DESIGN AND IMPLIMENTATION OF AN IoT-BASED SMART HOME CONTROL SYSTEM IN A TWO BEDROOM APARTMENT

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Abstract

Due to advancements in internet technology and smart systems, automation has become increasingly common in residential environments. This has led to the usage of smart, internet-enabled gadgets as a way to improve the control and security of electrical and electronic devices, as well as the facilities where they are installed, thus enhancing comfort and quality of life in our society. In Nigeria, citizens commonly turn on water pumping equipment so that water can be pumped into the storage tank whenever power is available. More so, people inadvertently forget to turn off switches and plugs before leaving their homes, especially when there is a power outage. These two acts call for smart control of appliances. This study describes the creation and application of a smart electrical appliance control system that makes use of the Internet of Things to allow remote switching of home lighting outlets and plugs from a web application on a Smartphone. Carbon paper, jumper wires, sockets, an AC bulb, terminal connectors, a microcontroller (ESP32), and relays were all employed in realizing the smart system. The created smart home control system was successfully installed in a prototyped two-bedroom apartment in real time to demonstrate the adaptability and efficacy of the system. In a series of performance tests, the entire system passed with an average precision of 100%. This demonstrates how an improved smart home control system improves the management and use of electrical equipment in a home.

Keywords: *Microcontroller***,** *Home* ***c****ontrol system, Internet of Things, Smart home, GSM module*

Introduction

In our increasingly digital world, the demands for efficient and effective control and monitoring systems for electrical appliances have never been higher. From smart homes to industrial settings, the need to manage and optimize the use of energy-consuming devices has become paramount. As technology continues to advance, electrical appliance control and monitoring systems have evolved to offer a wide range of benefits. These systems not only allow for remote control and monitoring of appliances but also provide valuable data on energy consumption patterns. However, implementing these systems can present challenges, such as compatibility issues with existing appliances and the need for skilled personnel to install and maintain them. Hence, research is being conducted to find new ways to overcome those obstacles. Notwithstanding, the introduction of IoT and the development of information technology have brought about quick changes in how electrical appliances and gadgets are monitored and managed at a facility. Combining these digital technologies enables smart connections for several internet- and Wi-Fi-enabled devices, which facilitate home automation and control, online security, and other functions (Shah & Mahmood, 2020; Yar et al., 2021). The usage of IoT-based smart home technology, which enables the interconnection of different devices and systems within the home and enables them to function together without a glitch, has therefore increased because of the provision of remotely controlled internet-enabled devices using the already-existing network infrastructure, enabling seamless connection between the real world and computer-based systems (Atzori, Iera, & Morabito, 2010). According to Viswakarma et al. (2019), this makes it easier for homeowners or users to monitor and manage a variety of electrical appliances and electromechanical systems from a single Smartphone app. It fully enables home automation, which leads to reduced energy use, fewer potential electrical risks like fire outbreaks or equipment or device damage, and more user comfort (Agarwal et al., 2019)**.**

Furthermore, there are two challenges, which are a cause for concern, that necessitate the need for remote control of electrical appliances in households in Nigeria. The first is that some citizens will frequently turn on the water pumping machine so that when mains supply is restored, water may be pumped into their water storage tank due to intermittent power supply in the country. Second, failure to turn off all switches and plugs before leaving one's premises, especially when heating elements like electric pressing irons, hot plates, water heaters, or water pumps are involved, greatly increases the risk of equipment damage and fire outbreaks, making the immediate area risky for everyone. However, IoT-based smart control systems for the home give users the convenience of remote access, allowing them to manage their appliances even when they are away from the house. This gives users peace of mind and allows them to make adjustments or turn off devices that may have unintentionally be left on, which can help prevent future problems. More so, this smart control system also offers the convenience of scheduling and automation (Ilesanmi et al., 2023). Hence, users can set timers or create routines to turn on and off appliances at specific times, reducing the stress of forgetting to switch them off manually. This not only promotes energy efficiency but also reduces the risk of electrical hazards caused by appliances left unattended and contributes to energy conservation by allowing users to remotely monitor and manage their energy consumption by being able to turn off appliances and lights when not in use to save on electricity bill.

