Original Research Article

Design and Implementation of an IoT Based Smart Home Monitoring and Control System Using NodeMCU

ABSTRACT

This paper presents the design and implementation of an IoT-based smart home monitoring and control system using a NodeMCU microcontroller. The system allows the user to remotely control electrical appliances through a web-based user interface dashboard. The system uses sensors DHT11 to monitor the temperature and humidity of the home and MQ 2 to monitor the air quality and alerts the user in case smoke or fire is detected. Various HTML scripts are executed to develop a web-based dashboard interface where the user interacts with the system. When connected to the internet, the system generates an IP address that is used to assess the web page for monitoring and control of various house appliances. A maximum coverage range of up to 42.05 meters indoors was achieved by the system using the onboard Wi-Fi module on the NodeMCU. In addition, a correlation was observed between the Wi-Fi coverage distance and the response time to a command signal from the web-based dashboard. The system provides energy efficiency, home security, and centralized remote control of appliances thereby minimizing human efforts and energy losses and providing a friendly and secure home.

Keywords: NodeMCU, IOT, Smart home, Webserver dashboard

1. INTRODUCTION

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. Smart home automation systems enable users to conveniently control and monitor their home appliances. In addition, they enhance efficient energy use and minimize energy losses [1].

The IoT comprises the network of physical objects (things) that are embedded with sensors and software for the purpose of interconnecting devices over the internet. Another significant use of IoT technologies is automation. By utilizing sensors and actuators, appliances can be controlled and environmental conditions can be monitored [1]. With the IoT technology, the "smart home," also known as "house automation," aims to make domestic tasks more convenient, safe, and cost-effective [2].

Generally, home automation systems include main components which are [1]: 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.

Although the idea of home automation has been around for a while, its technical difficulties, high price, incompatibility and range issues have stopped it from being commonplace in home automation. However, by addressing these challenges through IoT wireless technologies and the use of smartphone applications, the prospect of home automation systems will improve.
This paper proposes a user-friendly dashboard interface for control of home appliances and monitoring of temperature, humidity and air quality using a NodeMCU and a few peripheral components.

1.1 Related Literature

Several systems have been developed for smart home automation as can be found in the literature [3]-[35]. Some of these systems that are relevant to this paper are reviewed in this section and the limitations in such systems have been highlighted. In [9], "a smart home (SH) automation using Bluetooth and a GSM module was proposed. The work aimed to assist handicapped and elderly people to control home appliances from remote places. Bluetooth was used to control appliances indoors and GSM to control appliances outdoors. Bluetooth can reduce system costs because most cellphones and laptops have this built-in application. Users can monitor and control appliances remotely by sending SMS through GSM. However, such systems have limitations in both cases. Bluetooth has a limited range and data rate, while GSM is expensive due to SMS costs".
[12] Proposed "a smart home automation based on sensor technology that can automatically control home appliances using an Android-based smartphone as a remote controller. The authors utilized Raspberry Pi as the microcontroller and Bluetooth as the communication protocol. Wi-Fi was used to connect the smartphone to the Raspberry Pi controller. 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 outside the Bluetooth range".
In [13], "a home automation and environmental monitoring system was developed using Arduino Mega 2560 microcontroller with Bluetooth module. Several sensors and switches were used to control home appliances through a web-based applications. However, Arduino Mega is more expensive than NodeMCU, and the use of Bluetooth is unsuitable for smart home application due to its limited features".
"A Wi-Fi-based home automation system was designed and implemented" by [14]. "The developed prototype allowed users to control and monitor a home through Wi-Fi by using Arduino Mega integrated with an Android-based application known as Virtuino. However, the prototype had limited connectivity, and can only perform local control, and the remote control of the developed system should be enabled based on IoT to allow users to control it using a webserver even when they are not around their homes. A similar system using Arduino Mega with the Internet of things (IoT) was presented" by [15]. "The interconnected system consisting of an Arduino microcontroller was used to connect to an Ethernet shield, which was connected to a modem with an Internet connection. A relay was connected to the device for control while a dashboard through a HTML page with an assigned IP address was used. However, the system did not consider home monitoring and the system was not implemented". [15]
Reference [16] introduced "a web-based Internet of Things (IoT) architecture using GSM to implement the smart home system and presented a GSM-based control system. This work

suggested a structure to enable users to monitor and control smart devices through the Internet, where the users give commands through the web, and the user input is converted to GSM–SMS commands. The proposed structure 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 and can be directly connected to the devices through the GSM network. In addition, the module is controlled through an Internet of Things (IoT) agent by the GSM network. The user commands are executed and analyzed using a microcontroller to control home and sends an acknowledgment to the user. The prototype collects and transmits data through GSM– SMS".

