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Towards Sustainable Smart Living: Cloud-Based IoT Solutions for Home Automation

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Abstract

In recent times, the realm of home automation systems has garnered significant attention, thanks to the ever-evolving landscape of communication technology. The concept of a smart home, essentially an application of the Internet of Things (IoT), leverages the power of the internet to oversee and employ household appliances through a sophisticated automation infrastructure. Nevertheless, challenges persist within the existing home automation systems, such as constrained wireless transmission reach, a deficiency in backup power management, and the substantial financial outlay involved. Addressing these limitations, our study introduces an economical and resilient solution that combines cloud based IoT with an uninterrupted power management system, making a cutting-edge home automation prototype. This system relies on a microcontroller unit, specifically the ESP-32, which functions as a Wi-Fi-enabled gateway for connecting a variety of sensors and transmitting their data to the Blynk IoT cloud server. The data assembled from a multitude of sensors, including vibration sensors and voltage detectors, becomes readily accessible on users' devices, be it smartphones or laptops, irrespective of their geographical location. The system is further strengthened by a set of relays that link the ESP-32 with household appliances, allowing for centralized control. Structurally, the design uses a control box that can be seamlessly integrated into a real home environment, offering the means to both monitor and govern an array of household devices. This IoT-based home automation solution not only efficiently manages internet-connected appliances but also provides an effective emergency power management system, enabling remote initiation and deactivation of backup generators. It represents a innovative leap in the evolution of home automation systems, steering in convenience, efficiency, and cost-effectiveness.

Keywords: Cloud, Internet of Things, Automation, Sensors

1. INTRODUCTION

An aspect of the Internet of Things concept that aims to incorporate smart home devices is an automated home. The ability to constantly handle and monitor home appliances and gadgets is made possible by connecting them to the Internet. Home automation include thermostats that change indoor temperatures and produce energy usage data, light switches that can be controlled by a smartphone or voice

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command, and smart irrigation systems that start at a certain time of day and on a personalized monthly plan to save water wastage [1]. Various devices can now seamlessly communicate with each other, thanks to recent technological progress enabling wireless control through technologies such as Bluetooth and Wi-Fi. This innovation eliminates the necessity for physical connections between the Arduino board and a computer, reducing expenses and allowing the Arduino to operate independently. By employing a Wi-Fi shield to transform the Arduino into a Micro web server, this shield serves as the bridge for the Arduino to connect with the internet, relying on a wireless network or hotspot for internet connectivity. Leveraging this concept, a home automation system based on the internet is established for remote monitoring and control of household appliances [2].

The increasing advancement in wireless technology has enlarged the field of application of internet services [16]. Notable such application was in the deployment of wireless internet infrastructure in the monitoring controlling of industrial and military equipment. In recent times, such application and development have spanned across many nontechnical environments specifically in the home. The application of wireless monitoring and controlling of devices at home, dubbed, Home Automation System (HAS) has taken the central focus of IOT developmental research and application. With such increasing demand and ever-present research opportunities in area of controlling 'things' using internet, the developing world have not been left out, though home automation systems were widely considered as technology only applicable in an advanced developed society [3]. However, recently, emerging research has sprung up targeting the design and expansion of home automation systems for evolving and underdeveloped nations. Unlike more developed countries such as USA and UK, in Africa, especially in Nigeria, the development and application of home automation system continue to face numerous challenges such as lack of material and components needed for the design and construction of the system and most importantly, the issue of lack of stable power supply. Constant electricity supply is required for the function of any home automation system. Without constant power supply, the main purpose of monitoring and controlling devices at home and its environs is defeated [4].

IoT has engrossed numerous attentions in terms of research. Several ideas and implementation of home automation system using IoT technology have been at the front burner of many recent research works. Research by [5] "Smart Energy Efficient Home Automation System using IoT". In their research, they meticulously outlined the sequential procedure for a sophisticated smart home automation controller. Harnessing the power of design control, they harnessed IoT technology to metamorphose ordinary household appliances into intelligent and cutting-edge devices. Also, [6] proposed "IoT Based Smart Security and Home Automation" Their innovation centers on a system providing user-friendly home automation features, complete with an integrated camera module to enhance home

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security. Essentially, their Android software transforms a smartphone into a multifunctional remote control for all household devices, offering a unique blend of convenience and safety. In order to make home energy usage more accessible, "A Dynamic Distributed Energy Management Algorithm of Home Sensor Network for Home Automation System" paper presented by [7] Proposes an innovative approach to optimizing residential energy usage through the utilization of Power Line Communication (PLC). Additionally, the proposal introduces a unique Zigbee and PLC-powered gateway for monitoring the generation of renewable energy. To maintain a steady power supply for home networks, the implementation of ACS and DDEM algorithms is recommended for the development of an intelligent power management system, marking a distinct advancement in the field of energy efficiency. Again, "Enhanced Smart Home Automation System based on Internet of Things" was proposed by [8] the proposed methodology for reducing computing overhead in existing smart home solutions.