Literature review

IoT-based smart home technologies have been adopted in a number of industries to allow intelligent communication between people and technology without direct physical contact. Early intelligent home systems used Bluetooth technology, but its bandwidth had several restrictions. The development of digital communication and Internet of Things (IoT) technologies removed this restriction by enabling global interoperability for microwave access (WiMAX), Wireless LAN (Wi-Fi), ZigBee, and the GSM, which made it possible to control all household appliances and devices from any location in the world using an internet-enabled phone (Morshed et al., 2015). For connecting to and managing electrical devices, these communication methods offer several alternatives. For larger homes or outdoor automation, WiMAX, for instance, offers a broad coverage area and fast data transmission. While ZigBee is perfect for low-power devices that need long battery life, wirelesses LAN (Wi-Fi) is frequently used to link devices within a constrained range. Through mobile networks, the GSM provides remote control of home automation systems.

An automated smart house system was created using a Raspberry Pi and computer vision technologies (Patchava et al., 2015). The Raspberry Pi controls devices, takes video, and spots movement while invader is detected using computer vision technologies. Short messaging service (SMS) is used by Raspberry to alert user when an incursion is found. A smart house system incorporating a ZigBee Wi-Fi gateway, sensors, and actuators was presented by (Vivek & Sunil, 2015). It connects to a cubie board control unit, which includes a gateway and a graphical user interface, by wirelessly receiving signals from a distant place. A low-cost Raspberry Pi-based home appliance control system for three-bedroom apartments has also been suggested by (Jajodia & Das, 2017). The protection of persons and property depends on security systems, so, Nathan et al., (2015) developed an automated system that controls doors and windows based on weather conditions, including temperature, humidity, and other elements. (Rajeev & Seong, 2013), used an Android phone to control home appliances including fans and lights and to monitor their status. They also used the Android phone to send commands to an Arduino board using a Wi-Fi module. Another IoT-based home security system was presented by (Sisavath & Yu, 2021). The LPC1769 microprocessor and APP module make up the system. Between the PC, the node board, and the APP, the chip transports data. The switches via the APP control the Gusset plate's LED Light, and they display the temperature and humidity readings that the node board's DHT11 sensor sends to it. Additionally, (Singh et al., 2018) presented a smart home system based on an Android phone and an Arduino microcontroller. A smart home automation and security system that employs a biometric fingerprint scanner, keypad, calling bell, and an electronic lock with password verification to prevent unwanted access to the system was proposed in (Mostakim et al., 2020). The system consists of a camera that takes pictures and records videos, as well as a microcontroller that manages the device. Utilizing a Facebook post with an image and statement, the user may also keep an eye on the state of their house or place of business.

This project's goal was to remotely manage the lights and sockets in a model two-bedroom apartment using a Smartphone and the Ubidots web interface. The user's instruction is send over the internet; the microcontroller decodes the user's command, utilizes it to control loads, and updates the web application with the system status.

System design analysis

The two components of the system design are hardware design and software design. The relays, AC loads, mobile phone, mains and regulated power supply, and ESP32 microcontroller with inbuilt WiFi module is used to form the hardware structural design while a code burned into the microcontroller together with the codes in the Ubidots App form the software component. In Figure 1, the block diagram is presented. The relays are utilized to control the lighting and outlet sockets over the internet. By a click on the buttons on the Ubidots web App interface, the user sends a message to the microcontroller. The microcontroller decodes the user commands and uses them to regulate the loads and update the web application. With this, users can communicate with lighting fixtures and plug outlets using the program, which acts as a central hub. The program delivers signals to the microcontroller, which in turn gives the relay the proper instructions to operate the lights and outlet locations.

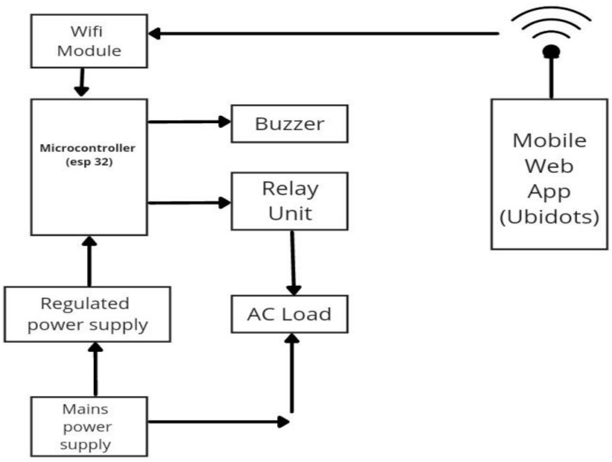

Figure **1**: Block diagram of an Electrical Smart Home Control System

Hardware Components

Microcontroller ESP32

The ESP32-DevKit includes two processors with built-in Bluetooth and Wi-Fi modules. It has 30 pins and can execute 32-bit programs. It features a 512 kb RAM and a clock frequency that can reach 240 MHz. Additionally, it supports a wide range of peripherals, which includes but not limited to capacitive touch, ADCs, DACs, UARTs, SPI. It has inbuilt temperature sensor and a Hall Effect sensor, and it is an open source microcontroller that may be used to carry out a variety of tasks using the Arduino IDE. The board consists of several digital and analog input/output pins and it is an open source IoT platform with the capacity to connect to Wi-Fi and function as a microcontroller. This functionality it to send and receive signals, which enable the user to send commands, needed the Relay to carry out its operations.