Reference [17] introduced "an Internet of Things (IoT)-based system for efficient energy management of devices and security. The main concept of this work is to control home appliances using smartphones through Wi-Fi as the connection protocol, which provides information on the required software and hardware components. The Internet of things (IoT) structure used acts such that all the devices are connected to a smart central control system, which is linked to the switch for each connected device and thus, enables access to each individual device".

In this work, we proposed a smart home automation system using a normal web server and a Wi-Fi module such that appliances can be monitored and controlled wirelessly by sending commands to the microcontroller (ESP8266) via the web server dashboard. The appliances to be controlled by the prototype system include indoor lighting point, outdoor lighting point, a power plug, and a fan. The system is also equipped with temperature, humidity and smoke sensors such that the status of the environment is monitored. One key advantage of the system is the user-friendly webserver dashboard feature that allows it to be used in any computer system or mobile phone that can access the internet.

2. MATERIAL AND METHODS

The SH system is built around the NodeMCU which serves as the main control unit. Peripheral devices used are the temperature and humidity sensor, gas sensor, relay assembly and loads all of which are controlled through the webserver dashboard. The microcontroller is programmed to communicate with the webserver and the other part of the system. To control and monitor home appliances the Internet Protocol (IP) address generated by the microcontroller is copied into a browser which will open the system dashboard through which it displays the present condition of the appliances/environment. The communication channel used is Wi-Fi. The system block diagram is shown in Fig. 1 where the different hardware components are illustrated

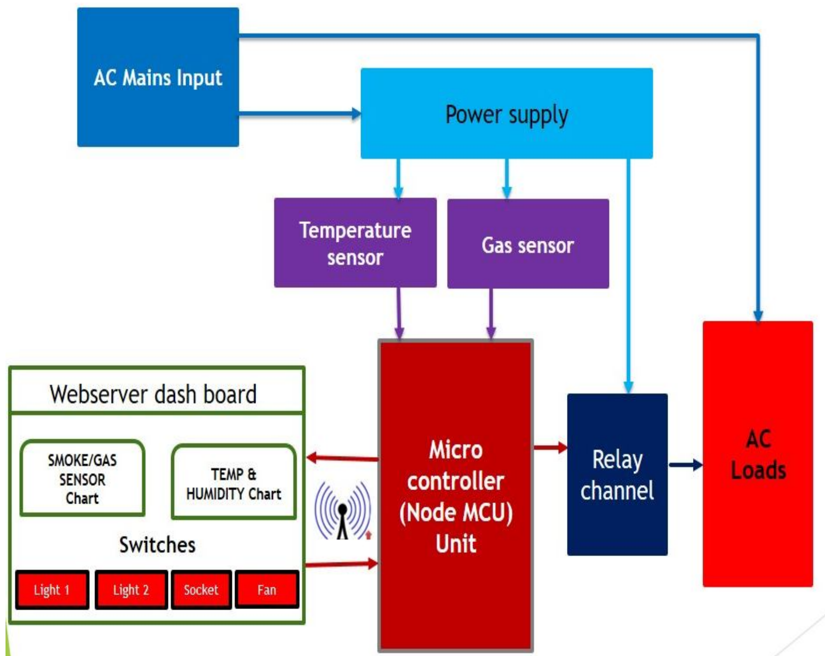


Fig. 1 Block diagram of the smart home automation system

2.1 Hardware Components of the System

The main hardware components used in the SH automation system are shown in Fig. 2. Each of the components are listed below with a brief description of their functions.

