, and better quality of life (Waheb et al., 2017). Therefore, these systems (SHs) improve convenience, save energy, and offer a better quality of life (Mohiuddin et al., 2026). As said before, this study presents the design, implementation, and validation of an IoT-based portable automation system called IoT-Based Voice-Controlled Home Automation System for SHs. It enables IoT automation and monitoring of SHs by using NodeMCU as microcontroller and Internet gateway.

In a nutshell, home automation systems include main components which are: (1) User interface: a device that can receive commands to control a system, such as a phone, computer, or display. (2) Transmission method: wireless, such as radio waves, infrared, Bluetooth or GSM. (3)

Central Controller: It is a hardware interface that sends the control signals and communicates with the user interface. The system determines how Internet-of-things (IoT) is applied in smart home products and the employment in our home in order to comprehend how it can be used for developing smart homes. Smart homes consist of intelligent interactions that become more popular over the time. The inter-relation between the Literature, products, and the development of IoT-enabled smart homes are all examples of the technology. The scope of the study is the application of Internet-of-things (IoT) system in the home appliances for the building and development of smart homes with many productive features like efficiency in energy, minimum in wastage, less human intervention, enabling easy operation, control and management. Currently, the home automation market worth 52.65 billion USD. By 2029, it is expected to grow to 66.45 billion USD (Mohiuddin et al., 2026).

The rest of the paper is structured as follows. Section 2 discusses the related works, while section 3 provides design methodology. Testing is explained in section 4. Section 5 discusses the experimental results. Section 6 provides the conclusion. Finally, section 7 highlights the potential future improvements.

1.1 Rationale of the Study

Home automation is a new technology that allows a house to perform some tasks automatically. It is becoming increasingly popular, not only for the sake of enhancing home conditions but also within business and industrial setups. The technology is always in motion, becoming more interactive by adding newer features to support greater needs from users. Home automation installation does not need very

complex procedures. It begins with the identification of the automation need. For example, if the primary need is the enhancement of home security, all the parts needed will be selected and outlined before the system is automated. Similarly, if high-energy lighting systems are installed, home automation can be employed to conserve unnecessary energy usage, resulting in enhanced comfort, security, and efficiency. Home automation is advancing very rapidly, with its use growing in different industries. The project herein is on automating a home setup. Therefore, its rapid growth, popularity, and high demand motivated the work.

1.2 Statement of Problem

The traditional home automation systems lack seamless control and interactivity. This solution addresses this limitation by implementing voice control through IoT technology, enhancing convenience and efficiency for homeowners. Engineering is all about finding solutions to a problem and making life easier and more comfortable for human living. This project is centered towards wired or wireless systems, while in the house not very likely to face many problems. However, when controlling through the application locally or remotely, we can face problems such as delays in performance. Delays can be due to poor internet connectivity and planning in the house. Hence a way of minimizing this problem is considered.

1.3 Limitations

The system implemented in this work does not automatically detect faults in the appliances it controls. All appliances connected to the system are assumed to be in a perfect working condition. Appliances which are defective will not respond

correctly to the specifications of the system design. In the case where an electrical appliance is defective, such will appear to be in an OFF state even if an ON command is sent to it.

2.0 RELATED WORKS

In this section, we will present the various systems available in the market and the recent advancements in the research working in this area. Most of the state-of-the-art systems today can be integrated with IFTTT recipes (Sneha & Ravindra, 2018). To give some context to the reader, IFTTT is the acronym of If This, Then That. It is an initiative in the Internet of Things space where several services can be integrated to provide a robust solution. In existing products, the smart home space has seen a lot of industrial investments in the recent years. The following are some of the successful smart home products available today:

Cho, (2025) designed and implemented a smart home appliances that work on the principle of artificial intelligence system. In his work, it is determined how artificial intelligence is applied in smart home products and the employment in our homes in order to comprehend how it can be used for developing smart homes. His research also reveals a gap between books and products. He states that smart homes consist of intelligent interactions that become more popular over the time. The inter-relation between the Literature, products, and the development of AI-enabled smart homes are all examples of the technology. The scope of the study is the application of artificial intelligence system in the home appliances for the building and development of smart homes with many productive features like efficiency in energy, minimum in wastage, less

human intervention, enabling easy operation, control and management.

Anandhavalli et al. (2015) designed and implemented an SH automation control using Bluetooth and GSM module. The objective of this study is to help handicapped and elderly people to control home appliances from remote places. They use Bluetooth and GSM wireless communications to control the home. Bluetooth is used to control the appliances indoor and GSM to control the appliances outdoor. Bluetooth can reduce system costs because most cellphones and laptops have this built-in application. Users can monitor and control the appliances from remote places by sending SMS through GSM. However, such a system has limitations in two cases. Bluetooth has a limited range and data rate, and GSM is expensive because of SMS costs.

David et al. (2015) developed a home automation and environmental monitoring system using Arduino Mega 2560 microcontroller with Bluetooth module. Several sensors and switches are used to control home appliances through websites or Android applications. The website controls Arduino by passing information to it as codes. The drawbacks of this system are: arduino Mega is more expensive than NodeMCU, and the use of Bluetooth is unsuitable for SH applications due to its limited features.

Davidovic and Labus (2015) developed an SH automation based on sensor technology that can automatically control home appliances using Android-based smartphones as a remote controller. The authors utilize Raspberry Pi as the microcontroller and Bluetooth as the communication protocol. Wi-Fi is used to connect the smartphone to the Raspberry Pi controller, which is connected to smart appliances to the same network AP. All sensors update their data to

a local server via Raspberry Pi. However, the user cannot access the server and cannot directly use the smartphone to send the commands to the Raspberry Pi controller when he is outside the range of Wi-Fi AP.'

Jabbar et al. (2018) designed and implemented a Wi-Fi-based home automation system. The developed prototype allows users to control and monitor the home through Wi-Fi by using Arduino Mega integrated with Android-based application known as Virtuino. However, the prototype has limited connectivity; it can only perform local control, the remote control of the developed system will be enabled based on IoT to allow users to control it using a webserver even when they are not around their house. The prototype also lacks automation of windows and doors and does not consider the safety and security of SH.

Ganesh (2017) presented a GSM-based design control system of SH. This work suggests a system that enables users to monitor and control smart devices through the Internet, where the users give commands through the web, and the users input is converted to GSM-SMS commands. The proposed system creates an interface between the SH and users through the Internet and GSM and provides a GSM-based wireless connection from the web server to the SH. These commands are sent to the integrated system module, which is placed anywhere in the world and can be directly connected to the devices through GSM network. In addition, the module is controlled through an IoT agent by the GSM network. The user commands are executed and analyzed using a microcontroller to control any electronic objects, such as lights and other home appliances, and send an acknowledgment. The prototype collects and transmits data through GSM-SMS. The initial test proves that the prototype is capable of

monitoring and controlling home appliances. It also has many other advantages, such as zero data loss, rapid delivery, ease of use, and energy efficiency.