Relay Unit

The relay unit is a single Pole Double Throw (SPDT) 16 channel relay module. It is employed to control the input signal to the electrical appliances (switches and sockets) used in this project. It uses 5 VDC from the Arduino ESP32 to operate. Because it has two contacts that may be configured in normally closed or open mode and one common terminal, the SPDT relay is especially useful in this application.

Power Supply

The AC part and the DC part make up the power section and the load, respectively: The microcontroller is attached to the regulated power supply, which has a 5 VDC output, while the lighting outlets and sockets are connected to a 220 VAC power source. The relay unit and buzzer, all receive 5 Vdc from the controller. Figure 2 depicts the circuit layout of a regulated 5 VDC supply.

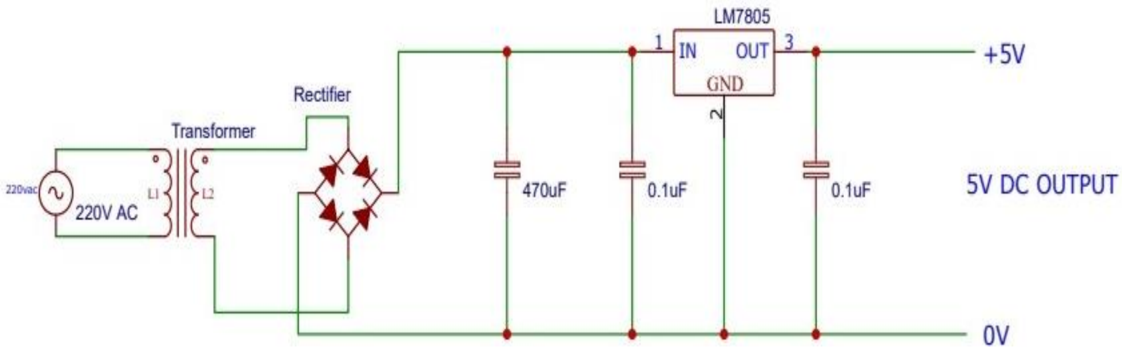

Figure 2: 5V Voltage Regulator circuit

Buzzer

The buzzer is a piezoelectric-type electromechanical audio signaling device. The fundamental job of the device is to change an audio signal into a sound signal. It is frequently utilize in timers, printers, alarm clocks, computers, and other DC-powered machinery. It can be tune accordingly to produce several sounds, such as alarm, music, bell, and siren. It serves as a buzzer in this project to signal the microcontroller's connection to a hotspot produced by a mobile device or router's internet.

AC Load

The number of bulbs required for each room is calculated using the lighting formula. To determine how much light is required for each room, either in foot-candles (imperial measurements) or lux (metric measurements), the Illuminating Engineering Society's (IES) suggested lighting table is utilized. One candela is equal to the lighting produced by one standard candle, and one foot-candle is the amount of illumination on a surface produced by a light source that is one candela distant from the surface. The 20 W AKT energy saving bulbs, with a lux output of 2800 lumens is used for the design. The following steps were followed to calculate the number of bulbs required per room: find the area of the room, calculate the required lumens for the room by multiplying the number of foot-candles by the area, and get the number of light requirement by dividing the required lumen by the bulb lumen. The calculation analysis for the lightening in the prototyped two bedrooms apartment is summarized in Table 1. The following expressions were used:

$$No. of\ Bulb = \frac{Required\ Lumen}{Rated\ Bulb\ type\ lumen} \quad (1)$$

$$Required\ lumen = Room\ Size * STD\ IES\ for\ room\ type \quad (2)$$

Table 1: Load table design

Room Type	Size (Square Foot)	Adopted IES require lumen (Lumen)	Lumen of Bulb Type	No. of Bulbs (approx.)
Bedroom	121	30	2800	1
Living Room	238	50	2800	4
Toilet and Bathroom	35	30	2800	1
Kitchen	49	40	2800	1
Store	35	50	2800	1
Terrace	56	70	1300	3
Corridor	40	50	1300	2

The layout of the two bedrooms flat is shown in Figure 3 and Figure 4 depicts the electrical wiring diagram.