These solutions employ intermediary gateways to link various sensor devices and use encryption algorithms like AES, ECHD, and hybrid. The proposed model provides a distinctive avenue for automation through sensor-based learning, a novel concept not readily available elsewhere. The system was developed using a temperature sensor, while additional sensors might be used depending on the situation. The research "Visual Machine Intelligence for Home Automation" by [9] introduces an unparalleled machine intelligence system designed to employ visual recognition for identifying the operational status of everyday household devices. The proposed method of appliance status detection culminates in the creation of a groundbreaking home automation system, setting a new standard in household automation technology. Moreover, [10] proposed a cost-effective Home Automation System (HAS) utilizing Wi-Fi, outlining a clear strategy for smart device communication. Another investigation by [11] focused on developing a voice-controlled home automation system integrating Natural Language Processing, artificial intelligence, and the Internet of Things (IoT). This system, incorporating technologies like GSM and NFC, offers an affordable means of interacting with home appliances. [12] introduced a cloud service designed to detect intruders, signaling law enforcement when necessary, using infrared security cameras in each room. Meanwhile, [13] delved into the healthcare aspect of ubiquitous and cloud computing, implementing a scalable cloud-based system tracking vital signs through embedded sensors.

In a distinct approach, [14] developed qToggle, an IoT-based Smart Home Automation System using an Application Programming Interface (API). This system, employing ethernet communication through ESP8266 and Raspberry Pi, enables users to control various home gadgets and sensors via a smartphone app. Conversely, [15] explored a home automated system using Bluetooth and an Android application, emphasizing voice prompts for user-friendly control. While

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existing literature predominantly relies on Bluetooth and Wi-Fi communication protocols, limiting the operator's proximity to the home application, this study identifies such limitations as a unique challenge. Consequently, the research addresses this issue by adopting cloud computing, overcoming distance constraints. Additionally, recognizing the vulnerability of home automation systems to power fluctuations, the study incorporates an uninterruptible power supply unit and provisions for emergency generator management to ensure system reliability under varying power conditions.

2. METHODS

In IoT-Based Smart Home Management System, the process that facilitates the design and development of the system was carried out in numerous steps.

2.1 IoT Smart Home Management Block Diagram

The operational framework of this study is illustrated in Figure 1 through a comprehensive block diagram. Serving as the central controller or microcontroller, the ESP-32 MCU unit plays a pivotal role in the system. Users interact with a mobile application to program commands for appliance operation, conveying switch instructions. The mobile app then wirelessly transmits these instructions to the ESP-32 MCU unit via a Wi-Fi network established using Wi-Fi communication. Embedded within the ESP-32 MCU, the Wi-Fi module facilitates seamless connectivity between the microcontroller and household devices, receiving commands from the application through cloud-based communication. Upon receiving the signal, the ESP-32 MCU utilizes an 8-channel relay to activate or deactivate the connected appliances. Physically interconnected, the relay, home appliances, and ESP-32 MCU collectively form an integrated system. A distinct power supply unit fuels the microprocessor, relay, and connected appliances. This power unit, supporting the 8-channel relay, MCU, and wireless router, is composed of a DC power source and incorporates a battery backup system, ensuring continuous functionality and reliability in case of power interruptions. The power supply unit is connected to an automatic changeover system that can supply power from either the mains supply or the emergency generator during failure of the mains. The ESP-32 can automatically detect the availability of both the mains and emergency power supplies and preferential connection is given to the mains supply. The auto starts and stop system for the emergency generator is also physically linked to the ESP-32. This system is used to start an emergency generator both in cold and hot conditions (when choke closed and open respectively). This module performs several functions summarized in the following steps:

1) If the generator is to be started in cold condition, the carburetor choke is shifted to closed position, or open position if it's to be started in hot condition.

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2) After the choke has been set, the module cranks the generator.
3) The system continues to monitor the revolution of the generator using the vibration sensor to detect when the generator has started.
4) When the generator has been detected to have started, the module automatically stops cranking of the generator while at the same time shift the carburetor choke position from closed to open.
5) Finally, the automatic change over switch supply generator output to the system power supply and backup unit.

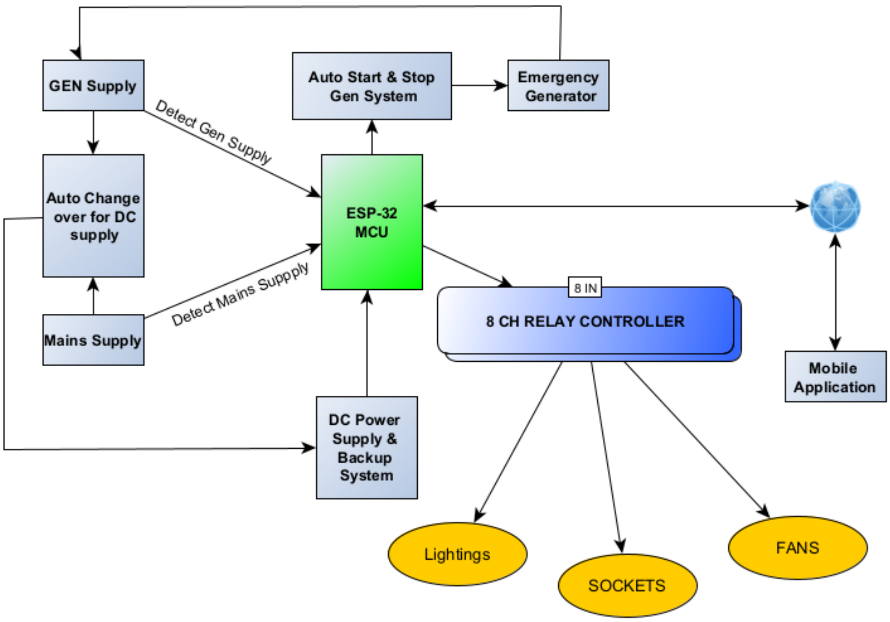

Figure 1. Block Diagram of Proposed System

2.2 Software Design

The realm of IoT software relies on platforms, embedded systems, collaborative partner systems, and middleware to address its primary functional domains: networking and control action. This investigation specifically employs the Blynk app within the IoT network, serving multifaceted purposes such as data collection, device integration, real-time analytics, and the extension of applications and processes.

