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IoT-Based Smart Home Automation System

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Abstract

This work presents a smart home automation system using IoT technology to enhance convenience, efficiency, and security. It allows users to control household devices via an IoT app connected to a Wi-Fi network, with data stored in Firebase for real-time synchronization. Key features include automatic lighting controlled by a PIR sensor to save energy and an automatic fan system with a DHT11 sensor that adjusts based on room temperature for comfort. The smart door system uses an RFID reader and servo motor to open/close the door, with an LCD showing its status. An ESP32 camera captures images when the doorbell is pressed, enhancing security. The IoT app enables remote device control via smartphones. EEPROM stores data like Wi-Fi credentials for reconnection after power interruptions. This system demonstrates how IoT can create smarter, energy-efficient homes with automated control, remote monitoring, and efficient data management.

1. Introduction

The concept of a smart home was introduced over 80 years ago and has evolved with advancements in technology. Recently, service providers and manufacturers have focused on developing and popularizing smart homes. Research has increasingly concentrated on the Internet of Things (IoT), which connects physical objects to networks for data sharing and task automation [1]. IoT has become a promising technology for managing and controlling smart devices with minimal human intervention, offering better monitoring and faster responses [2]. The IoT industry is seen as a key area for future technological growth, offering efficient services anytime and anywhere, overcoming constraints of time, space, and cost [3]. IoT is widely used in energy monitoring and environmental control in buildings, schools, offices, and museums, using sensors and actuators to manage lighting, temperature, and humidity [4][5].

Smart home systems enhance the convenience, security, and energy efficiency of houses by utilizing sensor technologies and the Internet of Things. Firebase is a real-time updating cloud-based database that processes and stores data from sensors and devices. This enables smart homes to be controlled by smartphones, automate chores, and adjust to user preferences [6]. Devices can reconnect to the network even in the event of a power outage via EEPROM (Electrically Erasable Programmable Read-Only Memory), which retains Wi-Fi usernames and passwords and other settings.

The ESP32 and ESP32-CAM microcontrollers are used in this project to control a wireless data transfer smart home system. Several sensors and actuators are part of the system. Motion-activated lighting is controlled by a PIR sensor, door unlocking is accomplished by an MFRC522 RFID reader, and fan control is accomplished by a DHT11 temperature sensor. Real-time status updates are displayed on an LCD while the ESP32-CAM camera keeps an eye on the surroundings. For additional safety, a servo motor operates the door lock, and a buzzer serves as a doorbell. For instance, to operate other parts like the servo motor for door control, the motor driver for fan speed, and a reset button, the Arduino Mega works in tandem with the ESP32. Wi-Fi network management is made easy by the ESP32 and Arduino Mega's Bluetooth connectivity. The Arduino Mega's integration with ESP32 peripherals improves the system's capacity to automate, monitor, and manage a range of smart home features for increased convenience, safety, and energy efficiency.

2. Methodology

The connection between the Smart Home Automation System's components from input to output is depicted in the block diagram in Fig. 1, which also shows the system's overall architecture. It demonstrates how the microcontroller system, which combines the ESP32 and Arduino Mega, receives data from sensors (such the DHT11 and PIR) and devices (like the RFID reader, push button, and ESP32 camera). While the ESP32 concentrates on processing and integrating with Firebase for cloud-based data storage, the Arduino Mega serves as a supporting module, managing other input/output functions and offering extended pin availability for intricate connections. The processed data controls outputs such as the buzzer, servo motor, fan, and lamp. Users can also remotely monitor and control the system with the help of the Android application.

