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Design and Development of IoT-Enabled Power Management System for Smart Home with Enhanced Security Feature

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ABSTRACT:
This article presents a proposed architecture for a smart and secure home automation system that incorporates advanced Internet of Things (IoT) capabilities. The system under consideration has been developed with the objective of maximizing the efficiency of power consumption in domestic electrical appliances. By employing a continuous monitoring mechanism for the power consumption of individual devices, this system serves the twin purpose of mitigating the risk of short circuits resulting from excessive electrical loads and enabling users to monitor the energy consumption of each appliance. Consequently, it facilitates the efficient management of billing processes. The proposed model utilizes Internet of Things (IoT) technology to integrate video surveillance at the residential entry, enabling live monitoring of visitors. The fundamental elements of this novel design comprise an Arduino board and a collection of sensors encompassing fire, temperature, humidity, and other variables. The sensors establish a connection with the system via the Thingspeak application, facilitating users' ability to retrieve real-time power usage data from a range of devices. In the event that a device exceeds a pre-established power threshold, the user will be promptly notified through the delivery of timely warnings. These alerts will be presented in the form of graphical representations, which will effectively illustrate the patterns in power consumption. Moreover, the system's scalability enables the automation of many devices, making it a highly attractive solution for applications beyond residential settings. This includes industrial automation, notably within the framework of Industry 4.0.

Keywords: Arduino, Power Consumption, Electricity Bill, Face Detection, Security

1. INTRODUCTION

In the dynamic landscape of modern living, the fusion of Internet of Things (IoT) technology and smart home power management has emerged as a transformative force, reshaping the way we interact with and optimize our living spaces. The synergy between IoT and smart home power management introduces an unparalleled level of connectivity, enabling seamless communication and control over various electrical devices and systems within our homes. This integration not only enhances the efficiency of power consumption but also empowers users with unprecedented insights and control over their energy usage patterns. As our homes become increasingly interconnected, IoT-driven smart home power management systems play a pivotal role in creating intelligent, energy-efficient environments. Through real-time monitoring, data analytics, and automated decision-making, these systems offer a holistic approach to power management, fostering sustainability and cost-effectiveness. This introduction delves into the transformative potential of IoT in conjunction with smart home power management, exploring the myriad benefits, innovative solutions, and the profound impact on our daily lives [1-5].

Home automation involves the automated operation of electrical appliances within a residential setting, enhancing convenience and bolstering security. In the context of the Internet of Things (IoT), the term "things" refers to a network interconnected by a shared pathway, enabling interaction, data exchange, and mutual control among users. The IoT system utilizes sensor data analysis to automate activities, improving efficiency and reducing reliance on human intervention. Even when physically absent, users can conveniently observe ongoing activities, with both the system and users receiving regular updates without significant prerequisites for future access. The smart door employs App-based recognition for access, requiring unauthorized individuals to obtain administrative authentication. The external ESP32 camera, upon detecting movement, transmits captured photos to the administrator via the Telegram application bot, enhancing door security by visually identifying individuals at the entrance. Additionally, recognizing windows as vulnerable access points, a KY-024 magnetic sensor detects intruders attempting to scale the structure, triggering an audible alarm to enhance overall security. In the kitchen, a fire sensor mitigates the risk of unnoticed fires, detecting flames and activating an audible alarm to alert the owner or occupant promptly. This notification facilitates swift action, enabling the owner to initiate fire control measures at the earliest stage and minimizing potential hazards.

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Acknowledging the impact of temperature rise on agriculture, a DHT11 sensor monitors temperature levels. When the temperature exceeds a predetermined threshold, the water motor is activated to provide irrigation, mitigating rising temperatures and offering potential applications in agricultural regions. This integrated technology has the potential to reduce losses and enhance the quality of life for both humans and infrastructure. The system combines various variables, each contributing to the overarching goal of creating a smarter and more energy-efficient home environment. Beginning with app-based recognition for smart door access, the system leverages cutting-edge biometric and access control concepts to ensure secure entry. The incorporation of an ESP32 camera with Telegram notification further fortifies door security by providing real-time visual verification. Additionally, the deployment of a KY-024 magnetic sensor for window security addresses potential vulnerabilities, while a fire sensor in the kitchen enhances safety measures by detecting flames and triggering immediate alerts. To optimize power consumption and environmental awareness, the system employs a DHT11 sensor to monitor temperature levels, activating the water motor for irrigation in response to elevated temperatures. This multi-faceted approach underscores the synergy of IoT technologies in not only managing power consumption but also fortifying security and ensuring the well-being of occupants within a smart home environment.