2.3 Data Collection

The software dedicated to IoT data collection manages various aspects including data aggregation, data security, data filtering, and sensing [17]. Its functionality lies

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in facilitating real-time connections between sensors and machine-to-machine networks through the implementation of specific protocols. In this study, the IoT device gathers information from various sensors and disperses it in line with parameters. Additionally, it was also operated backwardly by dispersing data between devices. Eventually, the system sends all of the data it has gathered to a centralized server.

2.4 Device Integration

The interconnectedness of all system devices is achieved through software-supported integration, shaping the physical structure of the IoT system. In this research, a streamlined process of device integration facilitated efficient connection of appliances to the network. Recognizing the indispensable role of the app, it stands as the defining software technology within the IoT network.

2.5 Real Time Analytics

The smart home automation studies provide for real time analysis and monitoring of the connected devices and gadgets. Real time analytics software are programs that transform data or input from numerous devices into actions that may be taken or into distinct patterns that can be examined by the users.

2.6 Choice of Programming Language

The choice of programming language was C++. C++ is the programming language developed and used in the Arduino IDE and sketch. It was pertinent to use this language since the design requirement and coding of the ESP-32 was done using the Arduino IDE. Another reason for choosing this language is because the ESP-32 libraries was developed in C/C++.

2.7 ESP32-Algorithm/Pseudo Code

Require: Monitor, control home appliances and manage emergency generator remotely.
Ensure: Continuous monitoring in real-time, encompassing aspects such as light, power supply, and emergency generator status, coupled with the ability to remotely command household devices such as lights, fans, water pump, and doors. Hence, we present the algorithm used in implementing the IoT system in this study as follows.

```
1.  Start
2.  Define Wi-Fi Access Point Username/Password
3.  Define Blynk Authentication_KEY & Blynk Server
4.  Define ESP-32 GPOI for Relay board // For switching actuators
    (lights, motor, fan, buzzer and appliances)
```

```
Define ESP-32 GPOI for sensors // For getting sensors data
V ← Vibration value // From Vibration sensor
V1 ← Voltage value // From Voltage 1 detector Sensor
V2 ← Voltage value // From Voltage 2 detector sensor
Set threshold SENSORS values: V, V1, V2
Initialize system // Switching OFF the system at t = 0
ESP-32 is connected to the Internet via Wi-Fi AP
Blynk server is connected to Blynk App
ESP-32 acquire the sensors data
for each round do
Get V, V1, V2
Upload data to Blynk Server over Wi-Fi
Update status of sensors/actuators in Blynk server
Synchronize data to Blynk Dashboard App. using Smartphone
Case (Light_Switches)
   if (Light_Switches (between 1-8)) then
   Switch ON lights according to the switch number
   else
   Switch OFF lights
   break;
Case 2 (Choke)
   if (Choke) then
   Switch Choke in closed or COLD position
   else
   Switch Choke to HOT
   break;
Case 3 (GEN_CO_SW)
   if (V2 >V1) then
   GEN_CO_SW Switch TO GEN
   Notify user
   else
   GEN_CO_SW switch to NEPA
   break;
Case 4 (GEN_CO_SW)
   if (V1 == V2) then
   Notify user
   GEN_CO_SW switch to NEPA
   break;
Case 5 (GEN_Slider)
   if (Gen_slider is slide to 1)
   Put the Gen on the ON position
   break;
Case 6 (GEN_Slider)
   if (Gen_slider is slide to 2)
   Crank the Gen
   if (V<3.30V) then
   GEN slider return to position 1
   else
   GEN slider return to position 0
   break;
end for
User monitors all sensors data in real-time remotely via Blynk
Dashboard App
Remotely control appliances via Blynk application
END
```

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3. RESULTS AND DISCUSSION

3.1 System Requirement (Hardware)

3.1.1 ESP32

As the primary controller, ESP-32 was used to link various sensors and gadgets to the internet. The ESP-32 was used in this study due to its simplicity, functions and programming skills. The ESP-32, a compact embedded system featuring 38 GPIO pins, assumes a pivotal role in cloud-based IoT applications. Its significance stems from the dual-mode Wi-Fi and Bluetooth (BT) connectivity capabilities embedded in the ESP32 module. As the central processing unit of the project, the ESP-32 stands out as a cost-effective and energy-efficient system-on-a-chip microcontroller, integrating Bluetooth and Wi-Fi functionalities. This study hinges on the ESP32 as its fundamental component, serving as the central nexus that interconnects all sensors. The board's programming, a critical aspect for project execution, employed source code written in C/C++, securely stored in the ESP32's on-chip memory. With an operational voltage range spanning 2.2 to 3.6V, the ESP32 ensures the smooth execution of the project's activities.

3.1.2 Pin Configuration of ESP-32

The pin configuration for the ESP-32 is shown in Figure 2.