- **(a) ESP8266 (NodeMCU):** is an open-source firmware and development kit that helps in prototype or building Internet of things (IoT) products. In addition to its CPU, RAM, and operating system, it contains and a Wi-Fi module that can easily connect to components, such as sensors and actuators.
- **(b) DHT11 Sensor Module:** measures both the temperature and humidity in an individual distinctive mode. The module ensures high reliability and excellent long-term stability due to the exclusive digital signal acquisition with respect to the sensing technology. [8].
- **(c) MQ Gas sensor Module:** MQ-2 gas sensor or detector is an electronic detector used for sensing the concentration of gases within the air like LPG, Propane, methane, hydrogen, alcohol, smoke and carbon monoxide gas. It contains a sensing material whose resistance changes when it comes in touch with the gas. This variation within the value of resistance is used for the detection of gas [ref].
- **(d) Relay Module:** a four-channel relay module contains four relays and the associated driver circuitry which makes interfacing with a microcontroller or a sensor easy. There are two terminal blocks with six terminals each, and each block is shared by two relays. The terminals are screw type, which makes connections to mains wiring easy and changeable. The four relays on the module are rated for 5V, which means the relay is activated when there is approximately 5V across the coil. The contacts on each relay are specified for 250VAC and and 10A in each case, as marked on the body of the relays.

(e) **AC-DC 5V Precision Buck Converter:** is a Switch Mode Power Supply Module. It can supply 5V DC from 220V AC and has a power rating of 3.5W. This makes it perfect for small projects that needs a 5V supply from mains.

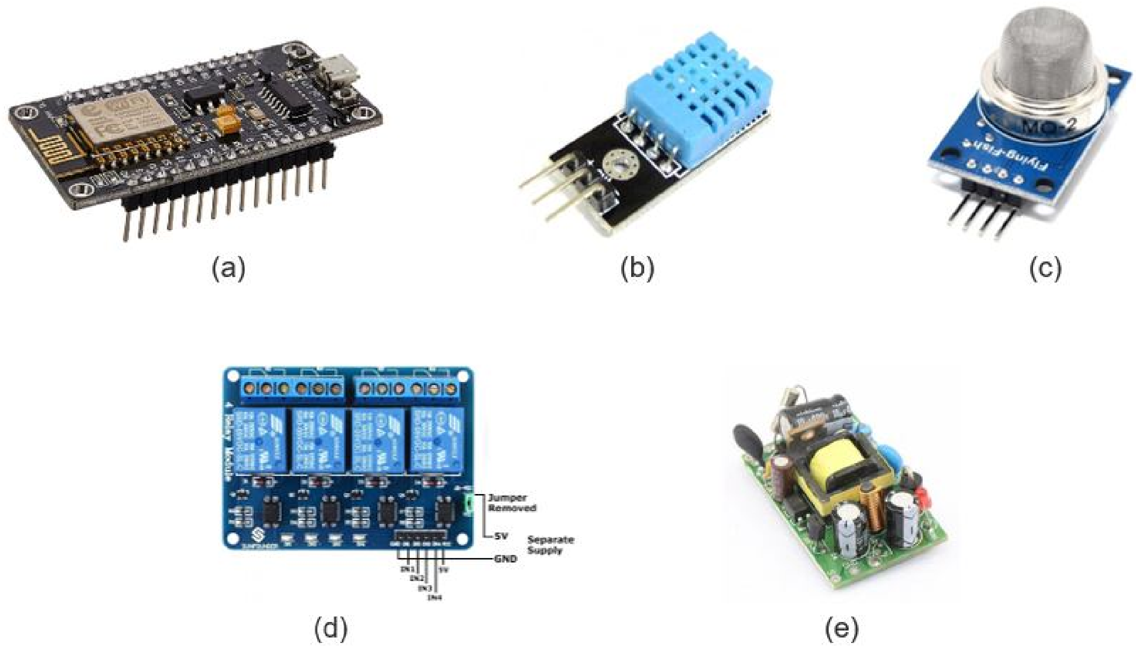


Fig. 2 Hardware components of the system (a) NodeMCU Esp8266 (b) DHT11 Sensor module (c) MQ-2 gas sensor module (d) Relay module (e) Power supply unit

2.2 Software Components of the System

(a) **Webserver Dashboard:** A web server dashboard is created using various HTML scripts, to allow users to interact with the system. The system can monitor the temperature and humidity of the environment via the web server dashboard and control the actuator unit smartly using smartphones, tablets, or computers.

(b) **Arduino Integrated Development Environment (IDE)**: Is an open-source software that makes it simple to create and upload codes to the microcontroller board. This program is compatible with NodeMCU and Arduino boards.