Melvin and Mununga (2025) presented a smart home automation system using Wi-Fi to support remote control and monitoring of home appliances via an Android application. The system is constructed on the basis of an Arduino UNO microcontroller equipped with a Wi-Fi module. In addition, several sensors are implemented to sense temperature, humidity, and motion inside the residence. Their aim is achieved by design and construction of a Wi-Fi-based Automation System for Smart Home prototype using Arduino microcontroller and Android-Based smartphone. The automation system is interfaced with home appliances with the help of a relay board. The proposed architecture facilitates optimal and easy control of electrical and electronic appliances with the help of Wi-Fi and a virtual mobile interface.

2.1 Limitations of the existing HAS

A modern home automation system should address critical challenges, including energy wastage and the requirement for remote accessibility. Most current home automation systems are not flexible, energy-efficient, or affordable, making them less accessible. Furthermore, traditional systems depend on manual controls or fixed schedules and cannot adjust to changes in the environment or user habits. The goal of this system is to identify the key limitations in current approaches and highlight the novel contributions of our proposed system in comparison. To address these issues and minimize the limitations of home automation systems, the present study proposes a cost effective and hybrid

(local and remote) IoT-based home automation system to allow users to control their homes easily and efficiently via a user-friendly interface using a smartphone. The system cost is considered by using NodeMCU and Alexa mobile app to monitor and control home appliances over the Internet.

In this study, NodeMCU is selected for the SH automation system because of its capabilities and cost effectiveness. The NodeMCU8266 is a small, low-cost device that is easy to program and integrate seamlessly with Wi-Fi networks. One of the key advantages of home automation using NodeMCU8266 is the flexibility it offers. The user can easily configure and program the microcontroller to control a variety of devices and appliances, which makes it an ideal solution for smart homes. Because of its low cost, the NodeMCU8266 is an affordable option for those looking to automate their homes. The NodeMCU can be easily controlled by the computer and smartphone through the Internet. In addition, the NodeMCU facilitates editing and uploading the codes using Arduino IDE whenever necessary with the micro USB port still in place. Its built-in Wi-Fi connectivity allows it to connect to the internet and communicate with other devices, while its low cost makes it an affordable option for a wide range of users. By programming the NodeMCU8266 using the Arduino IDE, users can customize the functionality of the microcontroller to control a variety of devices and appliances in their homes. There are numerous IoT-ready embedded systems, microcontrollers, and devices available in the market today that are cost-effective and highly capable. Among these, the ESP8266 stands out for its affordability, versatility, and compatibility with a wide range of actuators. ESP8266 board is cheaper than other microcontrollers, such as Raspberry Pi and Arduino UNO. This makes it an ideal choice for anyone looking to create a smart home.

The research reviews that one of the main issues in most existing HAS is their implementation and maintenance cost which is not affordable for most users. This system is a new system which overcomes the limitations of the existing home automation systems. By addressing critical research gaps, this system provides a practical alternative for modern home automation. This has been achieved by design and implementation of a low cost and user-friendly Wi-Fi based Automation System for Smart Home prototype using ESP8266 and Android Based smartphone. The system is developed to control all the electrical appliances at home easily and efficiently and enable the remote control by supporting the IoT concept. Additionally, Home automation is implemented in many ways but using voice module is the latest Technology. Voice control has become increasingly popular in recent years due to its ease of use and convenience. With this project, the user can easily operate their home appliances through simple voice commands. With voice commands, users can easily turn on/off lights, fans, air conditioners, and other appliances from the comfort of their couch, bed, or even while they're away from home, making it an ideal solution for people with disabilities or those who have difficulty using traditional switches and controls.

2.2 Research Contributions

The main contribution of this study is the development of an efficient, low cost, and portable IoT-Based Voice-Controlled Home Automation system to comfortably control and monitor home appliances over the Internet. To fulfill these requirements, this study adopts the following objectives and contributions:

- (i) Design and implementation of an SH prototype that facilitates the

monitoring and control of home appliances using an IoT platform and supports home safety by utilizing NodeMCU as a gateway to connect the system to the Internet.

- (ii) An algorithm for smart home monitoring and automation based on IoT.
- (iii) Implementation of an innovative portable IoT add on automation controller (IoT-Based Voice-Controlled Home Automation system) as a box that can be attached for monitoring and controlling a real home appliances.
- (iv) Validation of IoT-Based Voice-Controlled Home Automation system functionalities in terms of automation, safety and evaluation of the performance of the developed system.
- (v) Design and implementation of a user-friendly and intuitive control system.

3.0 METHODOLOGY

3.1 Introduction

This section gives the details of methodology with regard to system design and each major component used in this project with reference to system design requirements, types, and operational condition of the system. In addition, the selection of components and their integration are explained to fulfill the design objectives. The flowchart in Figure 9 illustrates the system operational principle. The research starts by identifying the problems encounter in existing SH systems. Most considerable problems of the available systems in the market are their high initial implementation costs and unfriendly user interfaces. After the connection of the NodeMCU and components, coding is performed to realize the required tasks. Then, the design is rechecked

to identify whether any problem exists with the system functionalities. Testing is conducted to validate the system effectiveness. The system is then finalized when it exhibits good performance.

3.2 System Design and Development

This section discusses the full design and development of the two major parts of this research work. It also carries information of the interconnection of the various components to make up the entire system. The methodology

employed in this work consists of both hardware and software parts. The hardware part is made up of the following: power supply unit, 4-channel relay module, and NodeMCU8266 which is the control unit as shown in figure 1. The software design involves programming the node microcontroller unit to communicate with hardware components.