The rest of the paper is organized as follows: In Section 2, state of art techniques has been discussed. The proposed system model is discussed in detail in Section 3 followed by the conclusion and future scope in Section 4.

2. LITERATURE SURVEY

Numerous studies are currently being conducted on the utilization of Internet of Things (IoT) devices in home automation platforms. Previously, a study was undertaken in conjunction with an examination of various applications pertaining to the Internet of Things (IoT). In a previous study [6], the authors have described the conceptualization and practical realization of a novel home automation system. This system employs Wi-Fi technology as its underlying network architecture to establish seamless connectivity among its many components. In a previous study [7], the researchers utilized an Arduino UNO connected to an ESP8266 module, specifically a Wi-Fi module. This configuration enabled the transmission of data regarding household appliances to a cloud server, making it available from any location. Additionally, the appliances could be remotely controlled through an Android application. In their study, the authors [8] have examined the impact of automation technology and the internet on human existence, highlighting their integration into everyday life. Energy loss refers to the lack of ability to remotely access and control equipment from remote locations. In the sixth reference, the authors conducted a comprehensive evaluation of multiple systems currently being utilized. In reference [9], a proposal is put out regarding the use of intelligent devices for the purpose of managing and overseeing home automation functionalities. In reference [10], a proposed web application is described that offers customers the ability to remotely activate and deactivate security measures, as well as manage lighting equipment from any location worldwide. This system introduces remote control functionality. In reference [11], a home automation system is suggested, which utilizes a microcontroller, a mobile device, and Wi-Fi to enable the activation or deactivation of various household appliances that are connected to the system. In a study conducted in [12], authors have showcased the application of Internet of Things (IoT) technology in the development of a home automation system. This system utilizes an ATMEGA 328 microcontroller to enable remote monitoring and control of electrical and electronic appliances through a website interface. The ability to access and operate these products via the Internet is a notable feature of the system [13]. In a scholarly publication, the authors have examined various approaches to manually operating household devices through the use of a remote control, specifically designed to cater to individuals with physical impairments [14]. In this study, the authors present a novel home security system that utilizes gestures as a means of detection. The system is designed to identify motion and subsequently communicate captured images to a Telegram bot. The purpose of this system is to effectively detect and monitor any potentially suspicious activity in the absence of the homeowner. When a visitor approaches the exit, an ESP32-CAM attached camera module captures images, stores them, and subsequently transmits them as a Telegram notification via TCP/IP [15].

A localized data processing framework for IoT-enabled Smart Homes, employing a master unit to efficiently manage local sensor networks. By identifying dependencies and classifying sensors as dependent, it optimizes power consumption, refines data for the Cloud Server, and enables real-time tuning to minimize redundancy [16-19]. Drawing inspiration from the aforementioned studies, this research article presents a novel home automation system that effectively computes the power consumption of individual appliances. The primary objective of this system is to prevent short circuits and automate the process of bill calculation. The study involves the measurement of power utilization of particular gadgets. By conducting an evaluation of individual power, it is possible to prevent the occurrence of system short circuits caused by excessive loads. Tracking the power usage of each individual equipment separately would streamline the billing system. In consideration of the security system, a video surveillance mechanism has been implemented, whereby photos are captured and subsequently transmitted to the owner via a Telegram bot developed by our team. The system can be set using either manual user intervention or automatic system processes. The convergence of Industry 4.0 technologies, including the Internet of Things (IoT), presents unprecedented opportunities for product innovation by seamlessly integrating data-driven insights, automation, and connectivity into industrial processes [20-22]