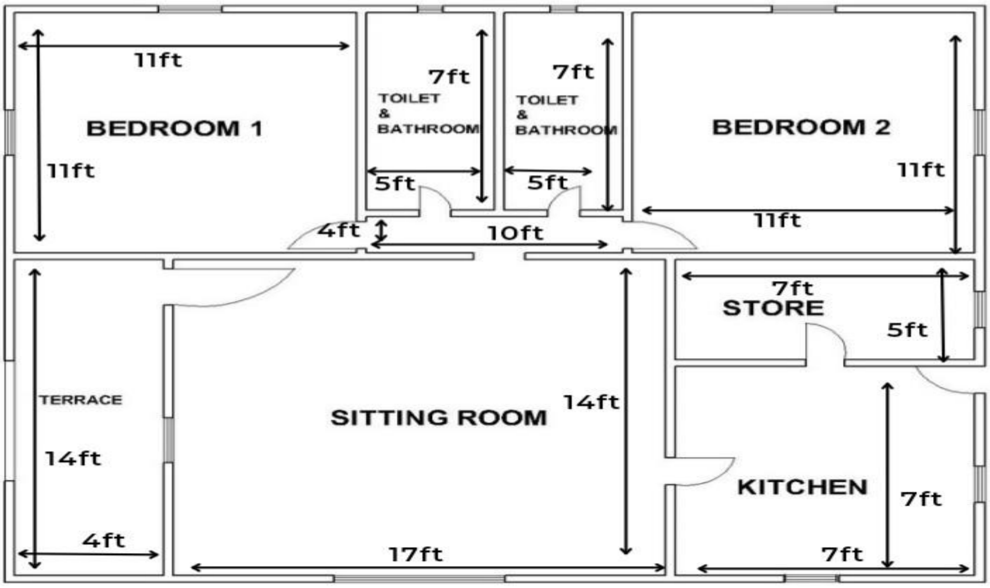

Figure 31: floor plan layout with dimensions

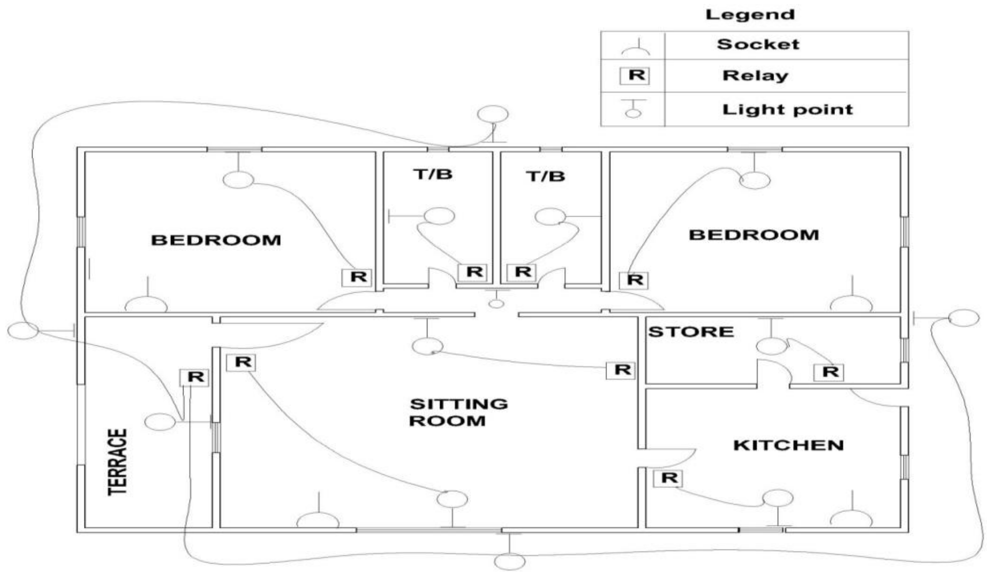

Figure 42: lighting points and socket outlet layouts

Software Components

Arduino IDE Software

A hardware programmable circuit board, also known as a microcontroller, and computer software are the two components of the open-source Arduino IDE platform for building electronic projects. The IDE is used to write and upload computer code to the physical board.