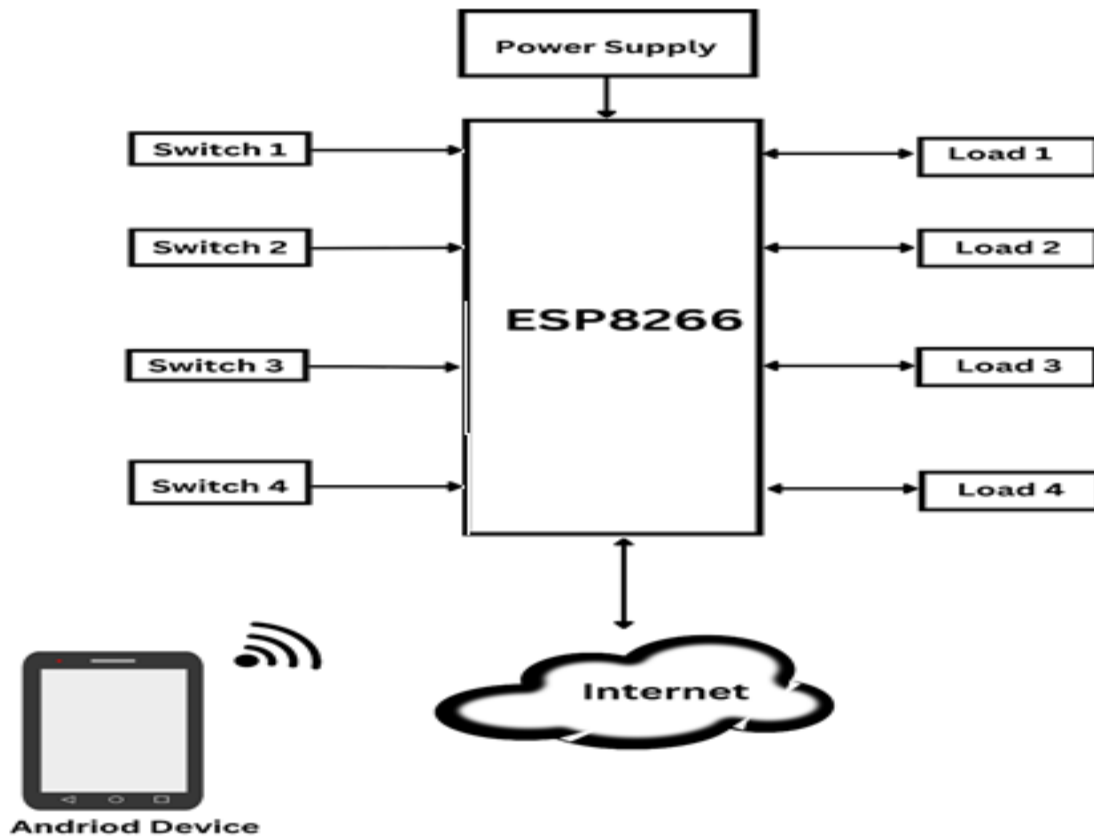


Figure 1: Block Diagram of Home Automation System

3.2.1 Hardware Design

The design of the home automation system using Alexa App is done in accordance to the circuit diagram showed in Figure 2. Each of these

units is treated accordingly. Certain specifications, parameters, and methods of implementation are considered in the system design and construction to get the expected results. The implementation of the design involves segmenting the overall system design into subsystems or modules which are individually designed and tested before the integration of the various units. As said before, the design is made up of a power supply unit, NodeMCU ESP8266, and 4-channel Relay

module. Also, Alexa mobile application is used to control all the four loads connected to the device through voice command. The program on the

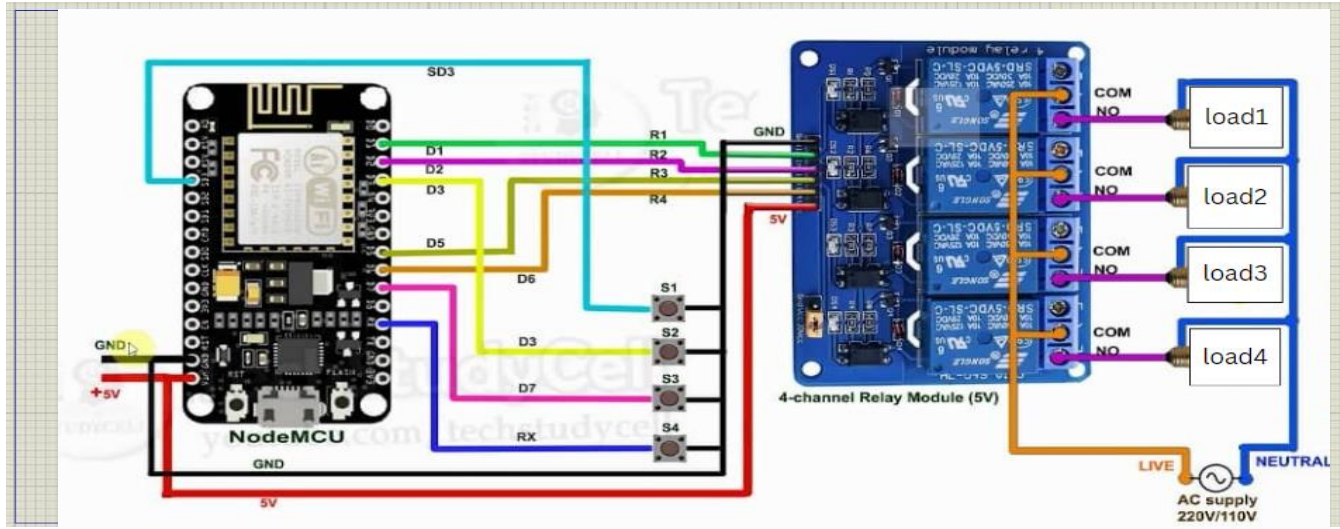


Figure 2: Circuit Diagram of Home Automation System Using Alexa App.