3. PROPOSED SYSTEM

A home automation smart security system with the capability to monitor and send alerts when we are away from our surroundings. Utilizing various sensors both inside and outside the home, our system detects motion through the PIR and ESP32 camera module. Upon sensing any movement, the ESP32 camera captures images, sending them to the owner via a Telegram bot developed by us over the internet. The homeowner can remotely activate a buzzer connected to the system through the Telegram bot, deterring potential intruders. Our project, implementing the Internet of Things (IoT), allows for these actions to be carried out from a considerable distance. Figure 1 illustrates the block diagram of the system under consideration. The ATMEGA328 microcontroller [23] is commonly employed in conjunction with a range of sensors, including those designed to measure temperature, humidity, fire, and magnetic fields, among others and the DHT sensor is employed to measure temperature and humidity, operating within a defined range and providing localized sensing within a specific environment. The fire sensor is typically designed for localized areas, such as a room or enclosed space, with a detection range within a few meters, making it effective for identifying smoke or elevated temperatures within a confined environment. A proximity-based sensor with a limited detection distance, it is effective within a few centimeters and is typically utilized for detecting the presence or absence of magnetic fields, making it suitable for applications like door/window security. PIT sensor around 5-to-7-meter ranging for residential applications. The ESP32 cam module utilizes a passive infrared (PIR) sensor to detect motion, capture an image, and subsequently transmit it via the Telegram messaging platform. The LCD screen presents the values of all the sensors. The door lock system utilizes a servo motor to execute the opening action by the transmission of a "/open" signal. In order to quantify the electrical current, a current sensor known as the ACS712 is employed. The purpose of this sensor is to detect and measure the amount of current flowing through a circuit. By utilizing this sensor, it becomes possible to monitor the energy consumption of an AC bulb. The measured data may then be shown on an LCD screen, facilitating the calculation of electricity usage for billing purposes.

The methodology implemented in this system involves the utilization of various sensors and devices to ensure enhanced security and efficient home automation. Fire Sensor: The fire sensor is designed to detect the occurrence of a fire. In the event of a fire, the sensor transmits a signal to the microcontroller, initiating the activation of the buzzer. The LCD panel concurrently displays the intensity of the detected fire, providing immediate visual information.KY-024 Magnetic Sensor: Implemented to detect intruders, especially in the event of theft. When a thief uses magnetic materials to scale a wall, the sensor detects the magnetic field, inducing a charge in the ions. This triggers the flow of electric current and sends a signal to the microcontroller, activating the alarm system. The magnetic value is displayed on the LCD panel for real-time monitoring.

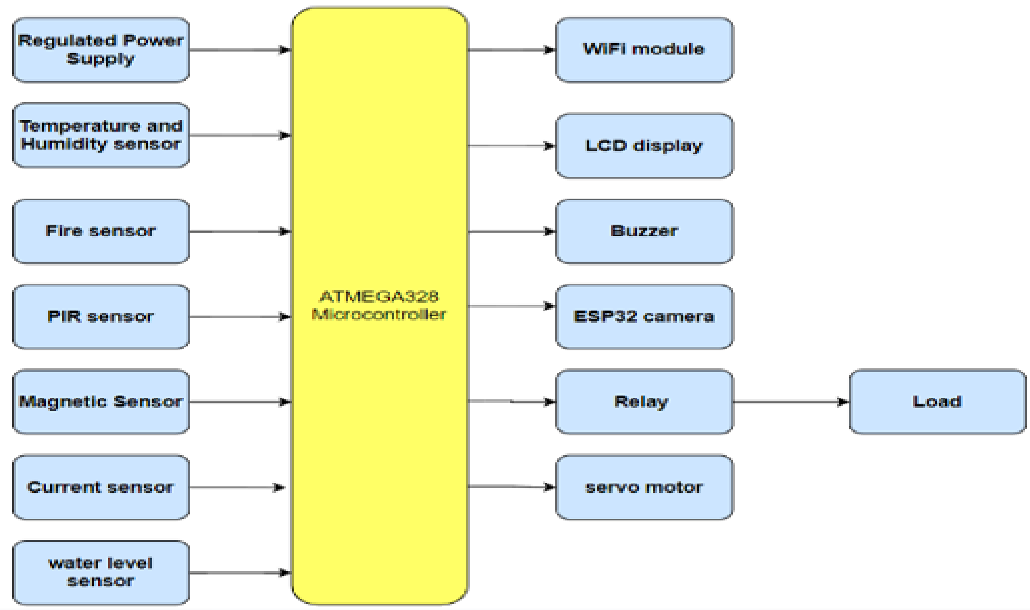


Figure 1. **Block Diagram of Proposed System**

- Servomotor: The servomotor facilitates the mechanized opening and closing of the door upon receiving specific bot commands ("/open" and "/close"). With the ability to rotate to a 90-degree angle, it establishes a connection with the door to ensure seamless functionality.
- Current Sensor and Bulb Integration: The current sensor is integrated with a bulb for real-time current consumption calculation. By issuing the "/on" command, the bulb is activated, allowing the current sensor to calculate and display the units consumed per hour on the LCD screen.