2.3 The Design Procedure

A schematic diagram of the whole SH automation system is shown in Fig. 3. When the system is on, the Wi-Fi module will be active. Connection to the system on the host computer or smartphone is established through the Wi-Fi module. The Node-MCU generates an IP address which when used as a web address displays the system's dashboard. The user can simply select which appliance to control and also monitor real-time data on temperature, humidity and air quality. This process is depicted on the flow chart shown in Fig. 4.

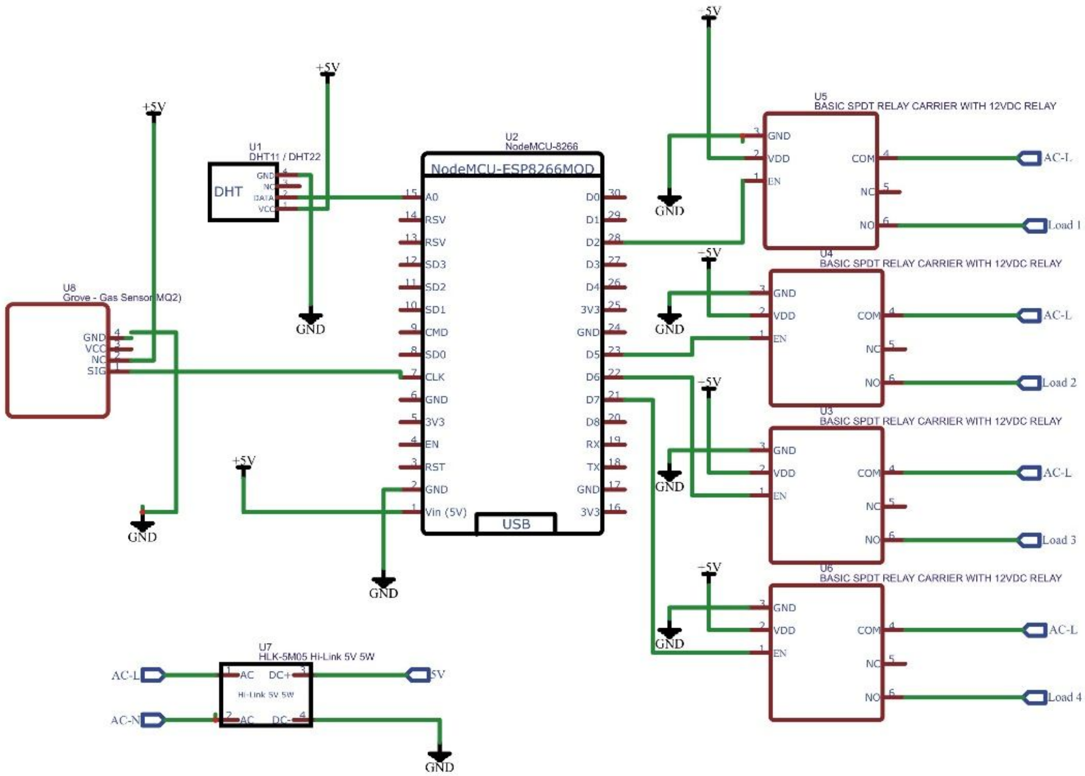


Fig. 3 Schematic diagram of the whole system

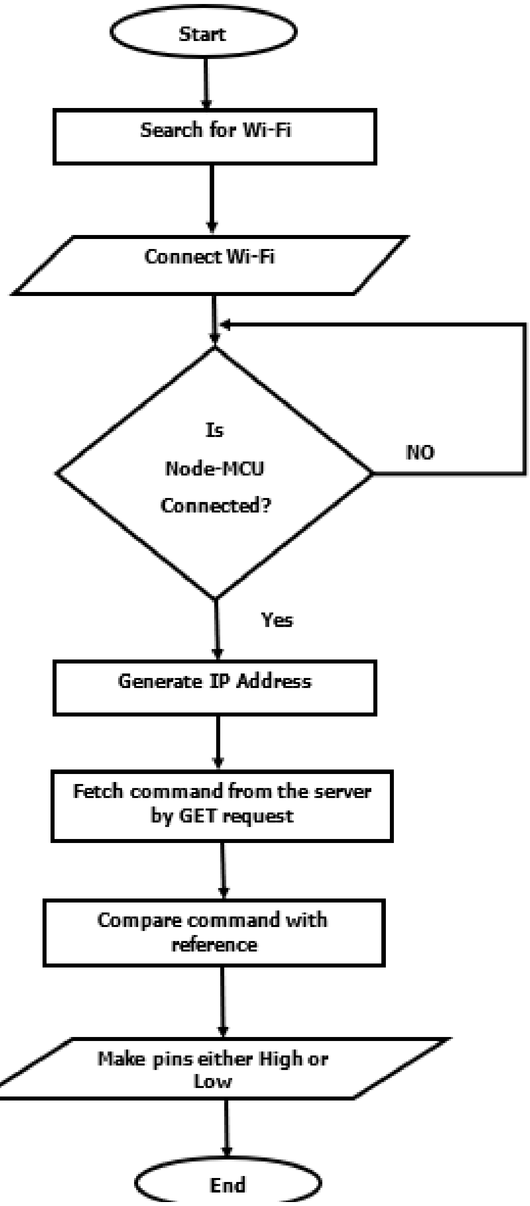


Fig. 4 Flowchart of the system

3. RESULTS AND DISCUSSION

The Wi-Fi-based smart home monitoring and control system using NodeMCU was designed and implemented in this paper. Fig. 5 shows the prototype of the complete work.