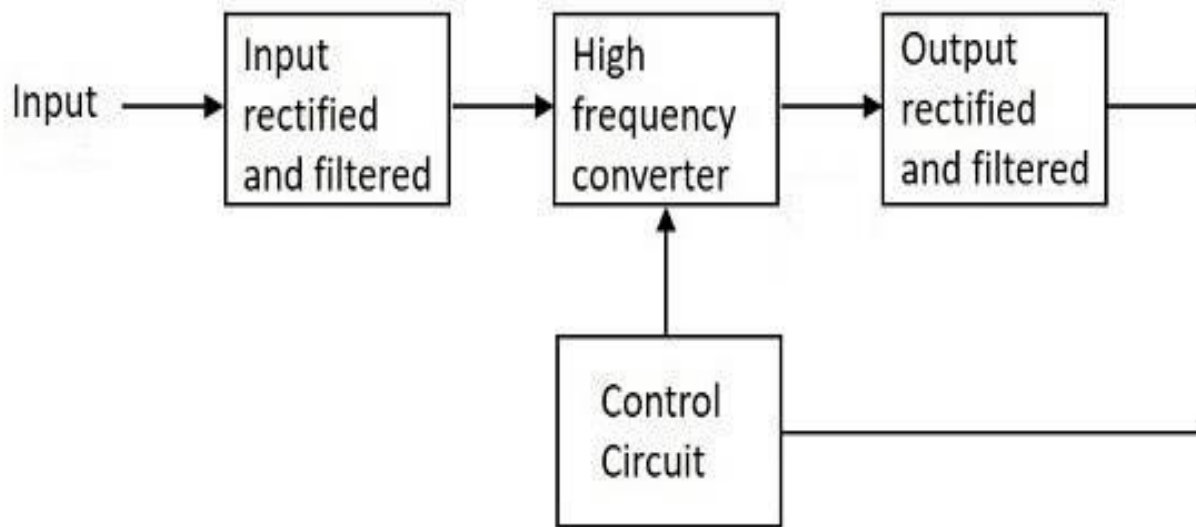


Figure 3: Schematic Diagram of Home Automation System Using Alexa

ESP8266 is written in Java via the Arduino IDE. NodeMCU can be programmed on Arduino software, which is an integrated development environment (IDE) to write the instruction codes and upload them to the node microcontroller unit.

3.2.1.1 Power Supply Unit Every electronic device needs power supply for its operation. The function of the power supply is to provide the necessary DC voltage and current with low level AC ripples with stability and regulation for the unit to operate efficiently. The power supply to the circuit is designed after considering the total voltage and current requirement of the circuit. The design specifications for this research work are as follows: Operating voltage is 5V, Operating current is 200mA. A Switched Mode Power Supply (SMPS) is used in this work. An SMPS is an electronic power supply device that converts electrical power from one voltage level to another efficiently. An SMPS is used in this work to transfer power from DC/AC to a DC load. Most switched mode power supplies convert a higher voltage (110V or 220V AC) to a much lower DC voltage like 24V, 12V, or 5V.

3.2.1.1.1 A Switch Mode Power Working Principle

A switched-mode power supply, sometimes known as 'SMPS', is an electronic power supply that integrates a switching regulator for efficient electrical power conversion. Like other supplies, an SMPS transfers power from a [DC or AC source](#) to [DC](#) loads while converting voltage and current. It consists of a complex circuit that contains a series of power electronics sub-circuits to efficiently convert the power from one voltage to another. In this work, the SMPS is used to stepdown the power to the required 12V needed by the circuit. An SMPS used in this work has the block diagram as shown in figure 4.

Figure 4: Block Diagram of Switched Mode Power Supply

(i) Input Stage

The power input stage generally consists of a full or half-bridge rectifier circuit that takes AC power as input and outputs a filtered DC output of the same voltage. In this work, this stage converts 220V AC to 220V DC. This stage also contains additional LC filter (inductor and capacitor) to further remove any ripples from input power.

(ii) High-Frequency Switch

This is the most critical stage of the power supply. Typically, SMPS has a power MOSFET (one or more) as the main switching device. A Pulse Width Modulation (PWM) signal rapidly turns ON/OFF the MOSFET to act as switch. This converts the smoothed DC voltage from the input stage into a high-frequency square wave. The switching device works in continuous conduction mode in most supplies to achieve better conversion efficiency. This circuitry supply is fed into a power transformer, which steps down or up the voltage according to the primary or secondary winding ratio. Some power supplies have multiple windings for feedback purposes and for obtaining multiple output voltages.

(iii) Output Stage

The output from the power transformer oscillates waveform, which gets further filtered by the output stage. This stage also contains similar filters to the input stage, but are able to handle more current at lower voltages. This is the final stage of the circuit that outputs the power to the connected load. Therefore, this stage outputs the required power to the connected fan and bulbs.

(iv) Control Stage

The switching device (transistor or MOSFET) needs to rapidly turn ON and OFF to

generate the square wave needed to feed the power transformer using a PWM signal. This PWM signal has both frequency and duty cycle. The duty cycle is the ratio between the on-time and the total time per cycle. The output voltage of the SMPS can be controlled by increasing or decreasing the duty cycle of the PWM signal fed to the transistor. When a load is connected, it starts drawing current, and the output voltage of the SMPS drops. At the moment, a separate circuit needs to be at alert to monitor the output voltage and as it drops, it needs to increase the PWM signal duty cycle. Similarly when a load is disconnected, the feedback circuit decrease the duty cycle to maintain the desired output voltage.

3.2.1.2 NodeMCU ESP8266

The NodeMCU ESP8266 is a small, multifunctional development board with the ESP8266 Wi-Fi module. It makes wireless communication and Internet of Things applications possible. The NodeMCU ESP8266, which has an inbuilt Wi-Fi module, GPIO connectors, and a 32-bit Tensilica microcontroller, is a popular choice for IoT project development and prototyping due to its low cost and simple interface. Firmware and data have plenty of room on the NodeMCU ESP8266, which has 4MB of flash memory for program storage. Its built-in USB-to-Serial converter and wide voltage range (3.3V) make programming and troubleshooting simple. The Pictorial view of the ESP8266 is shown in Figure 5.

In this work, the ESP8266 is the central section of the work, which controls the relay module to switch ON/OFF the bulbs. It is therefore inserted into the Vero board while other components are gradually connected to complete the construction. An android based application is launched on Smartphone. Through the application, the NodeMCU can be instructed to turn ON/OFF a switch. After the instruction is

passed through the Alexa assistant, the microcontroller unit gives the signal to the corresponding relay on the board. The application first searches for the recognizing module device. If it is available, then it launches the voice recognizer. It also reads the voice and converts the audio signal. A voltage regulator is used to convert the 12volts DC supply into a 5volts DC supply to be used by the NodeMCU microcontroller board.



Figure 5: ESP8266 Module

3.2.1.3 Relay Module

A 4-channel relay module is a versatile electronic component that can control several high-power devices. Each channel normally provides a switching voltage of 250V alternating current and a current of 10A, making it appropriate for a wide range of applications. The module is frequently powered by a low-level input signal (5V) and includes isolation to safeguard sensitive control circuits. Its four independent relay channels provide an easy-to-use solution for controlling and automating various electrical loads in applications, including robotics, industrial control, and home automation. In this work, relay module is used to control the bulbs and the fan. When a circuit is built, the voltage that will trigger it has to be considered. Normally, a relay is used in a circuit as a type of switch, an automatic switch. In this system, the relay circuit is used to turn the appliances ON/OFF. When a

low voltage is given to the relay of an appliance, it is turned OFF and when a high voltage is given, it is turned ON. The relay circuit is to drive four appliances in the home automation system. The Pictorial view of the relay module is shown in Figure 6.