- Passive Infrared (PIR) Sensor: Strategically placed near the door to detect movement and enhance security measures. When an individual position themselves in proximity to the door, the PIR sensor is activated, capturing an image of the object or person. The captured image can be transmitted to a designated mobile device using the "/photo" command for security verification.
- Data Storage and Analysis: Instantaneous data acquired by these sensors is stored on a cloud-based server. The Things View application is employed for viewing and analyzing statistical data, providing a comprehensive overview of sensor readings and system performance.

As depicted in Figure 2, in the event of a catastrophic occurrence, such as a fire, the sensor is capable of detecting the condition and then transmitting a signal to the microcontroller, thereby initiating the activation of the buzzer. Additionally, the LCD panel displays the fire intensity. Figure 3 illustrates the implementation of the KY-024 magnetic sensor for the purpose of detecting intruders within a residential setting. In the event of a theft, if the thief employs a magnetic material to scale a wall, the magnetic field generated by the magnet will induce a charge in the ions, initiating the flow of electric current and transmitting a signal to the microcontroller, so triggering the alarm system. The magnetic value will be presented on the liquid crystal display (LCD) panel.

Figures 4(a) and 4(b) depict the operational mechanism of a servomotor by the use of a bot command. Upon issuing the "/open" instruction, the servo motor will rotate to a 90-degree angle in the right direction, as depicted in Figure 4(b). When the command "/close" is issued, the servomotor will return to its initial position. The motor has the capability to establish a connection with the door in order to facilitate the opening and closing of the door.

Figure 2. **Fire detection Circuit**

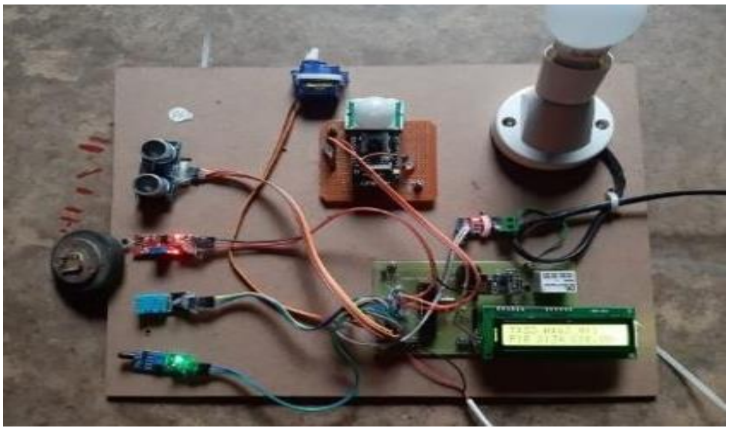
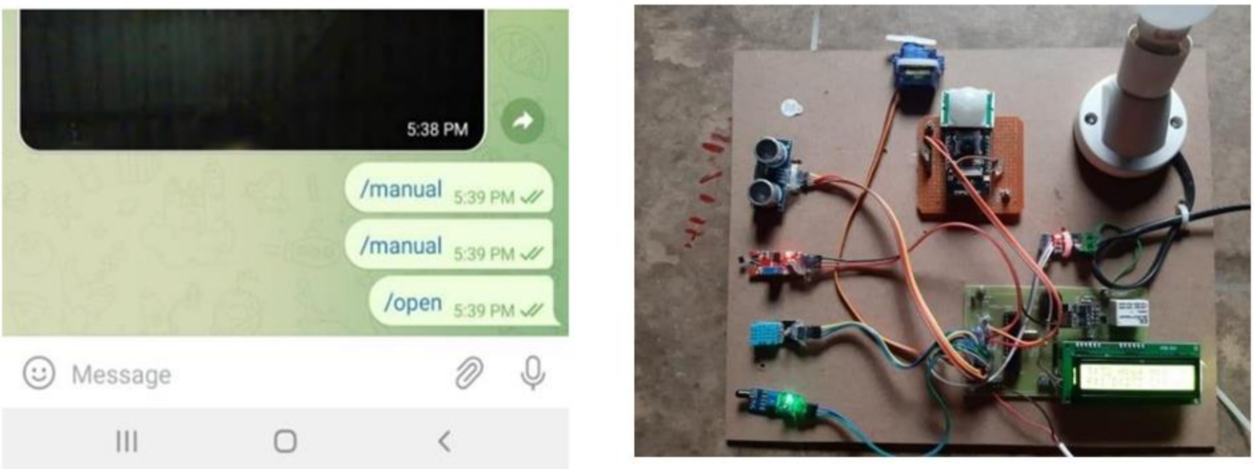
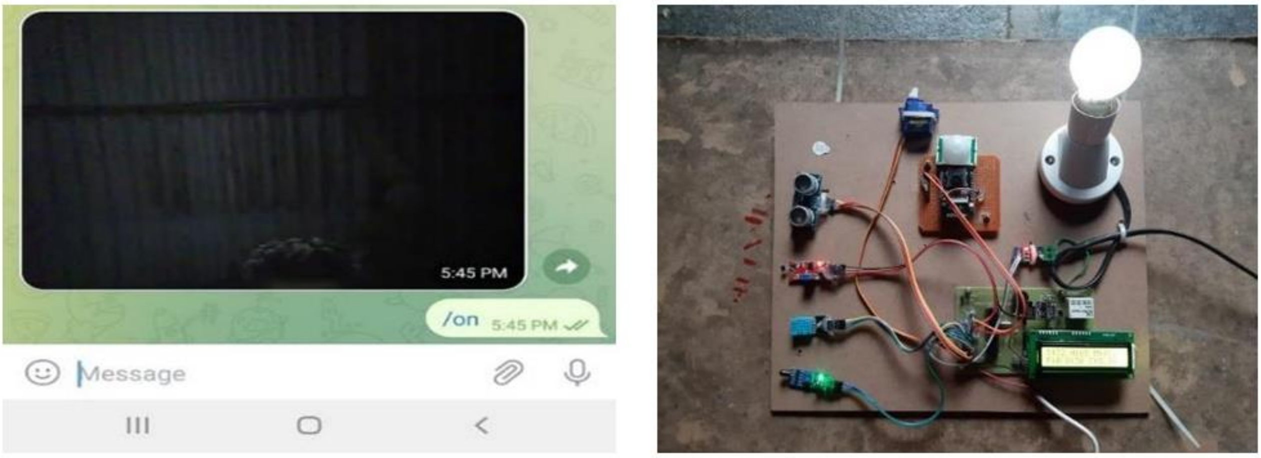


