



ORIGINAL RESEARCH ARTICLE

MODELING A SOLAR-POWERED IoT SMART HOME

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ABSTRACT

The concept of smart homes has gained more interest in recent years, as the unwavering advancement in IoT technologies enable devices to operate and communicate autonomously. As urbanization accelerate and energy demand increase, on-grid energy system faces significant challenges, including high carbon emissions, energy inefficiency, and reliance on nonrenewable energy sources. The incorporation of solar power into this system not only reduces dependence on traditional energy sources but also promotes sustainability by utilizing clean, renewable energy. The research Present a comprehensive model that addresses these challenges, focusing on energy efficiency, seamless IoT integration, user interaction, scalability. A potable model called SMHome system is powered by solar energy, developed with an algorithm for monitoring and controlling the home autonomously over the internet. The Arduino Nano collects data from various sensors (temperature, motion) and communicates with the ESP8266 for Wi-Fi connectivity. The ESP8266 sends this sensor data to a cloud platform via TCP, allowing remote monitoring and control through a mobile app. Integration with the IFTTT app enables automation, where specific triggers from the sensors can initiate actions, such as sending notifications or controlling devices based on user-defined conditions. The proposed SMHome system is structured in a form that a potable box powered by solar energy can only be easily and efficiently control appliances over the Internet and support home safety with autonomous operation. By integrating solar energy with IoT technologies, the research demonstrates the potential for improved energy management, reduced environmental impact and enhanced quality of life for residents.

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1.0 Introduction

Automation systems, developed since the late 20th century, control home appliances remotely. Microcontrollers have reduced costs, but widespread adoption is often seen as hobbyist or affluent. Remote controls for TVs, fans, air conditioners, and music players are implemented. Electricity and technology have led to a new era of home appliance control through mobile devices like Bluetooth, ZigBee, Wi-Fi networks, and GSM modules, but these systems do not allow residents to monitor and manage their homes from outside. Existing systems offer convenience, comfort, and safety but lack energy efficiency. Most do not utilize IoT technology, which connects billions of smart devices to the internet. Smart homes have built-in sensors or controllers, but they lack functionality and communication range. Access points allow devices to monitor conditions and control appliances. An integrated smart home automation system manages various appliances, including lights, thermostats, TVs, door locks, cameras, washing machines, and refrigerators. It's an IoT-based system that reduces electricity consumption, energy costs, and enhances security. Some systems can alert homeowners about motion detected in their absence.

The integration of solar energy with Internet of Things (IoT) technologies has emerged as a transformative approach to creating sustainable and efficient living environments. (Nithish et al., 2022) As global energy demands continue to rise alongside concerns about climate change and environmental degradation, the need for innovative solutions in residential energy management becomes increasingly critical. (Swati et al., 2020). The incorporation of solar power into this framework not only reduces dependence on traditional energy

sources but also promotes sustainability by utilizing clean, renewable energy. The research demonstrates the efficiency of smart energy transition through a solar-powered smart home, demonstrating the use of IoT technologies to optimize energy usage, reduce costs, and promote sustainable living practices. The user-friendly interface encourages informed energy management, fostering a culture of sustainability.

The main part of the home automation system based on IoT is the microcontroller, The Arduino Nano is a small, breadboard-friendly microcontroller board based on the ATmega328P (or ATmega168) microcontroller. (Sarishma *et al.*, 2020). It operates at 16 MHz and is designed for various applications, particularly in hobbyist projects and prototyping. It has multiple digital input/output pins (14 in total), analog input pins (8), and supports various communication protocols like I2C and SPI. However, it does not have built-in Wi-Fi capabilities. The ESP8266, on the other hand, is a low-cost Wi-Fi microcontroller produced by Espressif Systems. (How 2 Electronics, 2024) It features a 32-bit processor capable of running at 80 or 160 MHz and includes built-in TCP/IP networking capabilities, making it suitable for Internet of Things (IoT) applications. It has a minimum of 17 GPIO pins, supports various communication protocols (I2C, SPI, UART), and can connect to Wi-Fi networks directly. This makes the ESP8266 particularly useful for projects that require internet connectivity. (Instructables 2021).

The collaboration between Arduino Nano and ESP8266 in a solar-powered IoT smart home creates a robust framework for efficient energy management. By leveraging real-time data acquisition and wireless communication, this integrated approach not only enhances sustainability but also empowers users with valuable insights into their energy consumption. (Xilir, 2023). IoT can enhance existing home automation systems by introducing centralized control over the Internet. The Arduino Nano acts as the main controller, processing data from various sensors connected to the solar power system. Sensors connected to the Arduino measure critical parameters. It gathers information such as motion, lighting, current, voltage and temperature from the sensors, solar panels and batteries. The ESP8266 module provides Wi-Fi connectivity, allowing the Arduino to transmit data wirelessly to cloud platforms or mobile applications (such as IFTTT or MQTT) where users can visualize their energy consumption patterns and system performance. (How2Electronics 2024). This connectivity enables users to access real-time data about energy production and consumption from anywhere, facilitating better energy management. The implementation of IoT smart home systems presents both challenges and opportunities. Short Range of Communication Many smart home devices rely on wireless communication protocols such as Zigbee, Z-Wave, and Wi-Fi. (Simar *et al.*, 2023) These protocols often have limited ranges, which can lead to connectivity issues, especially in larger homes or those with obstacles that interfere with signals. This short range can hinder effective communication between devices, resulting in unreliable performance. A significant challenge in IoT smart homes is the lack of interoperability among devices from different manufacturers. Complexity of Setup and Maintenance, Cost Barriers and the most importantly energy management.

Many studies have concentrated on smart homes. Consequently, this review examines research on SHs in light of the increasing prevalence of home appliances within the IoT ecosystem. The findings and recommendations from this study enhance our understanding of users' attitudes toward privacy in smart homes. Additionally, relevant work in the field of home automation is presented. Smart homes (SHs) are conceptual frameworks rather than physical structures. The idea of home automation has been explored in science fiction for many years and was practically showcased by the American Association of House Builders in 1984, which helped define SHs. (CO-DA, 2023). Smart homes can be classified into two categories: wired and wireless systems. Wired systems employ optical fibers, bus lines, and power lines, while wireless systems consist of a sender and receiver. Currently, many applications utilize wireless technologies like radio waves or infrared for device communication. (Jabbar *et al.*, 2019). Smart homes can operate on both wired and wireless systems simultaneously, evolving into versatile portable controllers that enhance daily convenience. (Jabbar *et al.*, 2019). In an SH environment, diverse electronic devices connect to provide smart services to users. IoT-based smart homes play a crucial role in the development of smart cities globally, aiming to enhance living standards, safety, security, and resource efficiency. Key features of SHs include real-time monitoring, protection against hacking, remote control capabilities, and alarms for fire and gas leaks. Given that sensitive personal data is exchanged among these systems, robust security and privacy measures are essential to safeguard user information while ensuring reliable service delivery. The Internet of Things (IoT) represents a relatively recent advancement that empowers existing homes with enhanced computing and communication capabilities due to the rapid evolution of internet technologies. Within a smart home setting, appliances can connect directly to the home network, allowing users to control each device individually through voice commands or mobile devices. Common applications involve managing lighting, motion detection, security systems, entertainment options, and temperature regulation. Smartphones and computers are vital tools for controlling these devices as they serve as modern technological benchmarks. Users can access these gadgets anywhere and configure them online to connect with other devices. IoT encompasses a vast network of

interconnected objects and individuals that gather and display necessary data using numerous devices of varying sizes. These interconnected devices collect data from sensors linked to IoT networks, enabling analytics that highlight valuable information tailored to specific needs.