Ubidots IoT Platform web application

IoT applications can use the data analytics and visualization platform Ubidots. Sensor data is turned into knowledge that can be used for corporate decisions, machine-to-machine communication, academic research, and more effective use of the world's resources.

The other materials used for the construction and implementation of the electrical IoT-based smart home control system in the modeled house are plywood for the house walls, Carbon paper, Jumper wires, BC 547 transistor, Sockets, AC bulb, Terminal Connectors, Resistors and Diodes.

System implementation

The hardware implementation was done in a prototyped two-bedroom apartment while the software (the code to instruct the microcontroller to control the device) was implemented in the Arduino IDE, compiled and uploaded into the microcontroller ESP32. The microcontroller is connected to the internet via a smart phone's hotspot with the name; HOME and password; PASSWORD. Through the ESP32 circuit the microcontroller connects to the internet as configured on the Arduino IDE, to have access to Ubisoft web App and receive commands from the App. The microcontroller is connected to a 5 V regulated power supply. The remaining operations involve sending instructions to the microcontroller from the Ubisoft web application to operate lighting fixtures and the sockets, which are connected to the relay via a terminal connector, coupled to a 220 VAC source. The circuit diagram showing how the relay, load, and regulated power supply are connected is shown in Figure 5.

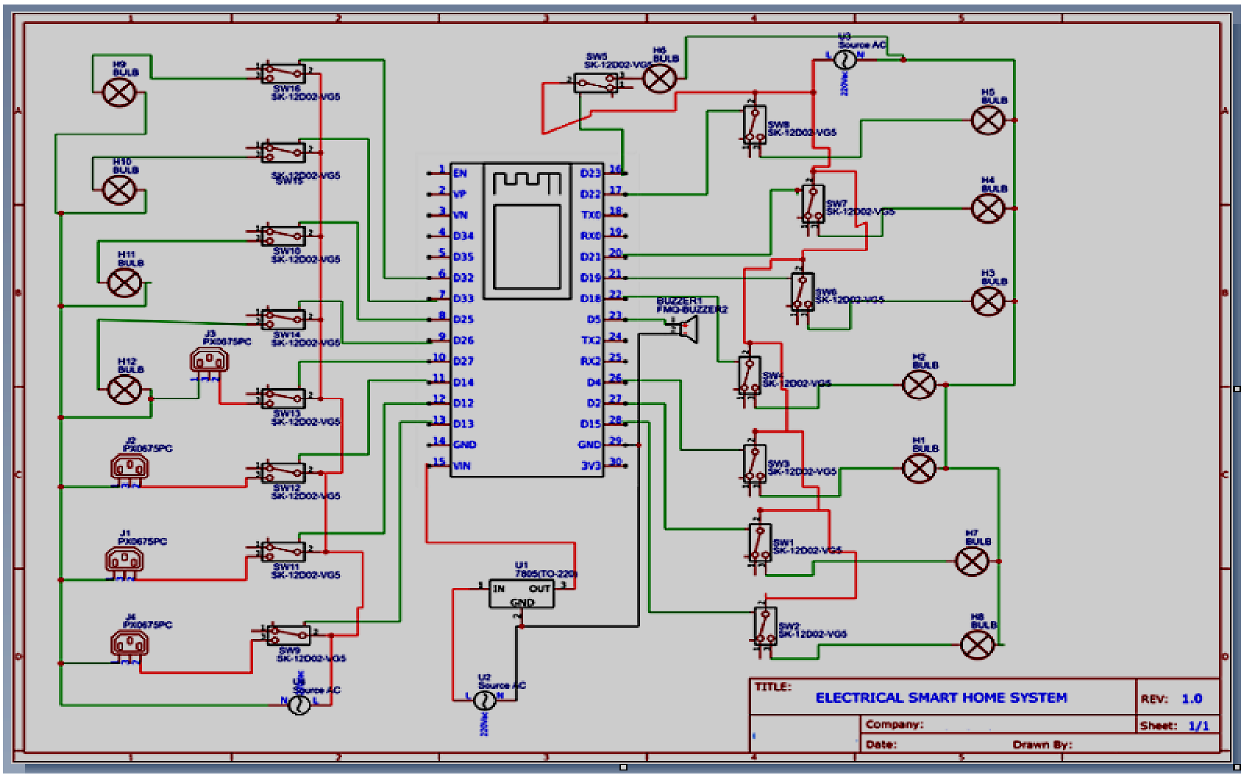

Figure 5: Circuit diagram of an electrical smart home control system

On the click of a button configured for the system on the Ubidots Web App, on the graphic user interface in the mobile phone, a command signal is sent to the microcontroller whose output controls the load accordingly. The user can send a command to the microcontroller to tell it what action to take in relation to the load using the cell phone as a communication channel. Figure 6 shows the system implemented in a prototype two bedroom flat, the outlook of the Ubidots display widget on the App, and the status of the GUI on the mobile phone and the load respectively.