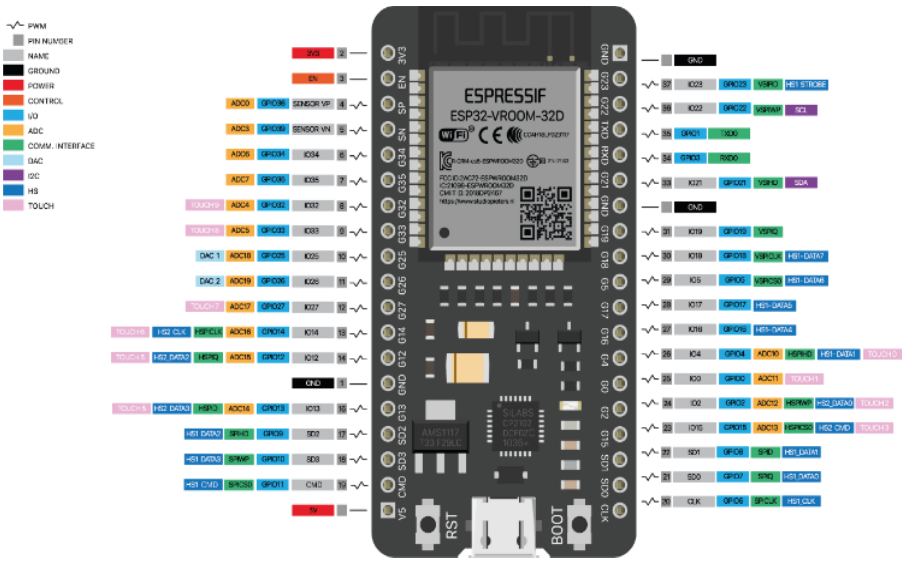

Figure 2. Pin configuration of ESP-32

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3.1.3 Relay Modules and Driver

The relay assumes a crucial function in this research, serving as the mechanism for overseeing high-voltage residential appliances. Employing a 5V 8-channel relay, the study effectively regulates eight appliances. This specific relay model incorporates eight control inputs (IN1 to IN8), along with VCC and GND, accompanied by eight outputs. Each of the eight appliances is connected to the relay's outputs, effectively governed by control inputs intricately linked to the ESP32's eight digital output pins, as illustrated in Figure 3.

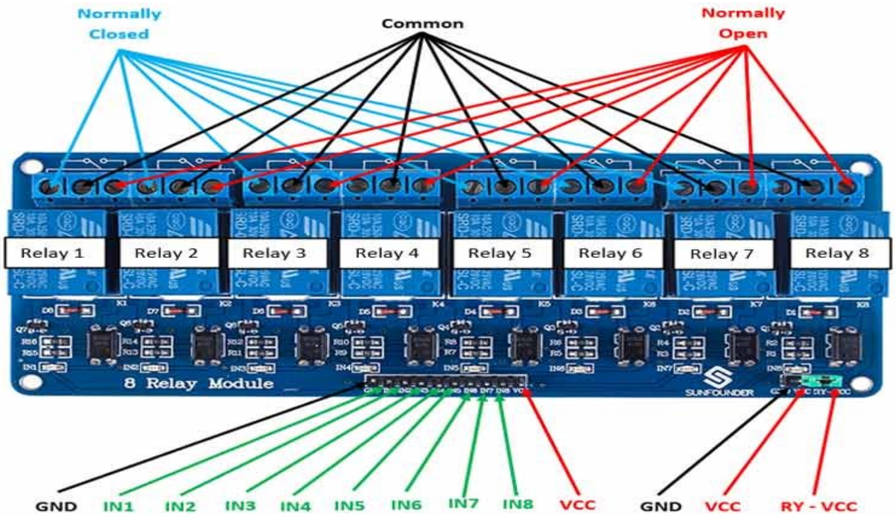

Figure 3. Channel Relay Module

The relay has two terminals, one of which is linked to the 5 V supply while the other is connected to ground from the 5V regulator. In addition to the 8-channel relay module, 6 more single unit relays were used for connection and switching for various circuit units including automatic change over unit for both battery charging and AC supply, auto choke system, automatic start and off of emergency generator.

3.1.4 Vibration Sensor

The level and frequency of vibration in a system, machine, or piece of equipment are measured by a vibration sensor. Vibration sensors were used to provide the system with information about conditions of emergency generator during cranking. This information enables the system to anticipate when the generator

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has started which then release the kick starter as well as activate the automatic choke mechanism to an open state thereby allowing the fuel carburetor to mix with air, which then achieved the process of auto starting of a generator. The sensor is shown in Figure 4.

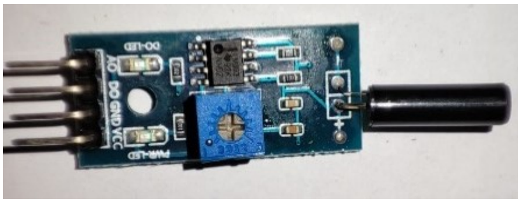

Figure 4. Vibration sensor

3.1.5 Motor-Slider-Crank Actuator

The motor slider crank actuator shown in Figure 5 is a device modified by the researcher for the purpose of controlling and adjustment of the choke lever of a small emergency generator. The construction and the operation of the crank actuator are as follows:

1) A gear reduction is created by turning a set of spur gears with a electric motor.
2) A rack-and-pinion gearset that is attached to the actuator rod is driven by the final gear.
3) The rack transforms the motor's rotating momentum into the required linear motion to move the choke from on to off position. While the motor has the ability to spin the gears and move the latch, however, doing it by hand does not turn the motor due to a clever centrifugal clutch that is attached to the gear and activated by the motor.
4) The metal hook in the image below moves right or left because it is horizontal when attached to the choke lever of the carburetor. When we pull the knob in or out, it imitates the movements.