Different experimental tests such as remote switching of appliances and real-time monitoring of temperature, humidity, and smoke were conducted to assess the performance of the prototype system.

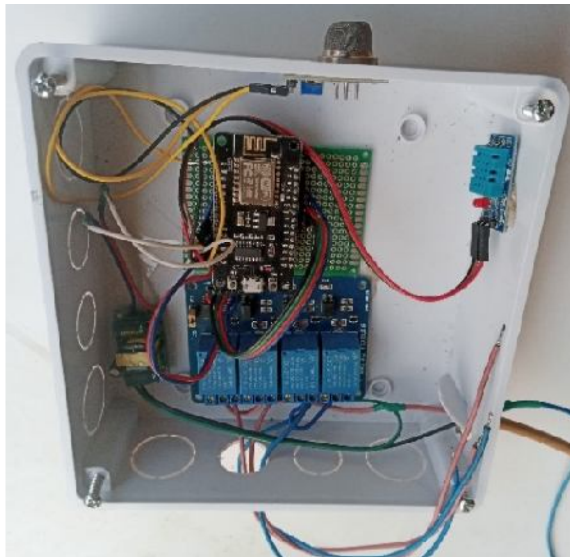
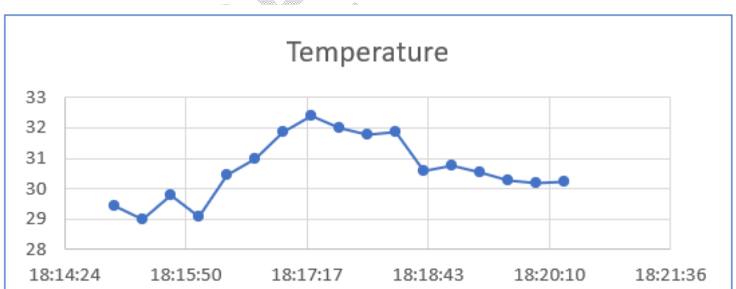


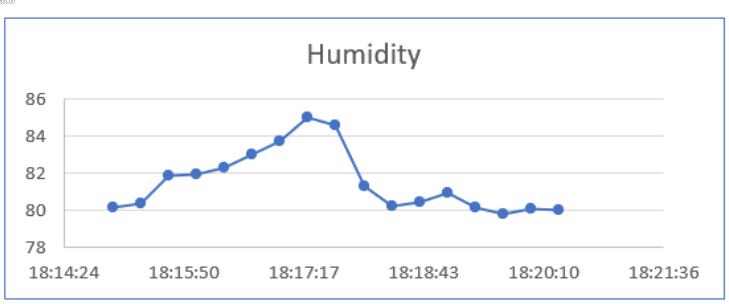
Fig. 5. Complete prototype of the Smart Home automation system

3.1 Temperature and Humidity Test

This test was conducted by introducing a hot iron close to the temperature sensor DHT11. Temperature and humidity data are continuously updated and saved on the web dashboard display which may be viewed through a mobile phone or computer. Fig. 6(a) and 6(b) show the obtained results on the dashboard.



(a)



(b)

Fig. 6. Real-time measurement of temperature and humidity from the dashboard (a) Temperature (b) Humidity

It can be observed from Fig. 6(a) that the temperature rises as a result of the heat from the iron. After the heat was withdrawn, the temperature drops to about 30 degrees. Similar readings were observed for the humidity as shown in Fig 6(b).