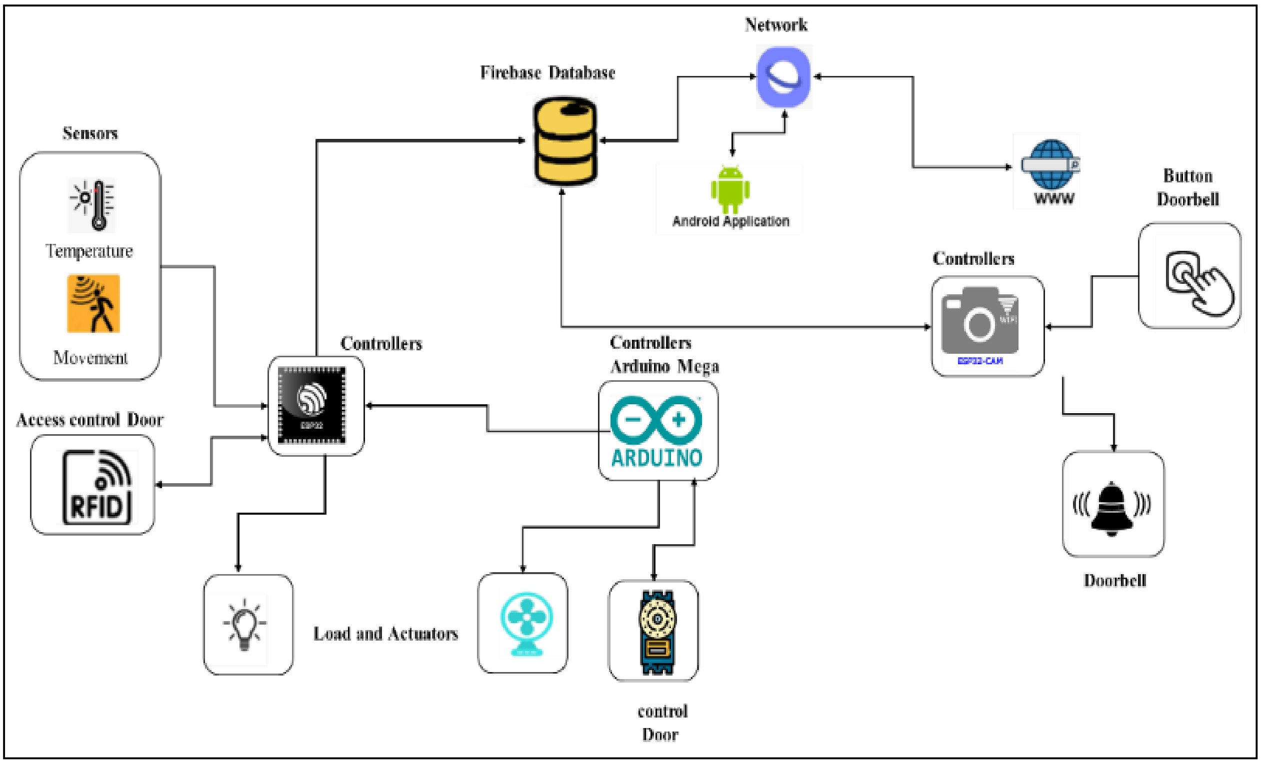

Fig. 1 *Block Diagram of IoT-Based Smart Home Automation System*

The flowchart in Fig. 2 outlines the project's workflow, beginning with Stage 1, where research and literature review guided the development of the prototype and hardware platform, with programming implemented using Arduino IDE. In Stage 2, the IoT application connects to Wi-Fi credentials stored in EEPROM, enabling seamless integration with Firebase for efficient communication and smartphone-based control. Finally, in Stage 3, the prototype is tested in a living room setting as part of the indoor automation system, with functionality and accuracy results recorded for analysis in the subsequent chapter.

Fig. 3 and Fig. 4 provide a detailed depiction of the operational workflow of the IoT-based Smart Home Automation System, highlighting the collaborative roles of the ESP32, ESP32-CAM, and Arduino Mega microcontrollers. These microcontrollers form the backbone of the system, each fulfilling specialized functions to ensure seamless integration and efficient operation.

The DHT11 sensor on GPIO pin 4 for fan control, a PIR sensor on pin 32 for lamp control, and an MFRC522 RFID reader linked to GPIO pins 5, 18, 23, 19, and 33 for door lock access are just a few of the components that are managed by the ESP32 microcontroller in this configuration, as seen in Fig. 5. SDA pin 21 and SCL pin 22 are used for communication on an LCD screen. For more control, the ESP32 also connects to an Arduino Mega through the RX and TX ports (TX1, RX1). The Arduino Mega's servo motor for the door is attached to pin 2, and the motor driver that regulates the fan speed is connected to pin 3. A buzzer is attached to pin 12 of the ESP32-CAM, and a button to pin 13 for additional control functionalities.