Home automation has evolved significantly, incorporating a variety of technologies each designed to address specific needs and challenges within the residential environment. From the early reliance on GSM-based systems to the integration of IoT and sophisticated microcontrollers, the journey towards creating seamless, efficient, and secure smart homes has been marked by innovation and adaptation. This review connects the dots between various approaches, highlighting their strengths, limitations, and the ways in which they have influenced subsequent developments in the field.

Early iterations of home automation often utilized Global System for Mobile Communications (GSM) technology, enabling homeowners to control appliances remotely through Short Message Service (SMS). Yusuf *et al.*, (2017) introduced a system that integrated an Arduino Uno with a GSM module (SIM900A), allowing users to send commands via SMS to control devices connected through relays. This approach offered the convenience of remote control from virtually anywhere with mobile network coverage. However, it also presented several drawbacks. Okorafor, (2023) pointed out the energy inefficiencies inherent in GSM-based systems, largely due to the lack of real-time monitoring and adaptive capabilities. These systems typically operate on pre-set schedules or manual commands, without the ability to adjust to changing conditions or user habits, leading to unnecessary energy consumption.

Yusuf *et al.*, (2017) acknowledged that GSM-based systems suffer from several limitations, including limited range (dependent on mobile network coverage), potential delays in command execution due to network latency, and a reliance on the availability and reliability of the mobile network. In critical situations where immediate response is required, these delays can be problematic. Moreover, the performance of GSM-based systems can vary significantly depending on the strength and stability of the mobile network signal, which may not be consistently reliable in all geographical areas or building structures. The dependence on SMS communication also introduces security considerations, as SMS messages can be intercepted or spoofed, potentially compromising the security of the home automation system. Despite these limitations, GSM-based systems provided an initial step towards remote home automation, paving the way for more advanced technologies.

Bluetooth technology emerged as an alternative communication method for home automation, offering advantages such as high communication rates, low cost, and enhanced security features. Yan *et al.*, (2015) emphasized these benefits in their work on a Bluetooth-based home automation system. Bluetooth operates within a limited range, typically around 10 meters, which restricts its ability to control appliances throughout a larger home. Muthukumaran *et al.*, (2019) proposed a low-cost, flexible, and secure wireless solution using Bluetooth, highlighting its potential for localized control and monitoring. The security features of Bluetooth, such as pairing protocols and encryption, provide a degree of protection against unauthorized access, making it a more secure option compared to unencrypted wireless communication methods.

However, the range limitation remains a significant drawback. Bluetooth-based systems are best suited for controlling devices within a single room or a small area, limiting their applicability in larger homes or multi-story buildings. Sen *et al.*, (2015) explored the use of voice-controlled home automation using Bluetooth, which can be particularly beneficial for elderly or disabled individuals who may have difficulty using traditional control interfaces. However, they noted that the accuracy of voice recognition can be affected by noisy environments, which can degrade the performance of the system. Davidovic *et al.*, (2015) integrated Bluetooth with a Raspberry Pi microcontroller, allowing smartphones to connect to the home automation system via Wi-Fi. However, this setup only worked within the range of the Wi-Fi access point, further limiting its usability. Despite these limitations, Bluetooth technology offers a cost-effective and secure solution for localized home automation applications, particularly in scenarios where short-range communication is sufficient.

ZigBee is another short-range communication technology that has been explored for home automation applications. It offers low data rates and low power consumption, making it suitable for battery-powered devices and sensor networks. Sayeed *et al.*, (2023) examined an IoT-integrated smart home system that utilized ZigBee for communication between devices. However, they noted connectivity issues and range limitations that affected the overall energy efficiency of the system. These limitations can arise from interference from other wireless devices, obstructions in the environment, and the physical distance between devices. (Jitendra *et al.*, 2010) highlighted ZigBee's physical range of 10 to 20 meters, which can be extended up to 150 meters using direct sequence spread spectrum (DSSS) technology.

Despite its low power consumption, the range limitations of ZigBee can pose challenges in achieving comprehensive and reliable home automation. In larger homes or buildings with thick walls, the signal strength may degrade, leading to unreliable communication between devices. This can result in devices becoming unresponsive or failing to operate as intended. ZigBee's low data rate may also limit its suitability for applications that require high-bandwidth communication, such as streaming video or transmitting large amounts of data. While ZigBee offers advantages in terms of power efficiency and cost, its range limitations and potential connectivity issues need to be carefully considered when designing a home automation system.

The advent of the Internet of Things (IoT) has revolutionized home automation, enabling enhanced control, monitoring, and automation capabilities through internet connectivity. IoT-based systems leverage a wide range of sensors, actuators, and communication protocols to create intelligent and responsive home environments. Mehra *et al.*, (2022) developed an IoT-based home automation system that used motion detection and sensors for lighting and gas detection, controlled by a Raspberry Pi. This system demonstrated the potential of IoT to automate tasks and improve safety in the home. However, they noted that the entire operation would fail if the power supply to the IPS failed, highlighting the importance of reliable power sources in IoT deployments. Kodali *et al.*, (2016) presented an MQTT-based system using ESP8266 for remote monitoring and control via Wi-Fi. MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol that is well-suited for IoT applications, offering low power consumption and low bandwidth requirements.

However, Kodali *et al.*, (2016) noted that their system had limited functionalities and lacked security considerations. Security is a critical concern in IoT-based home automation systems, as the interconnected nature of these systems makes them vulnerable to cyberattacks and unauthorized access. Without proper security measures, attackers could potentially gain control of devices, steal sensitive data, or disrupt the operation of the system. Despite these challenges, IoT-based systems offer significant advantages over traditional home automation approaches, providing greater flexibility, scalability, and functionality. By leveraging internet connectivity, these systems can be accessed and controlled from anywhere in the world, enabling homeowners to monitor and manage their homes remotely.

Arduino microcontrollers have become popular building blocks for home automation systems due to their versatility, ease of use, and low cost. These microcontrollers can be programmed to control a wide range of devices and sensors, making them suitable for a variety of home automation applications. Imran *et al.*, (2016) proposed an IoT-based system using Arduino Mega with an Ethernet shield, enabling internet connectivity and remote control. However, they noted that their system did not consider the home surroundings, highlighting the importance of integrating environmental sensors and feedback mechanisms in home automation systems. Kousalya *et al.*, (2018) used Arduino Uno for smart security and home automation, capturing images upon motion detection. This system demonstrated the potential of Arduino to enhance security and provide visual feedback to homeowners. Jabbar *et al.*, (2018) developed a Wi-Fi-based prototype using Arduino Mega and an Android application, allowing users to control home appliances remotely. However, they noted that their system was limited to local control and lacked security features. While Arduino microcontrollers offer a flexible and cost-effective platform for home automation, they also require careful design and implementation to ensure security, reliability, and usability. Integrating sensors, actuators, and communication modules effectively is crucial for creating a functional and user-friendly home automation system. Additionally, addressing security concerns and implementing robust authentication and encryption mechanisms are essential for protecting the system against unauthorized access and cyber threats.

To overcome the limitations of individual technologies, several studies have explored integrated approaches that combine multiple technologies to enhance home automation systems. Kaur *et al.*, (2016) combined GSM, Arduino, and an Android application for home automation and security, using SMS alerts for intrusion detection. This integrated system leveraged the strengths of each technology, providing remote control via GSM, local control via Arduino, and a user-friendly interface via the Android application. By combining these technologies, Kaur *et al.*, (2016) created a more comprehensive and reliable home automation solution. Ganesh *et al.*, (2017) structured an IoT architecture using GSM technology, enabling users to control devices remotely via the internet. This system used GSM as a backup communication channel in case internet connectivity was unavailable, ensuring that users could still control their homes remotely.