Figure 3. **Magnetic sensor (KY-024 linear hall effect sensor).**



(a) (b)

Figure 4. (a) Operating in manual mode (b) Servomotor based door open/close



(a) (b)

Figure 5. (a) Turn on/off the appliance using bot command (b) Bulb on

Figure 6. Detection of motion by PIR sensor and clicking the photo

Figure 5 (a) and 5(b) show the bot command to turn on the bulb for current calculation. When the bulb is ON, the current sensor will calculate the current usage and display the number of units consumed per hour on the LCD screen. Figure 6 illustrates the operational mechanism of the Passive Infrared (PIR) sensor. When an individual position themselves in proximity to the door, the passive infrared (PIR) sensor, which is situated in close proximity to the door, is activated. The PIR sensor is capable of detecting movement and subsequently captures an image of the object or human in question. This image is then transmitted to our mobile device. The photograph can be transmitted to the designated mobile device through the issuance of a command "/photo" in order to bolster security measures and grant an individual entry to the entrance subsequent to verification. Figure 7 depicts the instantaneous data acquired by the sensors and the subsequent storage of their readings on a cloud-based server. The Things View application is utilized for the purpose of seeing and analyzing statistical data.

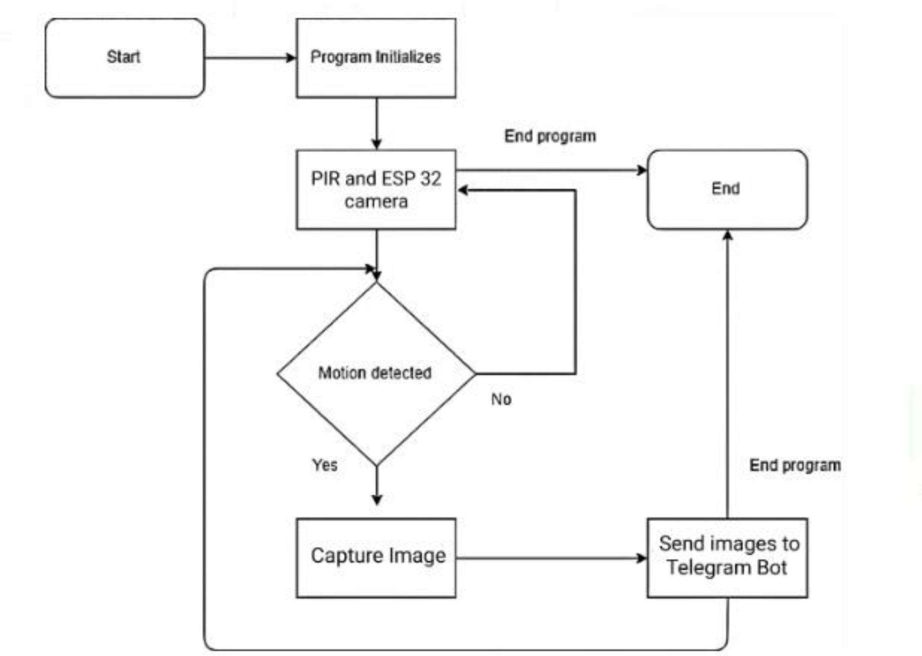


Figure 7a. Flow chart of PIR sensor

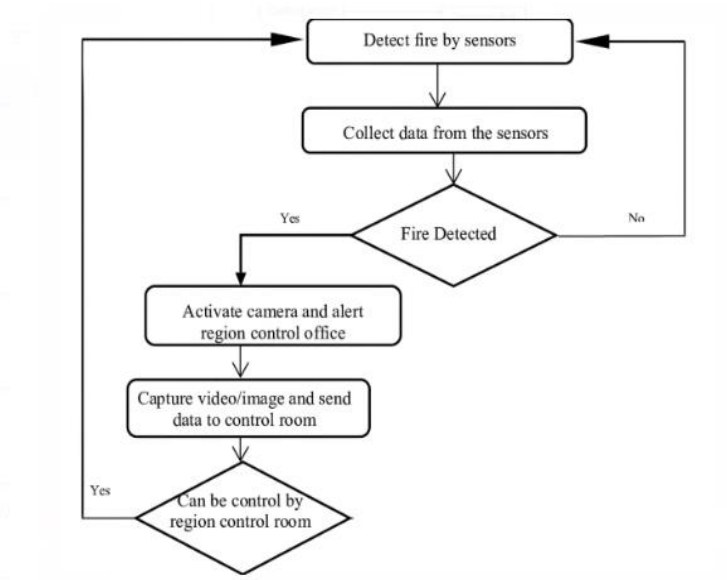


Figure 7b. Flow chart of fire sensor

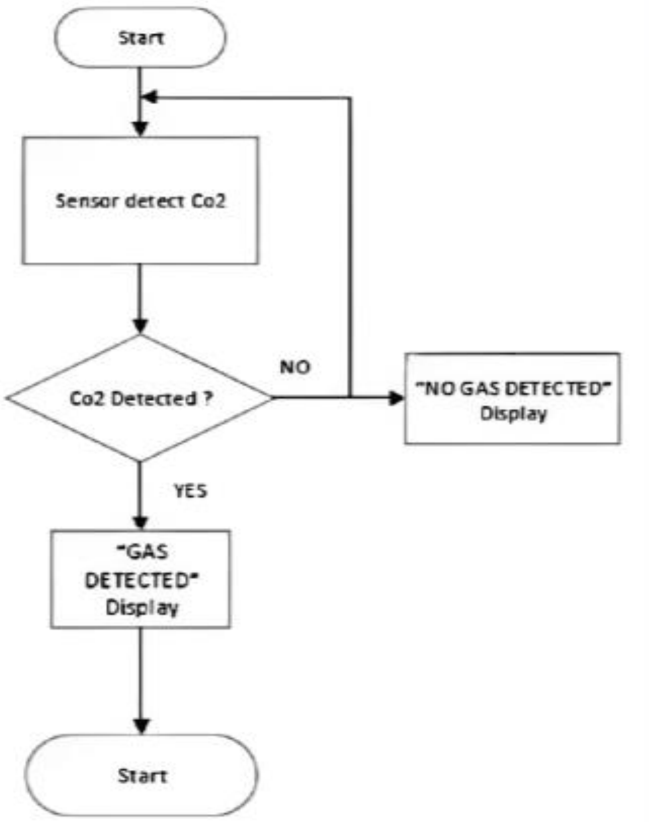


Figure 7c. Flow chart of gas sensor

For energy calculations Econsumed =∫*P(t)dt*
Where, Econsumed is the total energy consumed, *P(t)* is the power usage as a function of time.
Temperature-Activated Irrigation: a mathematical relationship between the temperature readings from the DHT11 sensor and the activation of the water motor for irrigation can be given as
T thresholdtemp=T threshold−k⋅SD(Tambient) …………………….. (1)
Where Tthreshold is the temperature threshold, *k* is a constant, and SD is the standard deviation.
Window Security Activation Threshold: a mathematical expression to determine the threshold for activating the audible alarm based on the readings from the KY-024 magnetic sensor. This involve setting a threshold magnetic field strength:
Bthreshold=(1/n) ∑Bintruder) +k⋅SD(Bintruder)..........................(2)
Where *Bthreshold* is the activation threshold, *Bintruder* is the measured magnetic field strength from the sensor, n is the number of readings, k is a constant, and SD is the standard deviation

(a) (b)

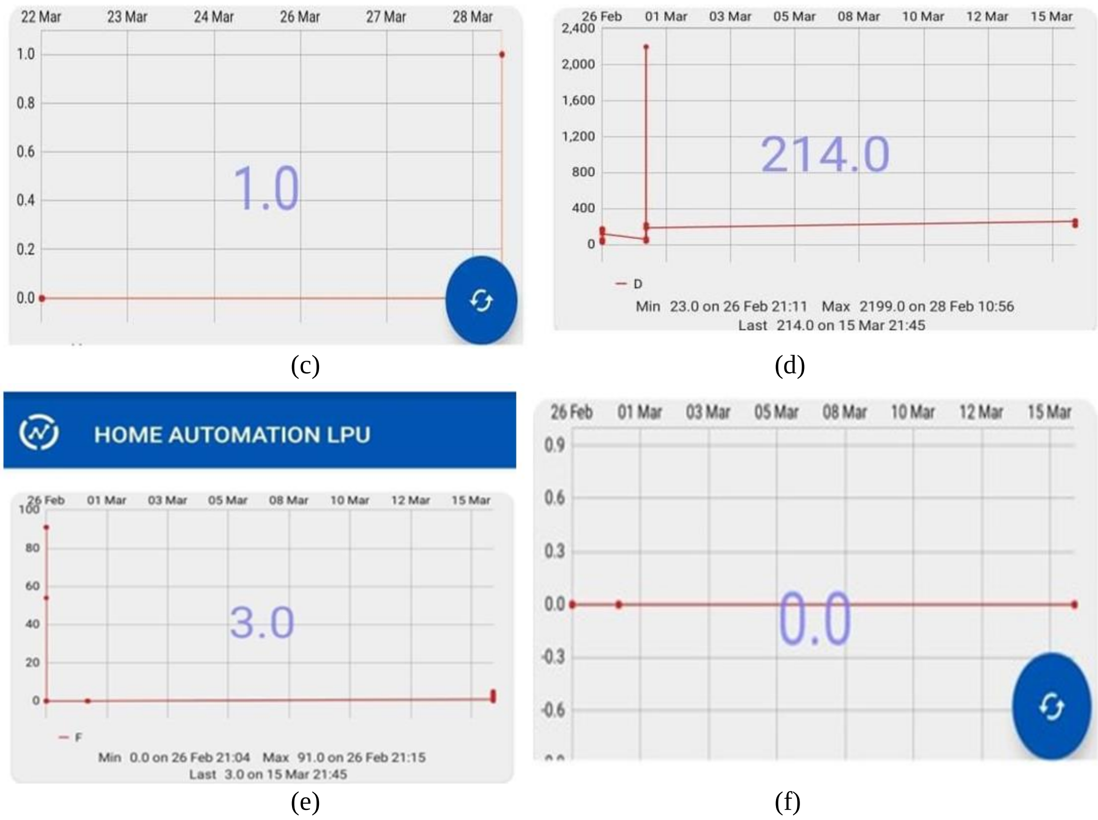


Figure 8. **(a) Temperature Reading (b) Humidity Readings (c) Magnetic Sensor Reading (d) Distance reading (e) Fire Detection Reading (f) Current reading of 40-watt AC bulb. [24]**

The results depicted in the described figures showcase the operational effectiveness and multifaceted capabilities of the implemented smart power management system. In Figure 2, the system's response to a catastrophic event, such as a fire, is illustrated. The sensor successfully detects the condition, transmitting a signal to the microcontroller, which, in turn, activates the buzzer for immediate alerting. Additionally, the LCD panel provides a real-time display of the fire's intensity, enabling quick assessment and response.