In this home automation system; fan, light bulbs, connectors, are connected to the relay module to control four appliances. Since this device is configured with Alexa, the software part of the work recognizes the device one is trying to set up. The Alexa connected to the NodeMCU ESP8266 Wi-Fi module receives commands wirelessly from your smartphone over the internet. This Alexa is used to encode the ON / OFF signal and sent it to the server and the ESP8266 board. All the configurations are programmed into the NodeMCU using Java. When the ESP8266 is powered by 5V, one can control the connected devices by voice commands via Alexa. The pictorial view of the Alexa Application is shown in figure 7. While the pictorial view of the Alexa Mobile Application is shown in figure 8.



Figure 6: 4-Channel Relay Module

(i) Operational Principle

This project works by receiving a command from a mobile phone using an application called Alexa home. When the system is powered ON, it is connected to Wi-Fi, and it is ready to communicate with the Hardware. The system receives a registered voice command from the

Alexa assistant. The detailed circuit diagram of the project is shown in figure 2.

(ii) Processing Unit

The NodeMCU is the central component in this system. This unit is responsible for performing the necessary computations after the input signals are being received from the input unit. The main unit (processing unit) in this work is the node microcontroller unit (ESP8266) which coordinate all the activities of the system.

(iii) Communication Unit

The communication unit is used for the transmission of user commands between the user's phone and the system. To send commands to the system, there is a need for communication interface between the user's phone and system. The communication interface used in this project is Alexa assistant. The Alexa assistant module is responsible for transferring the user's voice commands to the microcontroller unit. The module is then used to establish communication between the smartphone and microcontroller unit. The pictorial view of the Alexa Application is shown in figure 7. While the pictorial view of the Alexa Mobile Application is shown in figure 8.

3.2.2.1 Arduino IDE Software

The

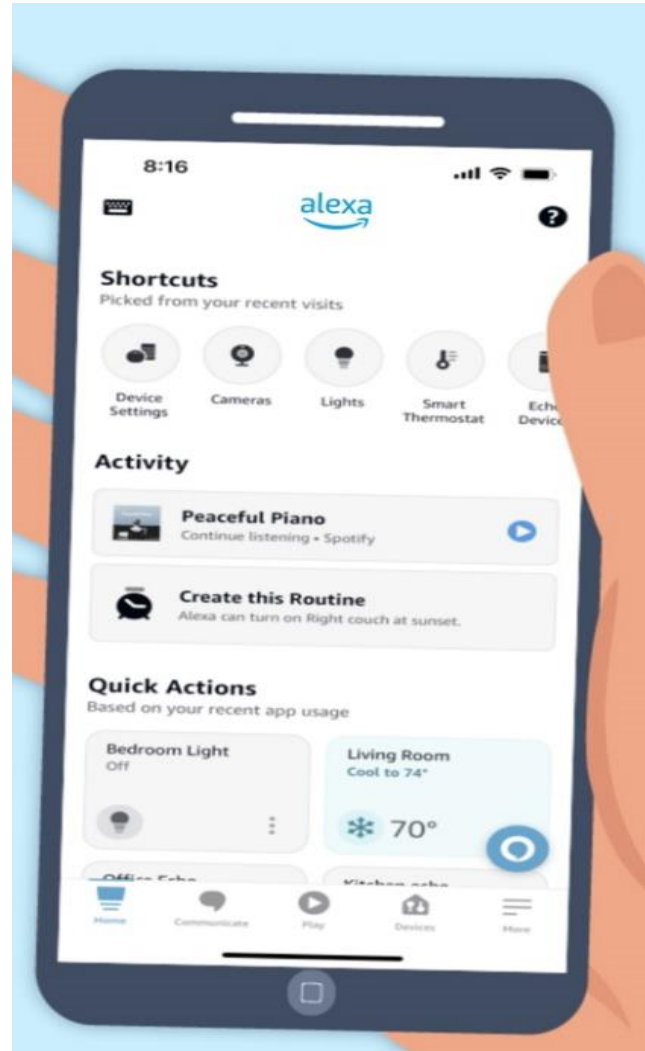
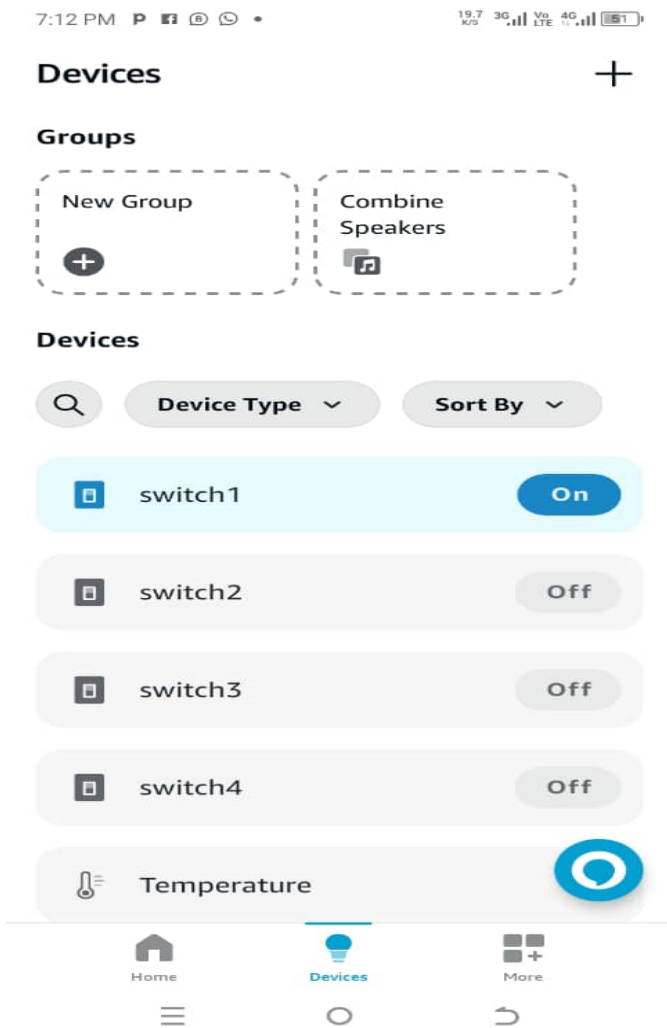


Figure 7: Pictorial View of the Alexa App.
Figure 8: Alexa Mobile Application

3.2.2 Software Design

After hardware design is completed, a set of instruction code that does the computing and processing in the ESP8266 microcontroller unit is developed. The instruction code is written in Java and finally transferred into the microcontroller unit. The software components used to implement this work are as follows: Arduino IDE software; Alexa mobile application.

software used in this work is the Arduino IDE software. Arduino IDE software is written in Java and the platform is used for writing and editing program codes which are interpreted to HEX files which the Arduino hardware supports. The step-by-step procedures used to achieve the work are as follows: The necessary libraries needed are included in the code; the board library of ESP8266 is installed and used to program the board; the source code is typed into the editor; the program is uploaded on the board; it is then tested and debugged.