Building upon this foundation, the proposed research aims to improve upon the work carried out by Jabbar *et al.*, (2018) in their "Design and Fabrication of IoT-Based Automation System for Smart Home." Specifically, this research focuses on modeling a solar-powered IoT smart home, harnessing solar energy as its primary power source rather than relying on traditional batteries. This approach aims to create a more energy-efficient and sustainable system, reducing its environmental impact and operational costs. Furthermore, the proposed



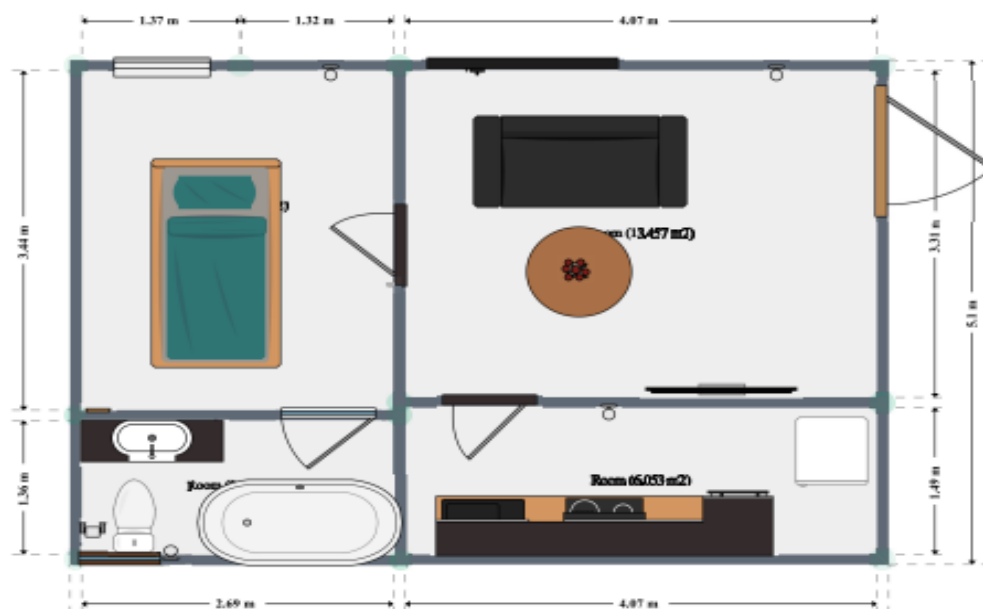
system will utilize Wi-Fi for connectivity, ensuring seamless remote access and control from anywhere with internet access. By integrating solar power and Wi-Fi connectivity, this research seeks to create a smart home system that is not only technologically advanced but also environmentally responsible and user-friendly. The focus on sustainability and remote accessibility aligns with the growing demand for smart home solutions that are both convenient and eco-conscious, contributing to a more sustainable and connected future.

## 2. Materials and Method

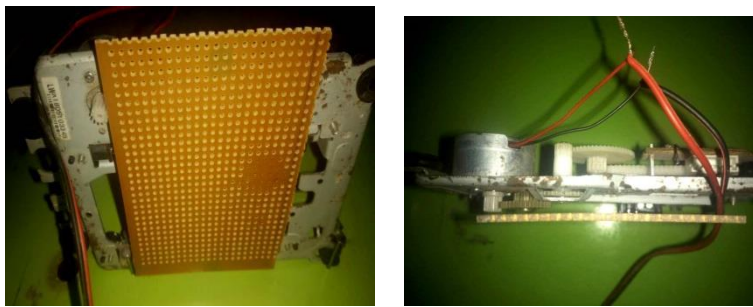
This section outlines the methodology employed in this study, which involves a systematic organization of various research phases alongside the detailed design and implementation of the Smart Home (SMHome) system, solar powered and its prototype. Additionally, it explains the selection and integration of components to meet the design objectives. The flowchart in Figure 2 depicts the conceptual framework of this research. The investigation begins by identifying the challenges faced by existing Smart Home systems, with the primary issues being high insufficient energy supply and user-unfriendly interfaces. The modeling phase concentrates on selecting materials and components for constructing the Smart Home prototype and developing the SMHome system. The Smart Home design is created using Planner 5D software, while the prototype is built from plywood. The design and implementation of the SMHome automation system are carried out, including wiring and connecting various components (such as bulbs, fans, motors, and sensors) to the integrated SMHome system (which includes Arduino Nano, ESP8266, relay boards, DC sources, etc.). Following the connection of the microcontroller and components, coding is conducted to enable functionality.

### 2.1 System Modeling

Figure 1 illustrates the comprehensive design and layout of the SH prototype. The Smart Home (SH) prototype is designed using Planner 5D software, aligned with specified requirements. The architectural layout features one bedroom, one bathroom, a kitchen, and a living room. Windows are operated via a sliding mechanism powered by an aluminum CD/DVD motor (plate 1), which facilitates seamless opening and closing. A Passive Infrared (PIR) motion sensor is integrated into the door system to detect movement, enabling automatic opening and closing based on occupancy. Additionally, a DHT11 sensor is installed to monitor temperature and humidity levels within the prototype. A solar panel is positioned alongside the prototype, in conjunction with a battery for energy storage. Table 1 shown the energy consumption of prototype. Overall, the SH prototype is fully integrated with the Smart Home (SMHome) system.



**Figure 1:** One Bed-Room Prototype Floor plan



**Plate 1:** Sliding Door Mechanism in Operation

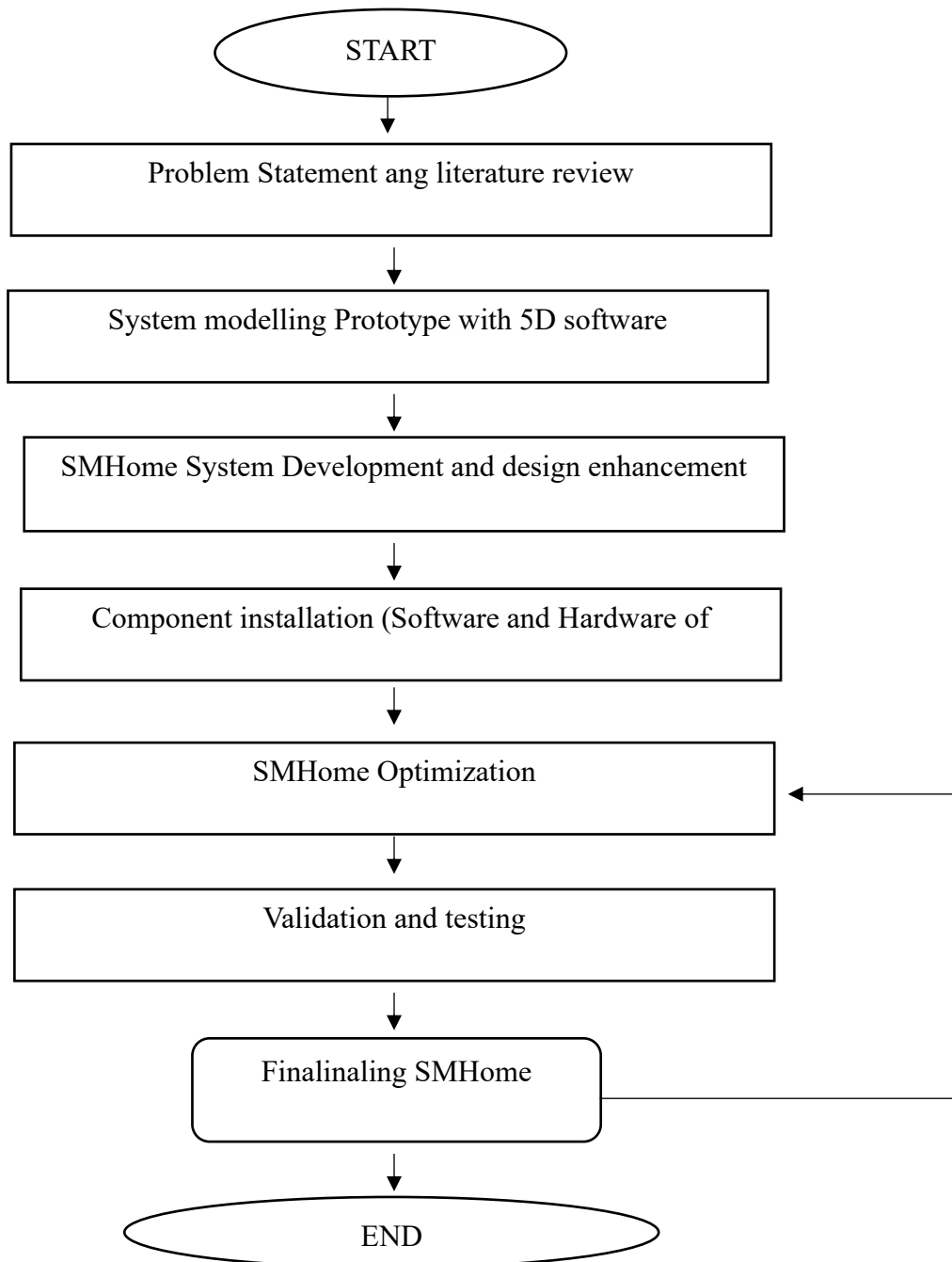
**Table: 1.** Actuators/Sensors Power Consumption for a Prototype