Figure 5. Motor-slider actuator

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3.1.6 Battery

A 6V 4.5AH battery unit is added to the backup system for providing uninterrupted DC power supply to the home automation system. The battery is charged either through the mains supply or emergency supply depending on the one that is available at the moment. In the case of power failure, the system will continue to be powered through the battery thereby averting issues of electricity failure which can render the home automation system useless. The battery specification is shown in figure 6. With a portable Wi-Fi device, it is possible to concurrently connect at least 10 devices, such as smartphones, computers, tablets, and iPads, gaming consoles, cameras, and more, to the private internet connection virtually anywhere in the globe.

Figure 6. MTN MiFi wireless router

3.1.7 Other Hardware Components

Other components used in the development of the system include basic home appliances and gadgets, jumper wires, passive and active electronic and electrical components.

3.2 Software Requirement

The software design methods used to program the proposed system, the Arduino IDE Proteus IDE and Blynk IoT platform for creating Android, iOS and web portal for remote and cloud control of the smart home are covered in this section.

3.2.1 Arduino IDE

The composition, compilation, and direct uploading of codes into the microcontroller are accomplished through the Arduino IDE, an open-source software. In the course of this work, Version 1.8.19 of the Arduino IDE was employed. This environment serves as the platform for scripting the software code, supporting both C and C++ languages. Furthermore, it facilitates debugging, code modification, and the compilation and uploading of code to tangible hardware modules, providing a comprehensive suite of tools for development and implementation. A screenshot of a section of the project source

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code written using the Arduino integrated development environment is shown in figure 7 below.

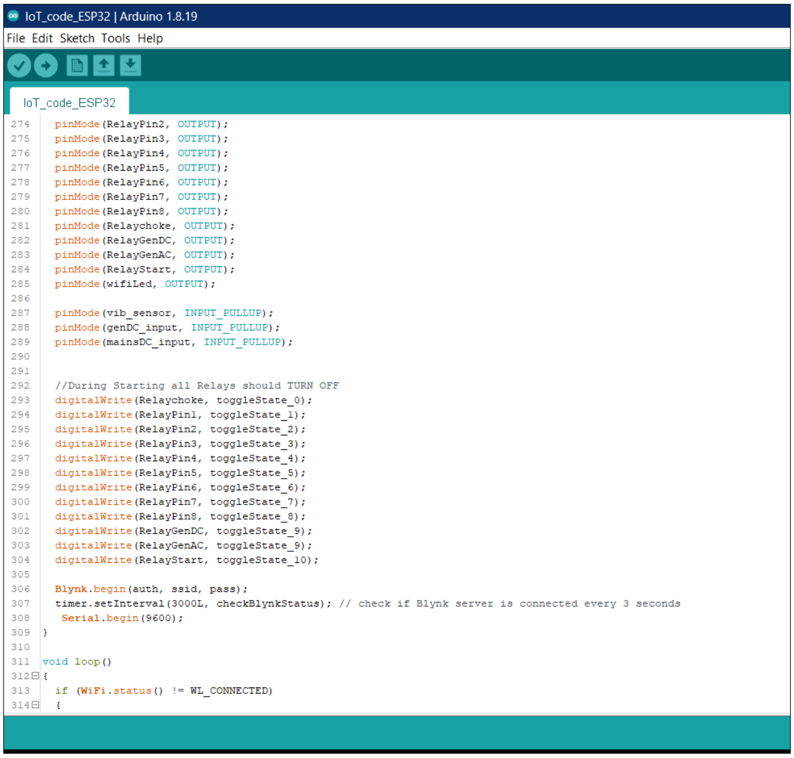

Figure 7. Arduino IDE

3.2. 2 Proteus IDE

Proteus IDE is a virtual system modeling (VSM) and circuit simulation application. Additionally, it contains a virtual system studio, a Proteus IDE that is available for free. Proteus VSM can be used for sophisticated embedded simulation, providing simulation at the system level based on the schematic circuit. Its database or library contains a large variety of components. If they are not already included in the original software library, additional components may be created as part of the library component in addition to their own database component. ESP-32 Library for Proteus is one example of such library components. The Proteus IDE was used in this project to design and simulate the project circuit diagram.

3.2.3 Blynk IoT Platform

Blynk stands out as an innovative IoT platform empowering user to craft personalized mobile applications, providing remote control and monitoring capabilities for a variety of devices and projects. Distinguished by its user-friendly

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interface, Blynk facilitates the creation of custom IoT applications even for individuals without prior programming experience. Its versatility extends to supporting various hardware platforms like Arduino, Raspberry Pi, ESP32, and more, streamlining the connection of sensors and other hardware components to the cloud.

At its core, Blynk is geared towards advancing the Internet of Things (IoT), enabling remote operation of devices such as Arduino and Raspberry Pi through IOS and Android applications. The platform offers an interactive digital dashboard where widgets can be effortlessly rearranged to construct the graphical user interface of a prototype. Beyond its intuitive design capabilities, Blynk boasts additional features, including data storage and visualization, sensor data display, and remote device operation.
The Blynk IoT platform comprises three integral components:

1) The Blynk Application: Empowers users to design visually striking interfaces for their IoT projects, utilizing a plethora of available widgets.
2) Blynk Server: Overseeing all connections from hardware to smartphones, it can be hosted locally as a private Blynk server or, as in this study, utilize the Blynk Cloud. Its open-source nature allows it to run on devices like Raspberry Pi, efficiently managing a multitude of connected devices.
3) Blynk Libraries: Facilitate seamless connectivity with the server, managing incoming and outgoing commands across major hardware platforms.