3.2 Smoke Detection Test

The smoke detection system alerts the user in the event of a fire outbreak. The sensor reads and displays the level of concentration of smoke in the air and a buzzer sounds an alarm. Fig. 7 shows the real-time data from the MQ2 sensor when smoke is introduced by burning a piece of paper. It can be observed that the smoke concentration in the air measured in part per million (ppm) rises sharply when a smoke was introduced.

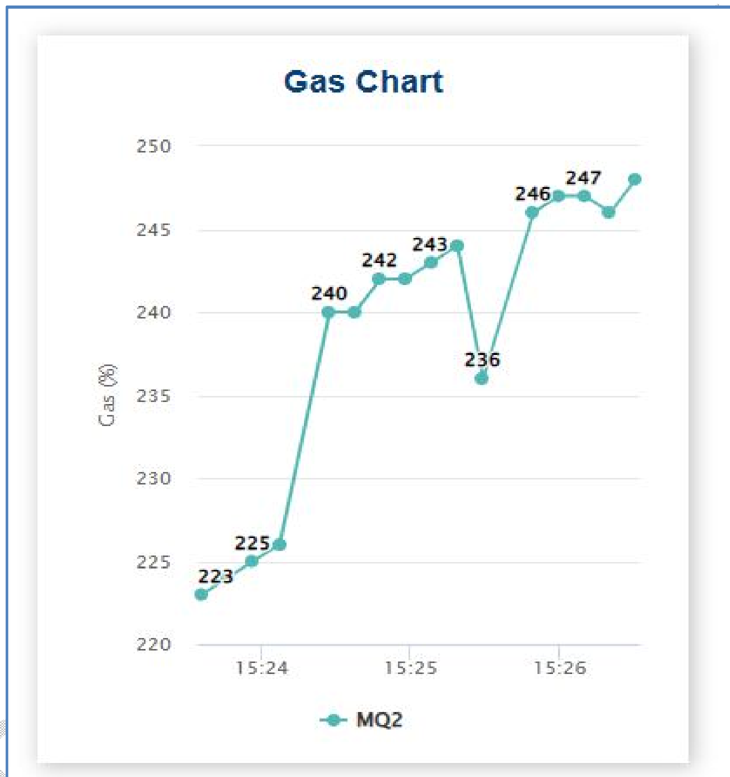
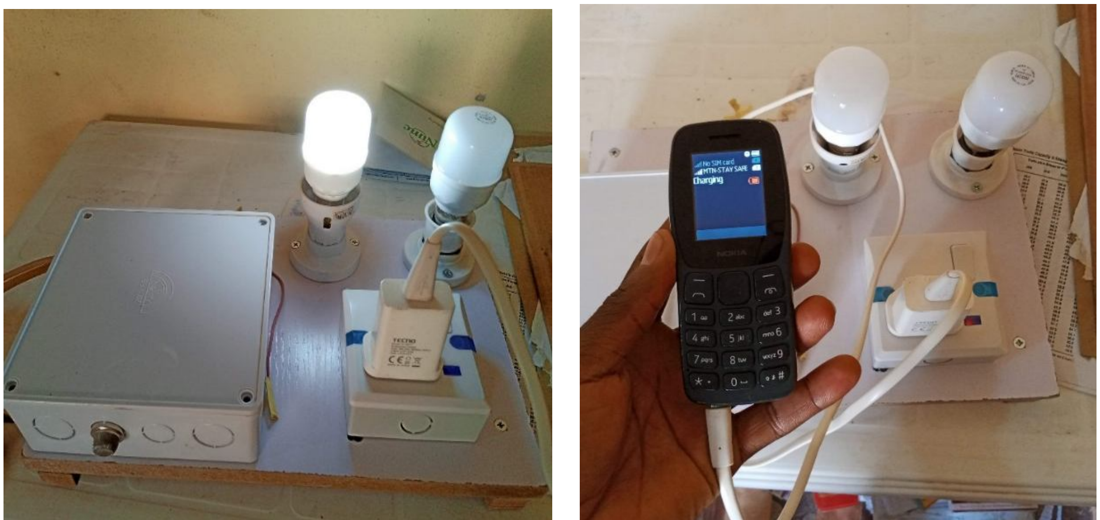


Fig. 7. Real-time measurement of smoke concentration in the air from the dashboard display

3.3 Control of Appliances

For the purpose of demonstration, two light points and two sockets were controlled remotely. Fig. 8 shows the test on the prototype system. The system was able to control the sockets via the webpage dashboard at a distance within the Wi-Fi coverage. Based on our test at various distances, a maximum coverage distance of 42.054 meters was achieved. A smart phone was used for hosting the dashboard, thus making the system portable, convenient and user friendly.