S/No.	Actuator/Sensors	Watts	Voltage/Current
1.	Mini Axial Fan	0.96W	5-7V, 0.08A
2.	Digital Temperature and Humidity Sensor DHT11	0.00165W	3.5V-5.5V, 0.3mA
3.	PIR motion Sensor		5V, 20mA
4.	LCD Display 16×2		4-5V
5.	Aluminum CD/DVD motor		5-7V, 0.5mA
6.	LED bulb	20-30milliwatts	0.02-0.03V

## 2.2 SMHome System Development and Design Enhancement

The hardware and software components are integral to the design of the Smart Home (SMHome) system, ensuring effective and seamless automation of the Smart Home (SH). In addition, the selection of components is done to fulfill the design objectives. The flowchart in Figure 2 illustrates the conceptual framework of this study. The hardware utilized in the construction of the SMHome automation system includes an Arduino Nano, an ESP8266 Wi-Fi controller board, a 6V solar panel, a 6V 1A battery, a voltage regulator, an LCD display, buzzers, a PIR motion sensor, a DHT11 temperature and humidity sensor, light-emitting diode (LED) bulbs, a mini fan, a 1.5V DC motor, and plywood for the SH prototype. The software components consist of the Arduino IDE software, a TCP server, and If This Then That (IFTTT). Together, these components facilitate the successful implementation and operation of the SMHome automation system.

Integrating solar-powered IoT smart home technology into the concept of smart homes (SHs) enhances energy efficiency and sustainability, which are critical in today's energy-conscious society, and also has revolutionized how devices communicate and operate. IoT enables smart appliances to connect directly to home networks, allowing users to control them via voice commands or mobile devices. This connectivity extends to solar power systems, which can be monitored and managed through IoT platforms. Solar-powered IoT systems optimize energy consumption by utilizing renewable energy sources. Smart home energy management systems can analyze usage patterns and adjust operations accordingly to minimize waste. These systems provide real-time data on energy production and consumption, allowing homeowners to make informed decisions about their energy use. By integrating solar power with IoT technology, smart homes contribute to sustainability efforts by reducing reliance on non-renewable energy sources and lowering carbon footprints. Utilizing solar energy can significantly reduce electricity bills. IoT-enabled systems can further enhance these savings by optimizing when and how energy is used within the home. As smart homes manage sensitive data through interconnected devices, security becomes paramount. Effective measures must be implemented to protect user data from breaches while ensuring reliable service delivery. This includes securing communication channels between solar power systems and other smart devices. For sake of this work the electrical storage system was used in form of electricity to store the surplus electric charge from solar. A lead-acid battery of 6V, 4.5A was used as shown in (Plate 2) to store the solar energy with 6V1A solar panel. To meet the sole aim of this project which to model an IoT SMHome system that is solely powered by solar energy, Dickson's rectifier method was adopted. Where both the battery and combined power was used as well as the solar panel type considered. The battery method used is in line with the linear conversion voltage regulator as compared to the switching method as it was the most easily available configuration to use. This design makes use of a feedback circuit which was used to check the reference voltage for changes in the D.C. voltage output through a passive element which was a kind of solid BJT or PN junction diode, the voltage regulator works by providing a permanent output supply irrespective of input voltage type, the major advantage of this type of method was giving output ripple voltage and fast response time to load line changes.



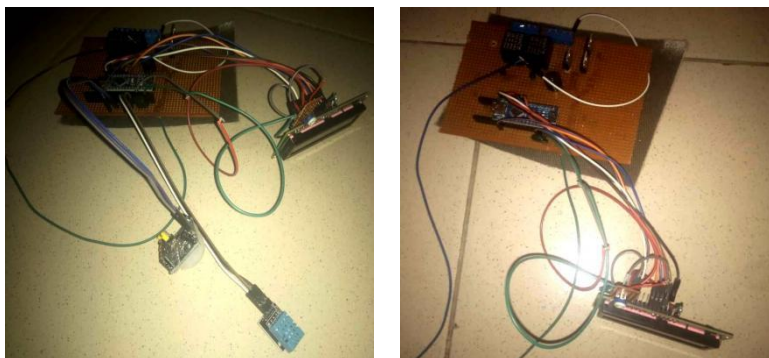
**Figure 2:** Research Workflow



**Plate 2:** Solar panel and the Battery

The hardware system implemented in the Smart Home (SH) prototype undergoes rigorous evaluation, with design enhancements and optimizations made in response to any identified errors until satisfactory performance is achieved. This phase is crucial for improving system functionality and detecting issues. Problems encountered during earlier phases are systematically identified and resolved, with this process repeated until successful implementation is confirmed. For instance, prior to the actual deployment of the system, LED bulbs

are utilized as substitutes for actuators to verify output readings. Once all programming code is compiled into the Arduino Nano, the actual actuators including fans, motors, buzzers, and bulbs are employed for real testing on the vero board before soldering as depicted in Plate 3. All wiring connections are meticulously checked using a multimeter, and each wire is labeled to facilitate clear verification of every connection within the system. During this phase, the system is assessed to ensure that all sensors, actuators, and the Arduino Nano are functioning effectively.



**Plate 3:** Deployment of the SMHome System Using Veroboard

System software components are selected and developed in this project, the software feedback is used to acknowledge data commands that have been carried out over the internet and for the sake of this project, the email is used through the IFTTT application, IFTTT (If This Then That) is an automation platform that connects various web applications and services, allowing users to create conditional statements known as applets. Each applet consists of a trigger, which initiates the action based on specific events (e.g., receiving an email), and an action, which is the task performed in response (e.g., sending a notification). The platform integrates with over 600 services, enabling seamless automation of tasks across different applications without requiring any coding skills. IFTTT's user-friendly interface allows users to easily create, manage, and explore applets, enhancing productivity and streamlining workflows in daily digital activities. IFTTT (If This Then That) can be integrated with the ESP8266 module and Arduino Nano to automate tasks using TCP/IP communication. The ESP8266 connects to a Wi-Fi network and utilizes HTTP requests to trigger IFTTT applets through webhooks, allowing it to send data or notifications based on sensor inputs or events. Users set up their IFTTT account, create a webhook URL with a unique key, and program the ESP8266 using the Arduino IDE to handle the connection and HTTP get requests to the IFTTT service. This setup enables seamless interaction between physical devices and online services, facilitating various IoT applications such as sending alerts when sensors are activated. It was chosen because of its flexibility working with home appliances directly and its short response time compared to other software feedback systems as it was solely designed for this purpose.