3.2.2.2 Alexa Home

Alexa home is one of the best smart home apps available. It has built-in support for Alexa Assistant functionality. The Alexa home is available on android phone, tablet and iPhone at the top of the home app screen, the name of one's home appears. If one sets up multiple homes, one can tap the name to switch between homes. The steps in setting up the app are as follows: Connect

to the Wi-Fi network, same as the ESP8266 module; Launch the Alexa Mobile app. (figure 8); Click on add devices and search for the ESP8266; Enter correct credentials to control the appliances. The flowchart in figure 9 illustrates the details.

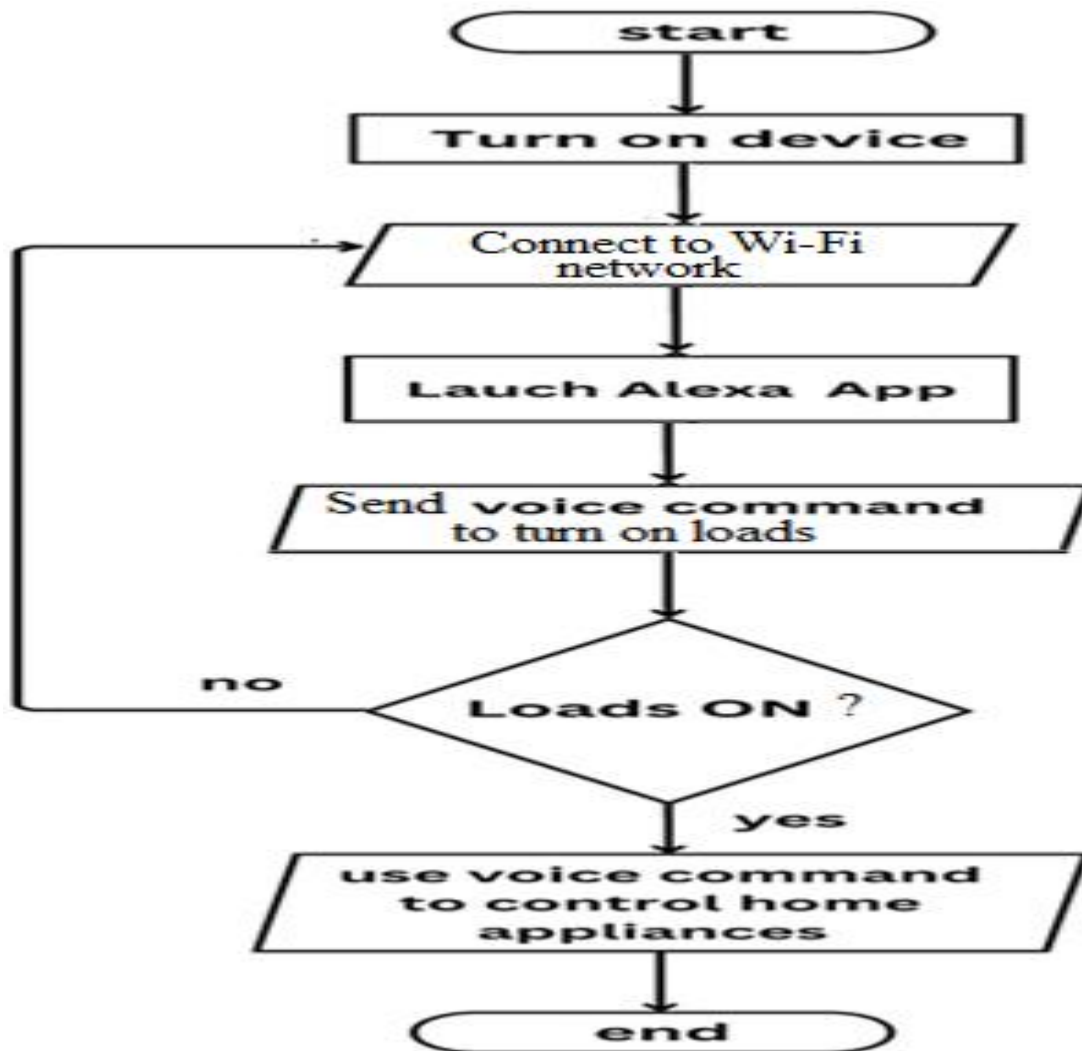


Figure 9: Flowchart of System Operation

4.0 TESTING

This section discusses the test carried out to ascertain the workability or functionality of the system. The two types of tests conducted are as follows: Continuity Test and Performance Test.

4.1 Continuity Test

Continuity test is carried out on all electronic components to know if they are working properly. All the components are checked individually even after they are mounted on the board to ensure that they are working properly. After soldering, continuity test is carried out for the entire prototype with the help of a Multimeter to ensure

that all contacts and connections are properly made.

4.2 Performance Test

The last test employed for this work is the performance test, where the construction is switched ON and OFF to see if it is working properly. The IoT-based smart home monitoring and control system using NodeMCU is designed and implemented using the Alexa mobile

application which serves as the control remote for the prototype. Figures 10 and 11 show the prototype of the completed work. Experimental tests such as remote and manual switching of appliances at different locations are conducted to assess the performance of the prototype system. To see if it is working properly, the results of the tests carried out are tabulated as shown in table 1 and 2.



Figure 10: Prototype of the Home Automation System in OFF State



Figure 11: Prototype of the Home Automation System in ON state

5.0 RESULTS AND DISCUSSION

This section presents the results obtained during the tests to verify the functionalities of the implemented IoT-Based Voice-Controlled Home Automation System. The system successfully

controls home appliances (bulbs and fan) using mobile phone via Alexa Assistant. Users can monitor and control the SH prototype by connecting to the Internet. The results of the tests carried out are tabulated as shown in table 1 and 2.