The operational mechanism involves a bidirectional communication process: clicking a radio button in the Blynk application dispatches a message to the Blynk Cloud, where the associated hardware, identified by a unique authentication token, is located. This process exemplifies the functionality outlined in Figure 8, illustrating the working principle of the Blynk application.

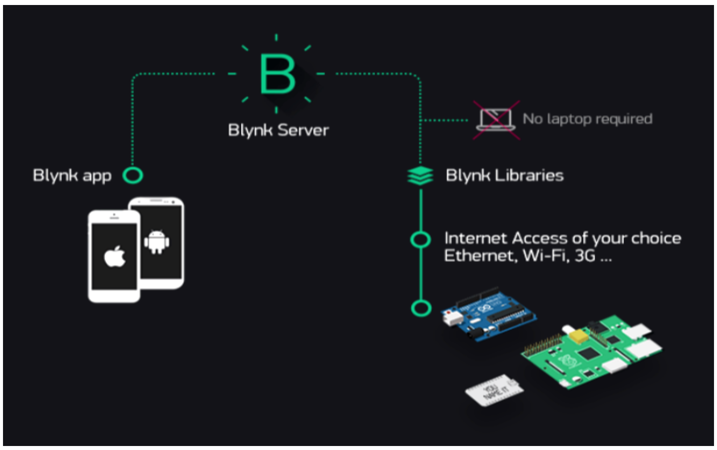

Figure 8. Working Principle of Blynk Application

3.3 System Specification

3.3.1 Use Case Diagram

The use case diagram indicating all actors and their specific roles is presented in Figure 9.

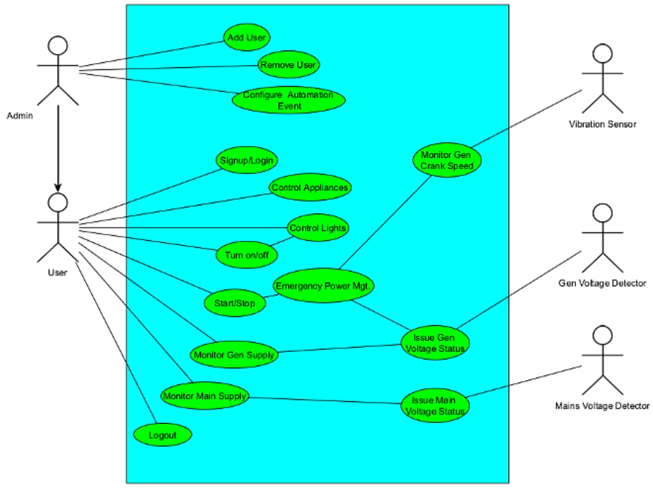

Figure 9: Use Case Diagram

3.3.2 Sequence Diagram

The sequence diagram indicating all interaction between users, Esp and the two endpoints is presented in Figure 10.

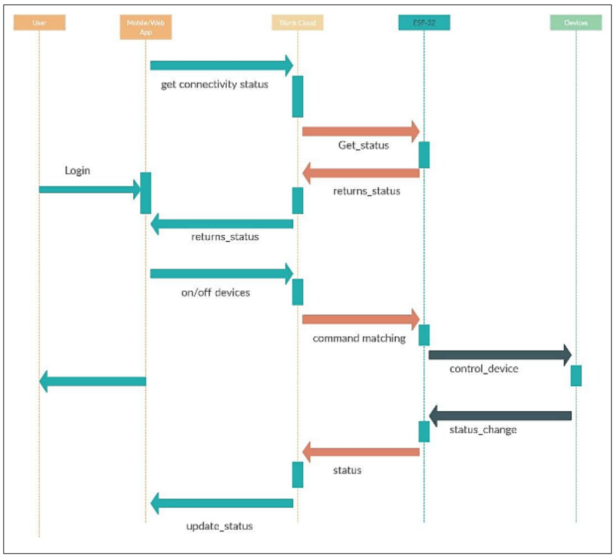

Figure: 10: Sequence Diagram

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3.3.3 Circuit Diagram

The project circuit diagram is shown in figure 11. The diagram is divided into six parts: mains supply AC to DC unit, Emergency supply AC to DC unit, Voltage detector units, the 8-channel output relay-controlled unit, the auto start and stop module and the home appliances connection endpoints. Also, the ESP-32 board is the brain of the circuit.