### **Steps for setting up IFTTT (Applets) Application**

The following are the step to create an IFTTT App.

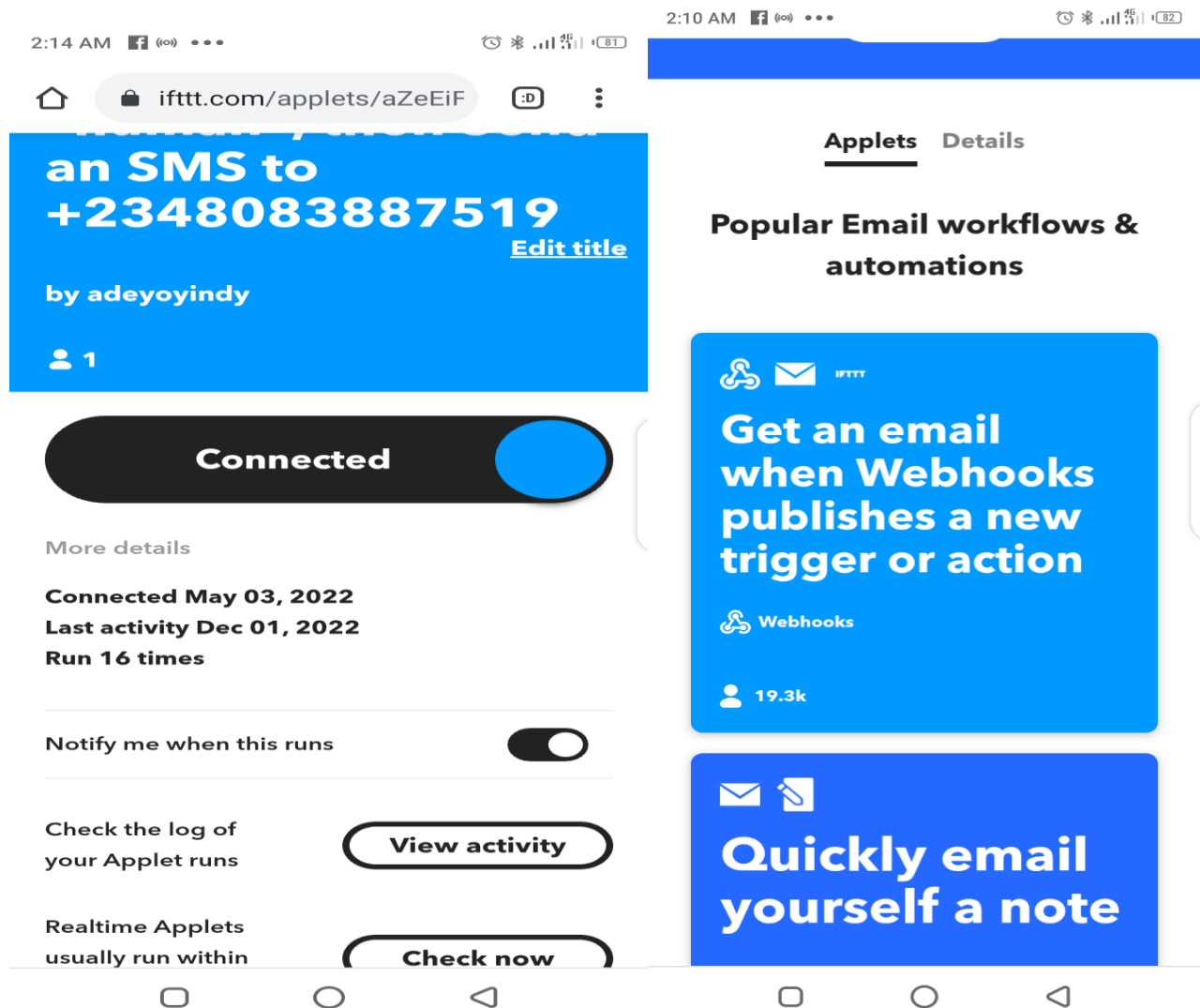
Step 1: Visit the IFTTT website and click on login or create an account,

Step 2: Click if this and select your service (Environment control & Monitoring and trigger)

Step 3: Now click then that and select the service and first action

Step 4: Now click the second plus bottom (+) to add additional actions as shown in Plate 4.



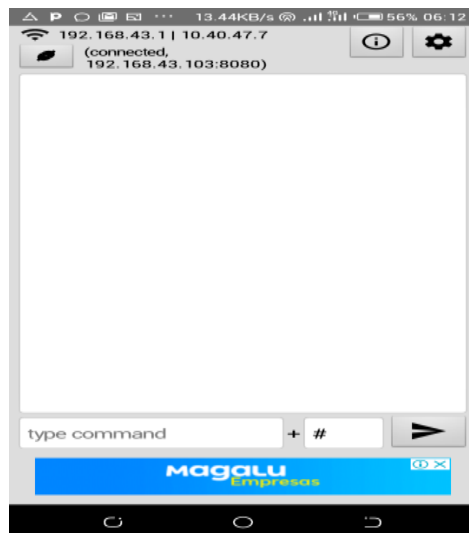


**Plate 4: IFTTT Applet**

TCP client/server is an android application which serves as a terminal used to connect various devices over WiFi networks using their IP addresses and a router. It can either be connected as a server or client. The server mode connected client sends and receives messages to the server and the server on turn sends and receives messages from the client. The server can connect to as many clients as possible. In this mode it can connect without interruption to any or all clients and control them at the same time. While the client mode is used to communicate with the server, send and receive messages from the server. The client cannot receive messages from other clients as it can only receive messages from one server at a time which it is connected to. Therefore, a client needs to be disconnected from a server and connect to another server before it can communicate to the server.

To create a TCP connection to an ESP8266 Wi-Fi module below as explain in the following steps and depicted in plate 5.

1. Determine the IP address and port number of the Wi-Fi module to connect to,
2. Create a TCPP client on your device
3. Use the '**connect**' method to connect the client socket to the wi-fi module's IP address & port number
4. Once the connection is established, it can send and receive data between the client and server ESP8266 wi-fi module