Table 1: Results Obtained (Voice Control) at different locations

S/No	Appliances	Locations	Number of Times Tested	Number of Times Responded	Response Time (s)	Appliance Status	Percentage Error (%)
1	Load-1	Adm. Block	10	10	2-4	ON/OFF	0
2	Load-2	Library	10	10	2-4	ON/OFF	0
3	Load-3	HND-1	10	9	2-5	ON/OFF	10
4	Load-4	HND-2	10	10	2-3	ON/OFF	0

Table 2: Results Obtained (Manual)

S/No	Appliances	Number of Times Tested	Number of Times Responded	Appliance Status	Percentage Error (%)
1	Load-1	5	5	ON/OFF	0
2	Load-2	5	5	ON/OFF	0
3	Load-3	5	5	ON/OFF	0
4	Load-4	5	5	ON/OFF	0

5.1 Discussion of Results

The system is tested in a conducive environment by connecting lighting loads and electrical appliances to the relay modules. Functional testing shows that the NodeMCU ESP8266 successfully maintains stable Wi-Fi connectivity and responds accurately to control commands from all three interfaces: voice, mobile application, and manual switches. It is possible to remotely control the home appliances using a Wi-Fi network.

Our findings show that the Internet of Things-based smart home automation system functions excellently in real-world scenarios regarding task automation and user-friendliness. The system greatly enhances the users' everyday routines and is straightforward to set up and operate. Yet, a few important facts are apparent:

1. Reliability and Efficiency

From the results obtain in table 1 and 2, the control approaches for voice mode and switch mode are both effectively implemented. However, the emphasis is laid much on the voice mode being the latest technology in question and as the main mode of the system operation. The results contain in table 1 indicate that, the voice mode is also implemented perfectly like the switch mode. The little percentage error obtains during the voice mode test shows that the system is reliable and efficient. Moreover, nothing is one hundred percent (100%) efficient including humans.

2. Latency and Responsiveness

Although the system usually reacts quickly to user commands, occasionally long delays are seen, particularly during periods of high usage. This emphasizes the importance of decreasing latency

by improving the network and cloud architecture. The average response time for local Wi-Fi commands is observed to be less than 2 seconds, while cloud-based voice commands exhibits a delay of approximately 2–5 seconds, mainly due to internet latency and voice processing time. The voice recognition accuracy of Alexa Assistant is found to be above 85% for predefined command phrases, demonstrating reliable natural language interaction.

3. Interoperability

The system successfully integrates a range of IoT devices from various manufacturers. However, several compatibility problems are found, underscoring the IoT ecosystem's continued need for standardized communication protocols and interoperability standards.

The manual override mechanism ensures safe operation and uninterrupted control even during temporary network outages. However, the performance of the system is influenced by Wi-Fi signal strength and internet availability, which can introduce minor delays in command execution.

In a nutshell, the experimental results confirm that the proposed IoT-based automation system is reliable and suitable for society-level deployment. The integration of voice control and cloud-based management significantly enhances user convenience and accessibility, particularly for elderly and physically challenged residents, while also contributing to efficient energy utilization.

6.0 CONCLUSION

This research presents the design and implementation of an IoT-based smart home automation system using NodeMCU ESP8266 which serves as the main control unit. The developed system aims to automate home

appliances, increases safety and enhances life quality and convenience. The proposed system successfully demonstrates real-time control of electrical appliances through mobile application and manual switches. The hybrid control mechanism ensures reliability, safety, and uninterrupted operation even during the network failures. The system has limited wireless transmission range connectivity because it utilizes short-range wireless interface which is Wi-Fi network.

The experimental results show that the system provides fast response time, high command accuracy, and stable performance over Wi-Fi network. The use of low-cost hardware and open-source software platforms makes the solution economically feasible for large-scale deployment in residential societies. One of the great achievements of this study is the utilization of IoT in controlling home appliances by enabling Alexa Assistant voice commands to help elderly and people with disabilities. The use of smartphone is crucial because it is one of the technological benchmarks in the modern era. The smart phone is used for sending the voice command via Alexa Assistant, thus making the system portable, convenient and user friendly.

7.0 FUTURE SCOPE

The current system can be further enhanced by incorporating the following features:

7.1 Security Enhancement

Security is still a top priority in home automation. Further research should look into using biometric authentication methods such as fingerprint and face recognition to strengthen access control and secure personal spaces. These new security features are expected to replace or supplement traditional methods of house

entrance, providing a more secure and convenient means of entry.

7.2 Sensor Integration:

Sensors are the key elements in the automated system of smart homes. Addition of motion, temperature, humidity, and light sensors to enable context-aware and fully automatic control. The future work should integrate these sensors to monitor home conditions.

7.3 Smart City Integration:

Extension of the system for large-scale applications such as smart street lighting, parking management, and public building automation. These enhancements will further improve system intelligence, scalability, and reliability, making it suitable for future smart city environments.

7.4 Artificial Intelligence:

Implementation of machine learning algorithms for usage pattern analysis and predictive energy optimization. Through the use of data processing, decision making, activity recognition, prediction-making, voice recognition and image recognition, it is discovered that Artificial Intelligence (AI) technology will support smart homes in the areas of energy management, device management, intelligent interaction, health care, security, personal robots and entertainment systems. In the future, smart homes will mainly aim on how people and the environment interact to create more individualized and sustainable structures. The basis for automation and real time decision making for the internet of things will be provided by artificial intelligence.

7.5 Hardware and software:

Further researchers should experiment using Raspberry Pi as the central control for the hardware, since it's a more advance computer and

for the software, further researchers should experiment using camera to broadcast live feed to the user via the Google home application for android devices and Siri for apple devices.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Muhammad Muhammad Ndamitso for supporting the research.

REFERENCES

Anandhavalli, D., Mubina, N. S., and Bharathi, P. (2015), "Smart Home Automation Control Using Bluetooth and GSM," *International Journal of Informative and Futuristic Research (IJIFR)*, Vol. 2, No. 8

Bhaskar, K., Venkat, P. Y., Veera, G. S. R., Bata, V., and Hemachandra, M. (2023), "Home Automation Using NodeMCU8266 Controlled Through Google Voice Assistant," *International Journal of Creative Research Thoughts (IJCRT)*, Vol. 11, Issue 3, ISSN: 2320-2882, Pp: 691-697, www.ijcrt.org

Cho, O. H. (2025), "A Study on Smart Home Appliances Based on Artificial Intelligence System," *Journal of Information Systems Engineering and Management (JISEM)*, Vol. 10, Issue 3s, e-ISSN: 2468-4376, <https://www.jisem-journal.com/>

Cristina, S. C., Calin C. and Bogdan, P. B. (2021), "An IoT-Based Smart Home Automation System," <https://www.mdpi.com/journal/sensors>

Christantonis, K. (2019), "Data Mining for Smart Cities,"

David, N., Chima, A., Ugochukwu, A., and Obinna, E. (2015), "Design of a Home Automation

System Using Arduino," *International Journal of Scientific & Engineering Research (IJSER)*, Vol. 6, No. 6, Pp. 795-801