In Figure 3, the implementation of the KY-024 magnetic sensor for intruder detection is demonstrated. In the event of a theft, the sensor detects the use of magnetic materials for scaling a wall, inducing a charge in the ions and triggering an alarm system. The magnetic value is concurrently presented on the LCD panel, enhancing situational awareness. Figures 4(a) and 4(b) elucidate the operational mechanism of the servomotor in response to bot commands. The motor exhibits precision, rotating to a 90-degree angle upon the "/open" instruction and returning to its initial position with the "/close" command. Its capability to establish a connection with the door facilitates seamless automation in door opening and closing. Figures 5(a) and 5(b) highlight the bot command to illuminate the bulb for current calculation. With the bulb ON, the current sensor accurately measures usage, displaying the consumed units per hour on the LCD screen. This feature promotes energy-conscious decision-making.

Figure 6 provides insight into the Passive Infrared (PIR) sensor's functionality. Activated by an individual's proximity to the door, the PIR sensor detects movement, captures an image, and transmits it to a mobile device through the "/photo" command. This not only bolsters security measures but also facilitates secure and verified access. Figure 7 encapsulates the instantaneous data acquired by the sensors, emphasizing the system's capability to store and analyze readings on a cloud-based server. The Things View application plays a pivotal role in visualizing and interpreting statistical data, offering users comprehensive insights for informed decision-making and system management.

- Our system integrates seamlessly with a diverse range of sensors, including gas, flame, and current sensors, offering a more comprehensive approach to home security. This holistic sensor integration enhances the ability to detect potential threats and respond proactively, setting our solution apart from some existing models that may focus solely on specific security aspects.
- The conventional power management features commonly found in existing studies. While optimizing energy consumption, our system incorporates real-time monitoring and alerts for any fluctuations in home electrical currents, providing homeowners with valuable insights into their energy usage patterns. This dual functionality of power management and security creates a more versatile and user-centric solution, aligning with the evolving needs of modern smart homes.

- Our study places a strong emphasis on user interaction and decision-making. The incorporation of a Telegram bot allows homeowners to remotely assess captured images and activate security measures, such as the buzzer, in response to potential security threats. This user-friendly interface enhances the practicality and accessibility of our system compared to some existing models, which may lack intuitive user engagement features.

Table 1 summarizes a comparison between the current work and other studies

Table 1. Comparison between the current work and other studies

References	Controller	Interface	Controlled Application
[17]	ESP32	RTDB service	Smart energy meter
[18]	Arduino AtMega328	Thingspeak	IoT based smart energy meter
[19]	WIFI module	Oled display	IOT Based Smart Energy Meter for Efficient Energy Utilization in Smart Grid
Our proposed work	Arduino ATMega328 with Wi-Fi module	Telegram bot	IoT enabled power management system with enhanced security. Sending notifications to the owner

4. CONCLUSIONS

This study introduces a proposed home automation and security system leveraging Internet of Things (IoT) technology. The system seamlessly integrates power man

agement and image detection functionalities. To evaluate its performance, precise power consumption measurements are conducted for each individual appliance, concurrently mitigating potential hazards like overloading and system short circuits. The system's ability to comprehensively monitor energy consumption enhances invoicing processes' efficiency. Furthermore, a surveillance system with a front-door camera is deployed, effectively capturing and transmitting photos to the user. Users are provided with two options for system updates: manual management or automatic updates facilitated by the system. The implementation of an ESP32 camera is incorporated for capturing photographs, initiating security notifications through the Telegram messaging platform.

This system is characterized by its cost-effectiveness, energy efficiency, and the capacity to provide real-time data through a mobile application. Its inherent flexibility and efficiency make it highly suitable for frequent use. Additionally, future research opportunities could explore the incorporation of voice command communication protocols, such as those offered by Google Assistant or Alexa, to control electrical devices and retrieve power consumption data from a website, further expanding the scope of this study.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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