**Plate 5:** TCP connection to Wi-Fi module

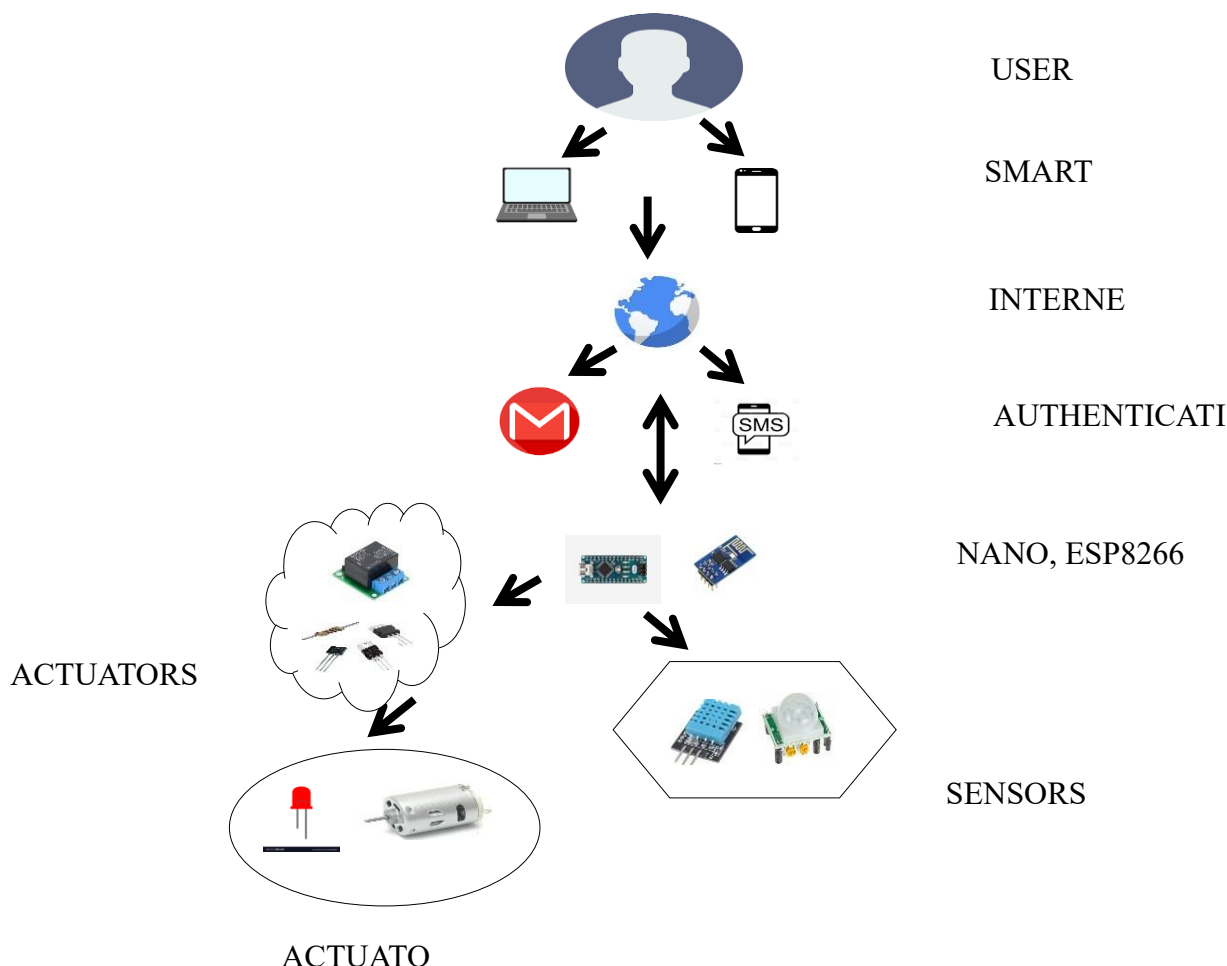
### 2.3 SMHome Implementation and system Architecture

This is another contribution to this work, the development of an innovative, market-ready portable controller (SMHome) that can be implemented in real residences to continuously monitor home conditions and conveniently manage home appliances over the Internet, regardless of time or location. This study proposes a process for home automation and control, implemented using the Arduino Nano microcontroller and all powered by solar energy. The Arduino Nano was chosen for the smart home (SH) prototype due to its capabilities and cost-effectiveness. To ensure the system is both intelligent and secure, several sensors, including temperature, humidity, and motion sensors, are utilized. Prior to the final implementation and fabrication of the developed system, various experiments with individual sensors and actuators are conducted on a veroboard to determine their effectiveness. This process aids in selecting appropriate materials and components for the system. The SMHome system (Plate 6) undergoes installation in the SH prototype and is retested following hardware implementation. The system is enhanced and optimized to address any errors until it operates as intended. The microcontroller function smoothly with the sensors and actuators in the developed SMHome portable automation system.



**Plate 6:** SMHome System Implementation

For software implementation TCP/IP is a communication protocol used for networking, while IFTTT (If This Then That) is a web-based service that enables users to create conditional statements for automating interactions between different applications and devices. The SMHome system effectively manages various home appliances, including lights, doors, windows, and fans, while also monitoring environmental parameters such as temperature, humidity, and motion through mobile devices or laptops via SMS and Gmail. Users can control and monitor the smart home (SH) prototype from any location at any time, facilitated by the ESP8266 module, which maintains a continuous Wi-Fi connection to the Internet. When operating in server mode, the ESP8266 allows users to log into a TCP/IP application to access the control system; upon receiving commands from the TCP/IP client, the server processes these instructions and relays them to the controller via the ESP8266. Following command execution, the ESP8266 switches to client mode to connect to IFTTT.com, sending trigger messages through webhooks that return feedback as SMS or Email notifications. After completing this process, the ESP8266 reverts to server mode for continued operation with the TCP/IP client. The system architecture of the work done is shown in figure 3.



**Figure 3: IoT system Architecture**

### 3. Results and Discussion

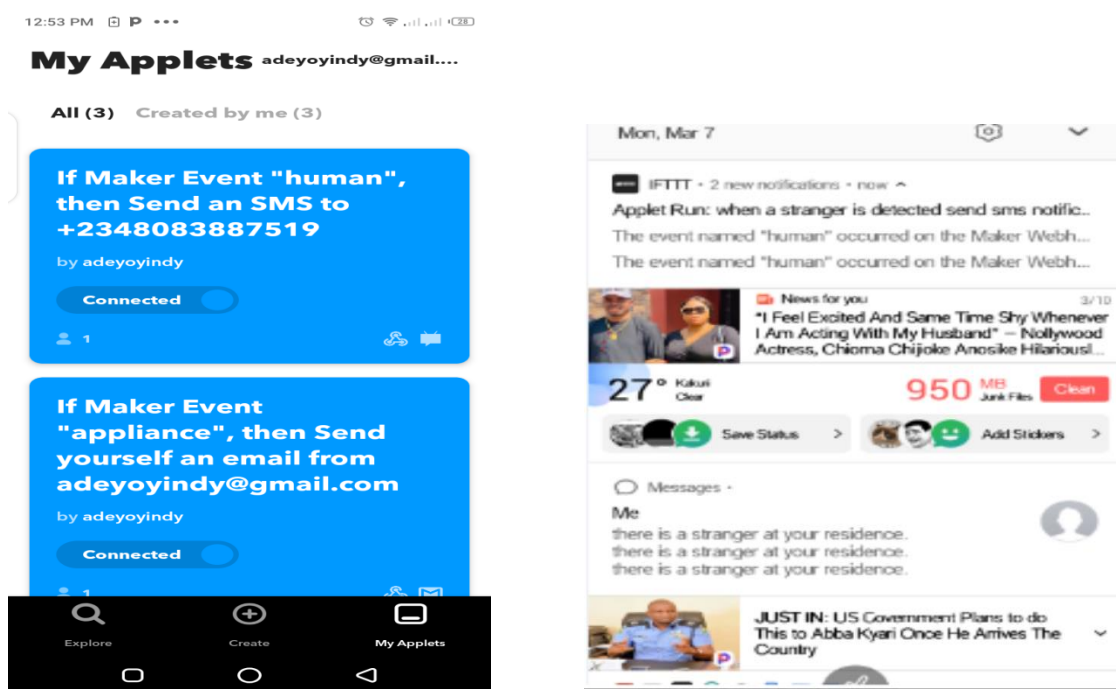
The modeling of a solar-powered IoT smart home prototype was successfully developed with the implementation of the SMHome system, which controls home appliances such as doors, windows, fans, and lights while monitoring temperature, humidity, and motion through an Android application utilizing IFTTT. Users can connect to their homes anytime and from anywhere via the Internet. The system integrates various sensors and actuators, enabling seamless remote management and automation of household functions. When the switch is turned ON, the LCD initializes as well as the microcontroller, which in turn initializes the Wi-Fi module. The solar panel is rated to be 6.5V/1A used to charge the battery (6V) when its level is low from the power supply by the voltage regulator, which constitutes the power, through the two terminals. The solar panels ensure that the battery is properly powered to meet the power demand of the circuit. It can also be used alongside the battery to power the circuit. A PIR sensor is a motion sensor that sends information about human movement around the house to a microcontroller, which then responds by taking the appropriate action. When any movement in the house is detected while the homeowner is away, its output signal activates the buzzer and notifies the server, which in turn notifies the owner. The room's humidity and temperature are both measured by the DHT11 sensor, which sounds like a buzzer when the temperature rises above normal. Also, it transmits data to the microcontroller, which in turn transmits a command to turn ON the prototype's fan. LED bulbs are used as the main source of lighting in the prototype. LED bulbs use shockproof materials, are energy efficient, and are more durable as compared with real houses with glass bulbs. They are low-power bulbs that require only 30–60 milliwatts to operate. The software component utilized for this project is IFTTT, an automation platform that facilitates communication between devices through a controller (ESP8266) connected to a Wi-Fi module. When an event is triggered by sensors or a TCP command from Wi-Fi, the ESP8266 activates its client mode and sends trigger messages to the IFTTT app, which can then send notifications via email or SMS regarding the event, as illustrated in plate 7. The applet triggers used in this project include commands for turning applications ON/OFF, temperature control, and motion detection. The trigger events (applets) used in these projects include;