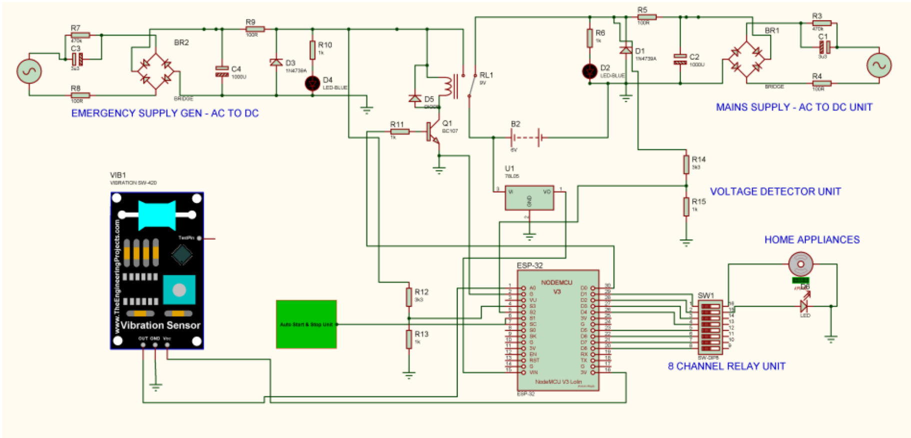

Figure 11. Project Circuit diagram

3.4 Smart Home Automation Implementation

The comprehensive design of the envisioned system is visually depicted in Figure 3.2. Throughout this study, the ESP-32 assumes the responsibility of processing and transmitting data acquired from the sensors. This information is directed to the Blynk IoT server, where the ESP-32 promptly responds to user commands issued via the server. These commands may include turning electrical appliances like LED lights ON/OFF. Leveraging its embedded Wi-Fi capability, the ESP-32 establishes a connection to the internet. Users of the application gain the ability to monitor data and regulate electronic appliances on the Blynk IoT server by accessing it through smartphone applications or desktop web browsers with internet connectivity. Application users receive notification through the real time reading of the sensor. For instance, when there is availability of mains or generator power supply, the voltage detector sensor will indicate it on the application through LED notification and also send the notification to the users. The Auto generator changeover system monitors the availability of the presence of mains and emergency generator supply. The changeover switch can only be operated when voltage sensor sends data to the server of the availability of only emergency power supply otherwise the changeover switch will only remain on mains supply. In case where the voltage sensors detect power supply from both mains and

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emergency supply, the changeover will default to mains supply. All the sensors in this research connected the analog to digitals input pins of the GPIOs of the ESP-32 and actuators and their output. The operation of the system is based on the coding written using C++ in the microcontroller. Sample sensors and actuators were used in this prototype project for demonstration. However, this system has the capacity to expand to include many sensors and actuators in the real application and implementation.

3.4.1 Implementation Procedure

The prototype of the smart home design includes the two standard bedrooms, a master bedroom, living room, two toilets, a porch, and a kitchen. The outside measurement is 50 cm x 50cm. The smart home prototype was fabricated using plywood. Using a hack saw, the plywood was cut to lengths and widths. Top bond wood glue was used to fasten the wood in the marked region. In order to reinforce the attachment, the plywood is fastened to the foundation of the house prototype with wood glue. The smart home prototype has three bedrooms, a master bedroom, a second bedroom, and a third bedroom. Included are a kitchen, living room, and two bathrooms. The wiring of the lights is arranged and installed on the wall and ceilings of the prototype. The top view section of the prototype house is shown in Figure 12. Hence, the full house prototype with light appliances installed is shown in Figure 13.

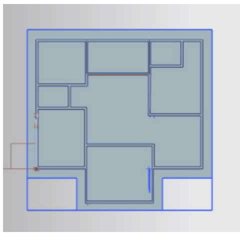

Figure 12. Top view of the design of the smart home prototype

Figure 13. Full house prototype with light appliances installed.

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The hardware assembly included the two AC to DC converters, voltage detectors, sensors, actuators connected to ADC pins of the ESP-32. The hardware assembly involve the connection of the specific pins to the GPIOs pins of the ESP-32 to the 8-relay module, changeover relays and emergency generator management circuits. The main functional assembly of the prototype was complicated due to various devices connected to it. The 8-relay module can be used to connect to any appliances to be controlled.

The most important step in hardware assembly was remembering which digital pin belongs to which relay. The Blynk application's configuration is followed for this connection. The radio buttons on the Blynk app are programmed to toggle a specific digital pin on the ESP-32. It is ensured that the relay connection is actually formed in accordance with this configuration. To illustrate the operation of the prototype, we connected the relays to LEDs in this design rather than actual household appliances. The prototype is supplied with backup power supply via a 6V battery while the mains and emergency power supply are used in conjunction.

3.4.2 Output Specification

With Blynk, it was possible to create custom dashboards that display real-time sensor data, receive notifications when certain events occur, and control devices remotely using android and apple smartphones. Blynk also offers a range of features such as data logging, integration with popular cloud services, and support for multiple user accounts. The screenshot of the android mobile and web Blynk interface used in this project is presented in Figure 14 and 15 respectively.