Figure 6: The sectional view of the two bedroom apartment and the Ubidots interface

Result and discussion

The Ubidots web App provides access to the display widget for the lighting and socket outlet buttons in the two-bedroom prototype apartment. The compartment of the apartment are identified by their label on the display widget, such as security light, sitting room socket, bedroom 1 light, etc. The complete system was put through a series of performance tests to see how well it worked. The black colour of the button signifies an OFF state for the button, while orange colour denotes an ON state (Figure 7). In response to a user command provided through the mobile phone that houses the Ubidots display widget, the microcontroller commands the relay to turn ON or OFF a specific appliance. When pressed, the button widget changes the state of the buttons and shows the electrical loads' status (ON or OFF). Figure 7 depicts this process. Percent Precision was used as a metrics for the evaluation of system performance, and it is expressed mathematically as:

$$\% \, Precision = \frac{(No.of \ good \ functional \ performance)}{Total \ No.of \ attempts} \times 100 \qquad (3)$$

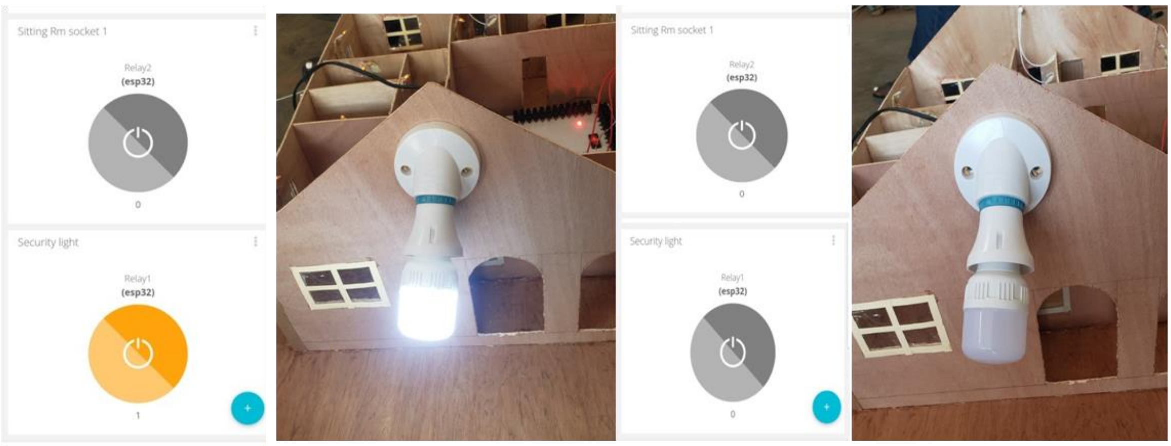

Figure 7: Sectional view of the designed system performance on test

Additionally, the developed system's functionality was tested by giving it ten (10) different tries to determine its performance, and the results are presented in Table 2.

Table 2: Result of the several test carried out on the system

S/N	Compartment	No. of attempts	Functional performance	Precision (%)
1	Sitting room	10	10	100
2	Kitchen	10	10	100

3	Toilet and Bathroom	10	10	100
4	Bedrooms	10	10	100
5	Store	10	10	100
6	Terrace	10	10	100
7	Passage	10	10	100
	Average precision			**100**

Table 2's conclusion reveals that the system's average precision was 100%. By this, the web interface in the IoT-based smart home control system implemented in a two-bedroom apartment was able to turn ON and OFF the lighting points and socket outlets.

Conclusion

This study uses the ESP32 microcontroller to create and implement an IoT-based smart home control system. The users can remotely control appliances using the IoT-based smart home control system. The Ubidots widget's buttons served as a channel of communication between the user, the microcontroller, and the load. The system's main components are the ESP32 microcontroller, the relay module, and the home appliances. The results of the real deployment of the IoT-based smart home control system show that each feature was functionally successful. The completion of this project enables electrical home appliances (lighting and sockets) to be operated easily online, which improved the security and convenience of utilizing and operating electrical devices in a home. This was accomplished using a web application on a Smartphone and an ESP32 module. In general, this smart control system improves the security and convenience of utilizing and operating electrical devices in a home.

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