#### a. Application ON

- b. Application OFF
- c. Temperature control
- d. Human detected

Messages appended to email and SMS used in this project are;

- i. Home appliance has been switched OFF by you
- ii. Home appliances has been switched ON by you
- iii. Temperature level is high
- iv. Stranger at your residence

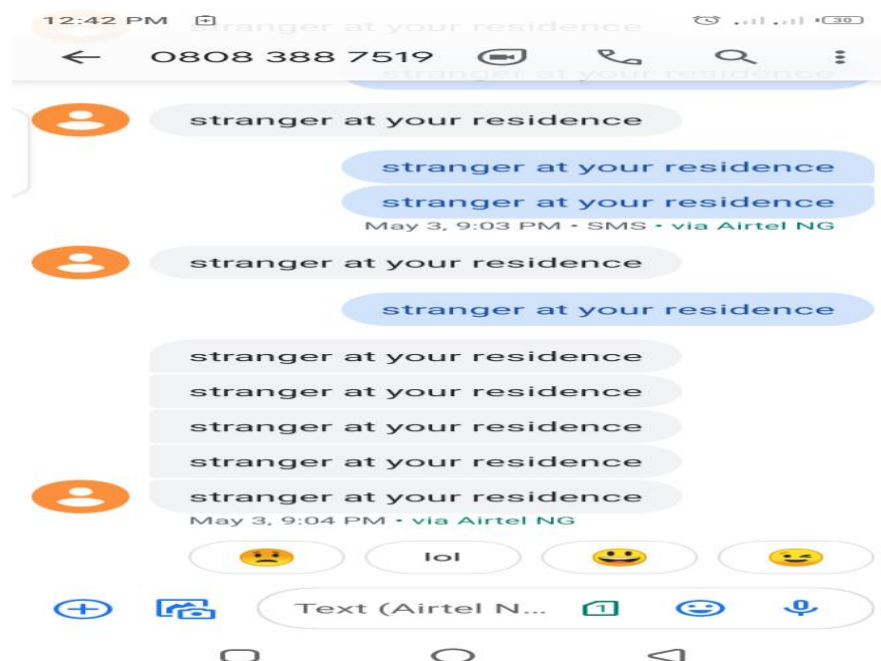


**Plate 7:** Applet Notification triggered by IFTTT app

The Android SMS application is used to connect IFTTT to your SMS network via webhooks. This is achieved by creating a trigger in the webhook and also connecting the link with Android SMS. This link is then added to the Android code to trigger the applet (event), which in turn triggers the SMS message to be sent to your phone as shown in plate 9. The Gmail application is used to connect IFTTT to your Gmail network via webhooks as illustrated in plate 8. This is achieved by creating a trigger in webhooks and also connecting the link with a valid Gmail account. This link is then added to the Android code to trigger the applet (event), which in turn triggers the Gmail message to be sent to your phone/computer. This project used it to respond to all Wi-Fi commands from TCP clients, while SMS is used to respond to the temperature and motion trigger events as in figure 3. The solar-powered IoT smart home prototype not only enhances energy efficiency and sustainability but also provides users with comprehensive control and real-time monitoring of their home environment, ensuring safety and convenience through advanced automation technologies.



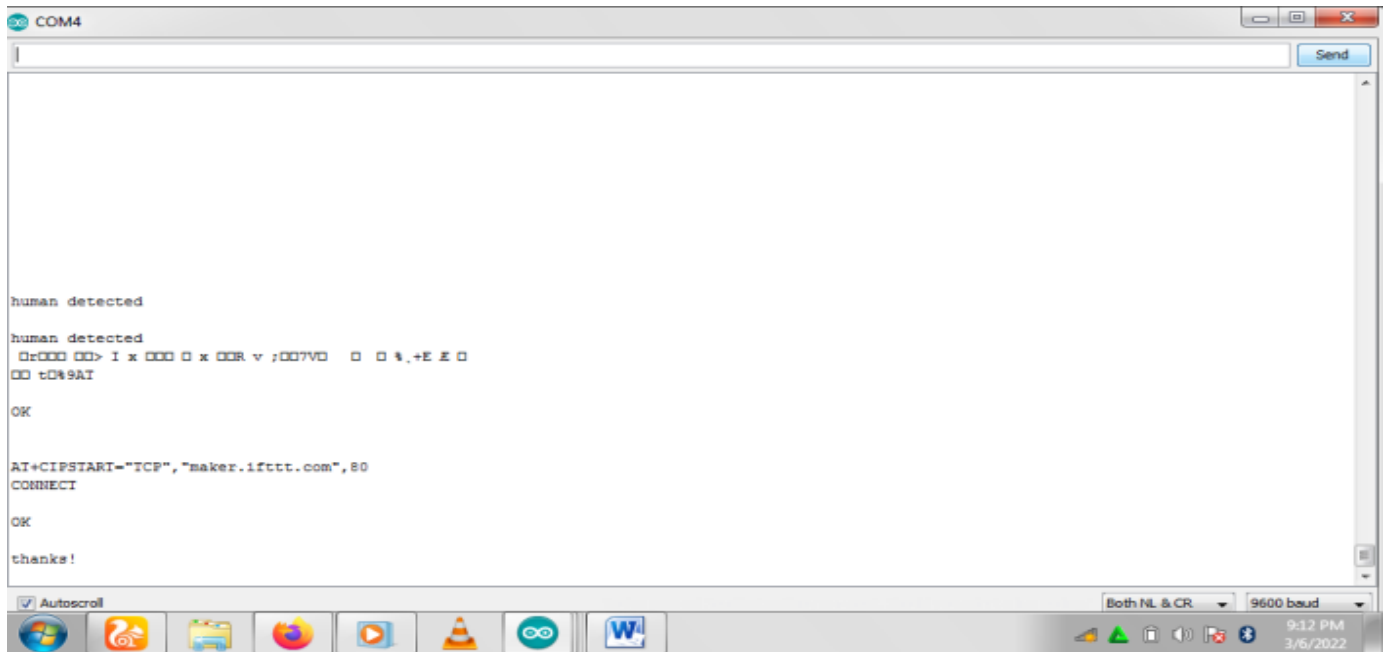
**Plate 8:** Gmail notification



**Plate 9:** Received message from IFTTT using SMS

An application called Arduino IDE is used to write code and send it to the microcontroller. The SMHome system's and its components' functionalities are coded, debugged, and tested using the Arduino IDE in this project. In addition to supporting a variety of Arduino boards, the IDE includes additional libraries, serial monitors for communicating with the board, and a debugging area for abnormal conditions. The project was further tested using Arduino IDE which displayed the various input of the user to transfer notification messages and to control the circuit as shown in plate 10 motion sensor transmitting signal to IFTTT when a human is been detected and plate 11 Sending email Notification when the appliances is switched on. Also, the top view in shown in plate 12.