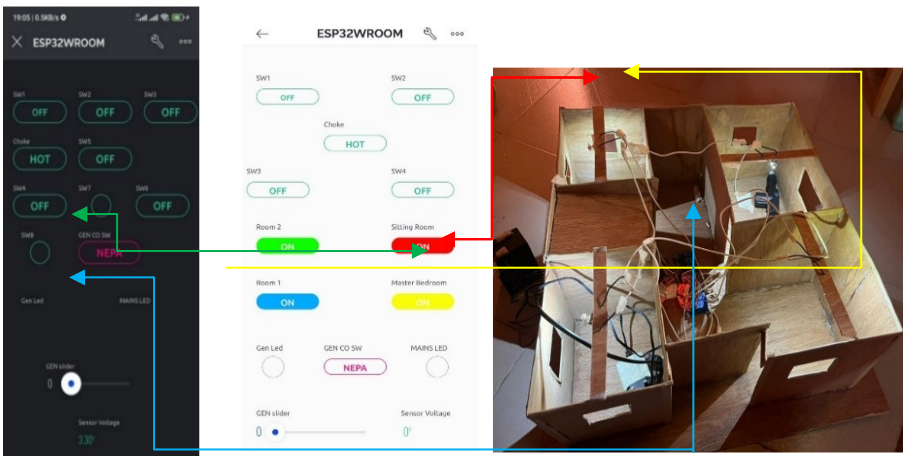

Figure 14. Blynk IoT Android App

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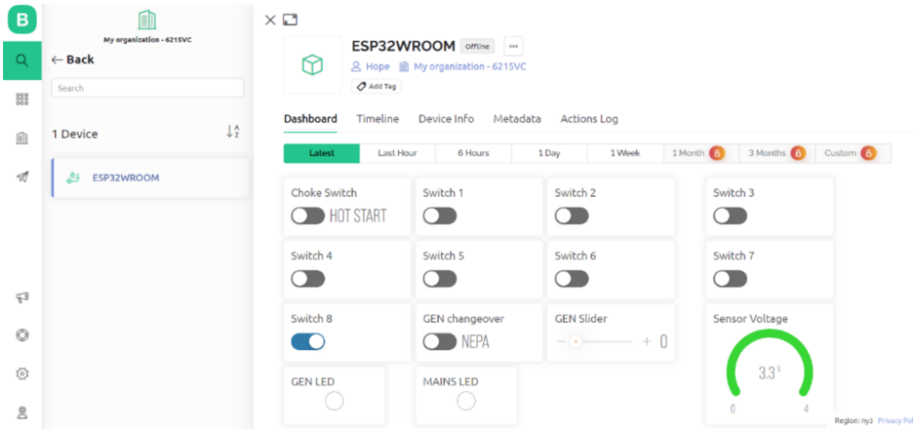

Figure 15. Blynk IoT Web Portal

4. CONCLUSION

The smart home automation system developed in this study successfully controls home appliances, monitor various sensors, operate emergency generator automatically with option for auto and smart changeover switch thereby guaranteeing constant power supply using smartphones/laptops through Blynk IoT-application. Users have the capability to monitor and manipulate smart home prototype from anywhere across the globe by merely connecting to the internet. A notable accomplishment of this research lies in resolving the challenge of power outages. This was achieved through the creation of a system featuring a backup power source, coupled with the ability to autonomously initiate and manage an emergency generator. This innovation presents a significant advantage for individuals residing in regions where a consistent power supply from the mains is unavailable. By creating several dashboards, users may operate and monitor their homes from anywhere at any time using any device that can connect to the Internet. Ensuring a continual link between the smart home system and the Internet involves tethering the ESP-32 to a pre-established Wi-Fi network. Nevertheless, the developed IoT-based home automation system, utilizing the ESP-32 microcontroller and cloud-based infrastructure, successfully addresses challenges in existing systems, such as wireless reach constraints and backup power management deficiencies. By seamlessly integrating into real home environments, the system not only efficiently manages internet-connected appliances but also offers a robust emergency power management solution. The obtained results align with the initial research objectives, demonstrating a significant leap in convenience, efficiency, and cost-effectiveness within the realm of home automation systems.

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Additionally, this study significantly contributes to the existing literature in smart home automation by presenting a comprehensive solution that not only controls appliances and monitors sensors but also addresses power outage challenges. The integration of a backup power source and an autonomous emergency generator management system distinguishes this research, particularly beneficial for regions with inconsistent mains power. The study's innovation in remote monitoring and control, facilitated by the Blynk IoT application and ESP-32, aligns with current trends in IoT-based home automation. However, the acknowledged sensor-related limitation underscores the importance of ongoing research to refine sensor integration, ensuring accurate and timely data collection for optimal system performance. Also, the Blynk app serves as the gateway for users to reach the integrated control system. This system facilitates the upward transmission of sensor data from the ESP-32 and the downward relay of instructions to the ESP-32. Accessibility to this control system is granted through any mobile device, laptop, or personal computer. As a result, users may manage all electrical appliances and keep an eye on the availability of mains supply and able to turn on and off emergency generator automatically. Hence, by assessing its functions against the constructed smart home prototype, the generated system's efficacy is confirmed.

Nonetheless, one of the problems faced during the testing phase of this research was maintaining a speedy and precise reading of the sensors, especially the vibration. The encountered limitation in the testing phase, particularly regarding the voltage disparity between the ESP-32 (3.3v) and the 5V operational voltage required for the vibration sensor, posed challenges in achieving speedy and precise sensor readings. The inability to directly power the sensor from the ESP-32 and the incompatible voltage ranges led to unreliable readings, causing delays in detecting generator RPM during cracking. This limitation could have influenced the results by introducing inaccuracies and delays in the data collected from the vibration sensor, impacting the overall performance and effectiveness of the home automation system. To address this in future research, it is crucial to explore alternative sensor options compatible with the ESP-32's voltage limitations or incorporate additional components, such as voltage dividers, from the outset. Additionally, optimizing sensor selection and placement, and refining calibration procedures may enhance the system's ability to accurately detect and respond to events, minimizing the impact of such limitations on the research outcomes. Conducting comprehensive testing and calibration procedures during the early stages of development can further contribute to overcoming potential sensor-related challenges in home automation systems. Nevertheless, the developed IoT-based smart home management system offers practical benefits by providing users worldwide with seamless control of appliances, sensor monitoring, and a reliable solution to power outages. With the ability to operate from any internet-connected device, it ensures constant power supply, especially beneficial for areas with inconsistent mains power. Despite sensor-related challenges, ongoing research can

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refine the system, enhancing its accuracy and overall effectiveness for widespread real-world applications. The innovation holds promise for improving both individual user experiences and contributing to the resilience of communities facing power reliability issues.

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