(a) (b)

Fig. 8. Real-time remote control of appliances (a) Lighting points control (b) Socket control

In order to test how fast the Wi-Fi module responds when a command signal is sent from the dashboard interface, the system was tested at different distances, ranging from 1 meter to about 42 meters (which is the highest range the Wi-Fi system was able to achieved). The response times shown in Table 1 were obtained by taking the average of a total of 100 trails at each of the specified distances by switching ON a socket. Two sets of response times were obtained before and after calibrating the system as shown in Table 1.

Table 1. Response time at different distances

Distance (meters)	Response Time (s) (Before Calibration)	Response Time (s) (After Calibration)
1.0	1.30	1.00
10.0	2.02	1.87
20.0	2.55	2.42
30.0	3.50	3.39
42.0	4.96	4.87

The results shown in Table indicate a slight improvement in the response time when the system is calibrated. Based on the regression analysis, the R-squared values of 0.9773 and 0.9828 obtained as shown in Fig. 9 for the calibrated and uncalibrated systems respectively indicate a strong correlation between the response time and the distance from where a command is initiated. Thus, the best position to place the system should be at a central location in the home in order to achieved a wide coverage radius.

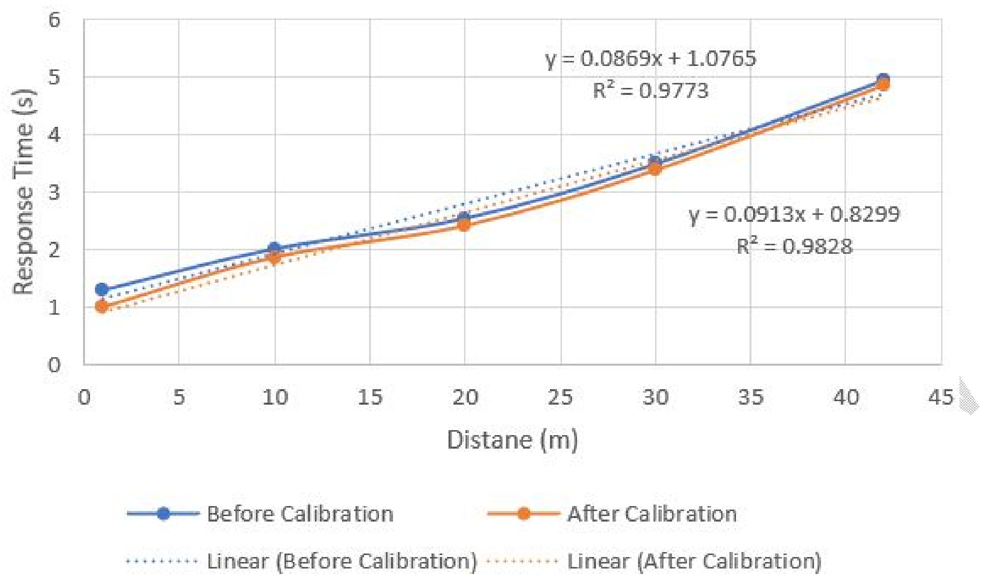


Fig. 9. Regression analysis for the system before and after calibration

4. CONCLUSION

This paper presented the design and implementation of a Smart Home automation system using NodeMCU, DHT11 sensor module, MQ-2 gas sensor module, relay module and web-based interface for the purpose of controlling home appliances and real-time monitoring of the home environment. Although the prototype system was able to control a handful of home appliances, nonetheless, the system can be upscaled easily to allow for complete control of all home appliances. A coverage range of up to 42.05 meters was achieved by the prototype system and a strong correlation was observed between the response time and the distance. Hence, it is recommended to positioned the system at a central point in the home for effective coverage radius. Finally, the system provides users with a convenient and inexpensive solution for real-time home control and monitoring using their smartphones.

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