**Plate 10:** Motion sensor transmitting signal to IFTTT when human is detected



**Plate 11:** Sending email Notification when appliance is switched on



**Plate 12:** Top-View IoT smart Home Automation Prototype

#### 4. Conclusion

The objectives of this Research were successfully achieved through the Modelling of a prototype IoT smart home automation system powered by solar energy. The key outcomes are: A functional prototype was modeled and built that demonstrates the feasibility of a solar-powered smart home automation system. This serves as a proof-of-concept and foundation for further development and refinement. The ESP8266 microcontroller was effectively used as a gateway to connect the system to the internet. TCP and IFTTT protocols were integrated to enable automation of the sample model, proving the ability to remotely control and monitor the system. An add-on portable box automation controller called SMTHome was successfully implemented. This provides a convenient way to extend the automation capabilities and control the system from anywhere. The final prototype was thoroughly tested and verified to ensure proper operation. The model was assessed against the original objectives and found to meet the requirements of a solar-powered, internet-connected smart home automation system with remote control functionality. The Internet of Things (IoT) smart home automation system boosts convenience, security, and intelligence. The smart home system powered by solar provides quality electricity supply to the house and helps to minimize the electric bill, by enabling the home user to control the electrical appliances anytime without any human energy. The proposed system can be expanded with additional sensors and actuators. Also, the developed system can also be improved to make it suitable for future commercialization.

#### References

- CO-DA, 2023, How Homes Got Smart: A Look at the History of Smart Home Automation, <https://co-da.com/history-of-smart-home-automation/>, accessed June 16, 2024.
- Davidovic, B. and Labus, A. 2015. A Smart Home System Based on Sensor Technology. Facta Universitatis, Series Electronics and Energetics, 29: 451–460.
- Ganesh, EN. 2017. Implementation of IOT Architecture for SMART HOME Using GSM Technology. International Journal of Computer Technology, 4(1):42–48.
- How 2 Electronics. 2024. IoT Home Automation using ESP8266 Web Server. <https://how2electronics.com/iot-home-automation-using-esp8266-web-server/>, accessed September 21, 2024.
- how2electronics, 2024, IoT Solar Panel Monitoring System with ESP8266 & MQTT, <https://how2electronics.com/iot-solar-panel-monitoring-system-with-esp8266-mqtt/>, accessed June 13, 2024.
- Instructables, N.D., ESP8266 Wifi Controlled Home Automation, <https://www.instructables.com/ESP8266-Wifi-Tutorial/>, accessed June 13, 2024.
- Imran, SS., Vignesh, J., Singh, VK. and ArunPrasath, DT. 2016. Smart Home Automation Based on IoT Using Arduino Mega. Proceedings of the International Conference on Current Research in Engineering Science and Technology (ICCREST), 2348–8379.
- Jabbar, WA., Alsibai, MH., Amran, NSS. and Mahayadin, SK., 2018, Design and Implementation of IoT-Based Automation System for Smart Home", Rome, Italy, 2018 International Symposium on Networks, Computers and Communications (ISNCC): 1–6.
- Jabbar, WA., Ramli, RM., Kian, TK., Zubir, SN., Zamrizaman, NSM., Mohammed, B., Shepelev, V. and Soltan, A. 2019. Design and Fabrication of Smart Home with Internet of Things Enabled Automation System. IEEE Access, 7:1-10.
- Jitendra, R., and Pawar, S. 2010. Zigbee Based Home Automation. SSRN Electronic Journal. <https://doi.org/10.2139/ssrn.1587245>.
- Kaur, S., Singh, R., Khairwal, N., and Jain, P. 2016. Home Automation and Security System. New Delhi-110063, India, Advanced Computational Intelligence: An International Journal (ACIJ), 3(3): 17–23.
- Kodali, R., and Soratkal, S. 2016. MQTT Based Home Automation System Using ESP8266. Proceedings of the IEEE Region 10 Humanitarian Technology Conference (R10-HTC): 1-5. <https://doi.org/10.1109/R10-HTC.2016.7906845>.

- Kousalya, S., Priya, G.R., Vasanthi, R., and Venkatesh, B. 2018. IoT Based Smart Security and Smart Home Automation. International Journal of Engineering Research & Technology (IJERT), 7, ISSN: 2278-018.
- Mehra, M. S. 2022, IoT-Based Smart Home Automation System Using Raspberry Pi. International Journal of Engineering Research & Technology (IJERT), 11(07). DOI: [10.17577/IJERTV11IS070165](https://doi.org/10.17577/IJERTV11IS070165).
- Muthukumaran, M., Kannusamy, M., Kanagaraj, M., and Guruveswaran, A. 2019. Bluetooth Based Home Automation using Arduino. International Journal of Engineering Research & Technology (IJERT), 7(2).
- Nithish Kumar, R., Sethuraman, M., Fayaz, A.N., Subash, R., and Jayarajan, J. 2022. Smart Based Solar Powered House System Design. Iconic Research and Engineering Journals, IRE 1703423: 61-65.
- Okorafor, C.H. 2013. Construction of a GSM Based Home Automation Using AVR. Caritas University, Amorji-Nike, Enugu: Department of Electrical and Electronic Engineering, 1-50.
- Sayeed, A., Aditya, J.K, Dwivedi, P.R, Harikashi, A.V and Parthasarathi, T. 2023. Smart Homes: A State-of-The-Art Review of Automated Systems and Their Integration. Proceedings of the KILBY 100 7th International Conference on Computing Sciences 2023 (ICCS 2023), Available at SSRN: <https://ssrn.com/abstract=4488185> or <http://dx.doi.org/10.2139/ssrn.448818>
- Sarishma, S., Sushant, C., Sumitra, S., and Vivudh, F. 2020. Smart Home Automation using ESP8266 and Internet of Things. Proceedings of the 5th International Conference on Next Generation Computing Technologies (NGCT-2019):1-5.
- Sen, S., Chakrabarty, S., Toshniwal, R., and Bhaumik, A. 2015. Design of an Intelligent Voice-Controlled Home Automation System. International Journal of Computer Applications, 39-42.
- Simar, S., Anand, S., and Satyarthi, MK., 2023. A Comprehensive Review of Smart Home Automation Systems. Advances in Computer Science and Information Technology, 10(2).
- Swati, N., Kumari, S., Kumar, V., and Behera, RK., 2020. Solar Powered Smart Home Design with IoT, IEEE-HYDCON, 1-5.
- Xilir Projects, N.D, IOT Based Solar Panel Monitoring System Using Arduino & ESP8266, <https://xilirprojects.com/product/iot-based-solar-panel-monitoring/>, Accessed June 13, 2024.
- Yan, W., Wang, Q., Gao, Z., and Zhenwei, G. 2015. Smart Home Implementation Based on Internet and WiFi Technology. Proceedings of the 34th Chinese Control Conference (CCC), Hangzhou, China, 28–30 July, 9072–907.
- Yusuf, S., Gupta, A., Rahul, P., Rahul, S., Shashank, S., and Shilpi, SN. 2017. GSM Based Home Automation System. International Journal of Electrical and Electronics Research, 5(2): 1-4.