Davidovic, B. and Labus, A. (2015), "A Smart Home System Based on Sensor Technology," *Facta*

Universitatis, Series: Electronics and Energetics, Vol. 29, No. 3, Pp. 451-460

Ganesh, E. (2017), "Implementation of IoT Architecture for Smart Home Using GSM Technology," *International Journal of Computer Techniques (IJCT)*, Pp. 2394-2231

Jabbar, W. A., Saad, W. K., and Ismail, M. (2018), "MEQSA-OLSRV2: A Multicriteria-Based

Hybrid Multipath Protocol for Energy Efficient and QoS-Aware Data Routing in MANET-

WSN Convergence Scenarios of IoT," *IEEE Access*, Vol. 6, Pp. 76546-76572

Jabbar, W. A., Alsibai, M. H., Amran, N. S. S., and Mahayadin, S. K. (2018), "Design and Implementation of IoT-Based Automation System for Smart Home," *International*

Symposium on Networks, Computers and Communications (ISNCC), Pp. 1-6: IEEE

Katariya, J. K., Manjunath, H. R., Malviya, A., and Kumar, R. (2024), "Securing the IoT Wireless Communication System: A Multi-access Physical Layer Approach,"

Multidisciplinary Science Journal, Pp. 6, ISSN: 0320.

<https://doi.org/10.31893/multiscience.2024ss0320>

Kodali, R. K. and Soratkal, S. (2016), "MQTT Based Home Automation System Using ESP8266," IEEE Region 10 Humanitarian Technology Conference (R10-HTC), Pp. 15: IEEE.

Lucero1, H. R., Asuncion, V. M., Abenir, J. C., Maiquez, I. M. Y., and Noda, J. L. (2025), "IoT-Based Home Automation: A Modular System with Smart Monitoring and Control Features," International Journal of Research and Innovation in Applied Science (IJRIAS), Vol. X, Issue VIII, ISSN No. 2454-6194, DOI: 10.51584/IJRIAS, Pp: 2167-2172

Mattoo, A. and Kumar, S. (2019), "Internet of Things (IoT): A Progressive Case Study," Handbook of IoT and Big Data, p. 251

Muhammad, A., Ali, Y., Abubakar, S., and Abbas, A. (2023), "Design and Implementation of an

IoT Based Smart Home Monitoring and Control System Using NodeMCU," Journal of Engineering Research and Reports (JERR), Vol. 25, Issue 2, ISSN: 2582-2926, Pp: 78-88,

Article No.JERR.99771, <https://www.sdiarticle5.com/review-history/99771>

Mohiuddin, M. Md., Touhid, B., Erin, J. E., Sazzad, H. Md., and Hafizul, I. Md. (2026), "An IoT-

Based Smart Home Automation System: Enhancing Security, Energy Efficiency, and Remote Accessibility. Multidisciplinary Science Journal,

<https://doi.org/10.31893/multiscience.2026262>

Muthmainnah, M., Mulyadi, M. F., Tazi, I., Mulyono, A., Hananto, F. S., Chamidah, N., and Kusairi (2024), "Development of an Automated Monitoring System for Soil Moisture and

Temperature in Smart Agriculture to Enhance Lettuce Farming Productivity Based on IoT," Multidisciplinary Science Journal, 6(11), 233,

<https://doi.org/10.31893/multiscience.2024233>

Maslan, M. N., Ramli, I. R., Fauadi, Md., Ayob, M. H. F., Baharom, M. E., Ghazali, M. F. I., and Tanjung, T. (2025), "Design and Implementation of Outdoor Home Smart Farming Based

on Raspberry Pi for Home Assistant Management," Multidisciplinary Science Journal, 7(8), 418,

<https://doi.org/10.31893/multiscience.2025418>

Melvin, J. C. S., and Mununga, S. (2025), "IoT Based Smart Home Automation System: Design and Development," Scientific Journal of Engineering and Technology (SJET), Vol. 2, Issue 2 ISSN: 3007-9519 (Online),

<https://doi.org/10.69739/sjet.v2i2.438>, <https://journals.stecab.com/sjet>

Nagayo, A. M., Al-Ajmi, M. Z., Guduri, N. R. K., and Al-Buradai, F. (2024), "Monitoring Stress Levels and Associated Clinical Health Risks Utilizing IoT and AI Technologies to Promote

Mental Health Awareness in Educational Institutions," Multidisciplinary Science Journal, 6, ss 0327, <https://doi.org/10.31893/multiscience.2024ss0327>

Popli, S., Jha, R. K., and Jain, S. (2019), "A Survey on Energy Efficient Narrowband Internet of

Things (NB IoT): Architecture, Application and Challenges," IEEE Access, Vol. 7, Pp. 16739-16776,

Seetharamudu, S., Raveendra, N. M., Jithendra, B., Hemavardhan, K., Abhilash, S., and Zuber, G. (2024), "Smart Home Automation Using Alexa with NodeMCU," International Journal of Scientific Research & Engineering Trends (IJSRET), Vol. 10, Issue 2, ISSN (Online): 2395-566X, Pp: 569-573

Sneha, M., and Ravindra, P. (2018), "Voice Controlled Home Automation Using Amazon Echo

Dot," IOSR Journal of Computer Engineering (IOSR-JCE), Vol. 20, Issue 3, Ver. III, e-

ISSN: 2278-0661, p-ISSN: 2278-8727, Pp 16-19, www.iosrjournals.org

Stojkoska, B. L. R., and Trivodaliev, K. V. (2017), "A Review of Internet of Things for Smart

Home: Challenges and Solutions," Journal of Cleaner Production, 140, 1454–1464.

Vyawhare, D.G., Saurabh, S. S., Rahul, N. G. (2023), "Home Automation System Using IoT," International Journal of Scientific Research in Science and Technology (IJSRST), Vol.

10, Issue 10, Print ISSN: 2395-6011, Online ISSN: 2395-602X, Pp: 97-100, www.ijrst.com

Varghese, S. G., Kurian, C. P., George, V., John, A., Nayak, V., and Upadhyay, A. (2019), "Comparative Study of Zig Bee Topologies for IoT-Based Lighting Automation," IET Wireless Sensor Systems,

Woodford, C. (2018), "Smart Homes and the Internet of Things," in Explain That Stuff, Ed,

Waheb, A. J., Tee, K. K., Roshahliza, M. R., Siti, N. Z., Nurthaqifah, S. M. Z., Mohammed, B., Vladimir, S., and Soltan, A. (2017), "Design and Fabrication of Smart Home with Internet of Things Enabled Automation System," IEEE Access Multidisciplinary, Rapid Review, Open Access journal, Vol. XX,