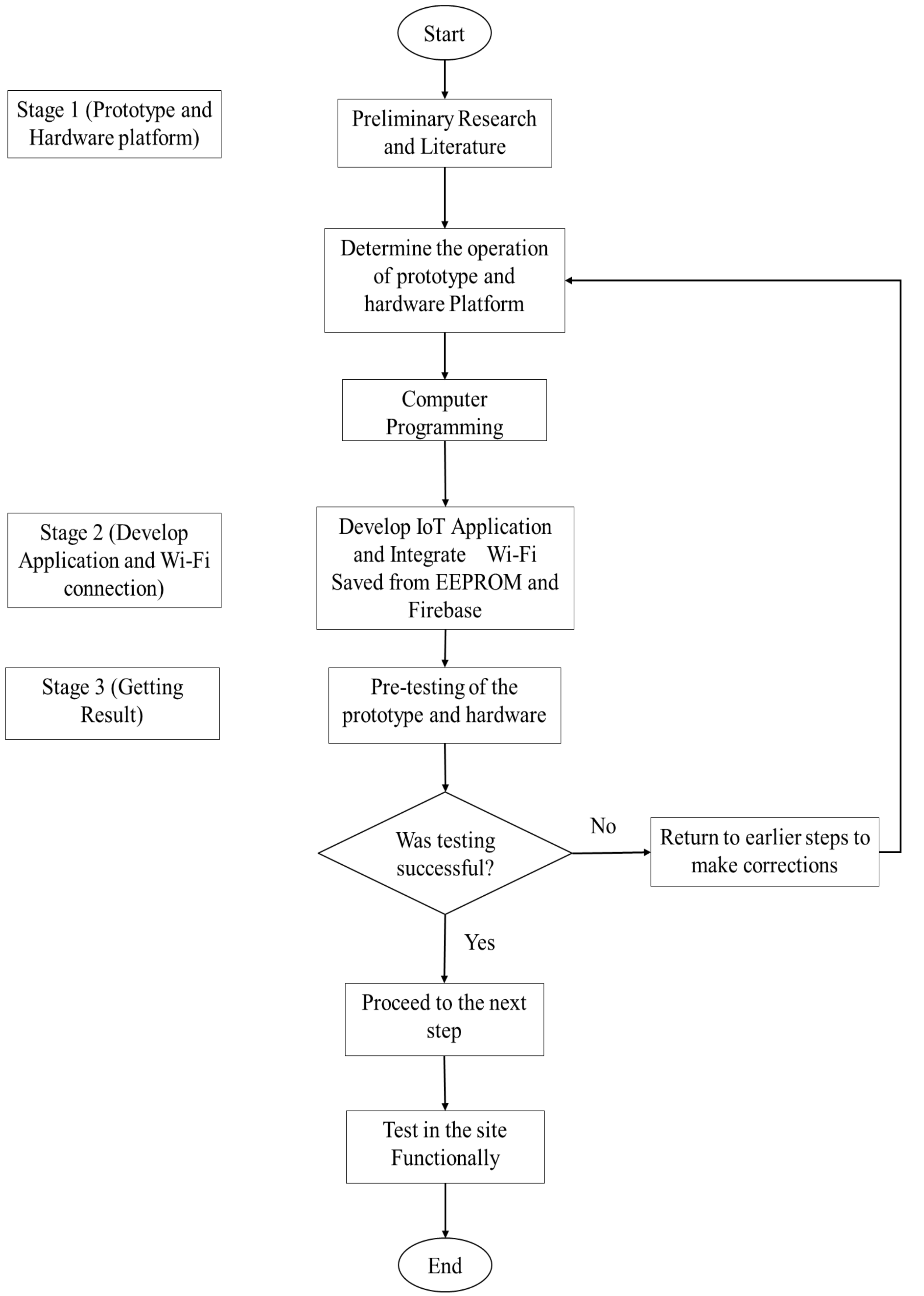

Fig. 2 *Flowchart of the work*

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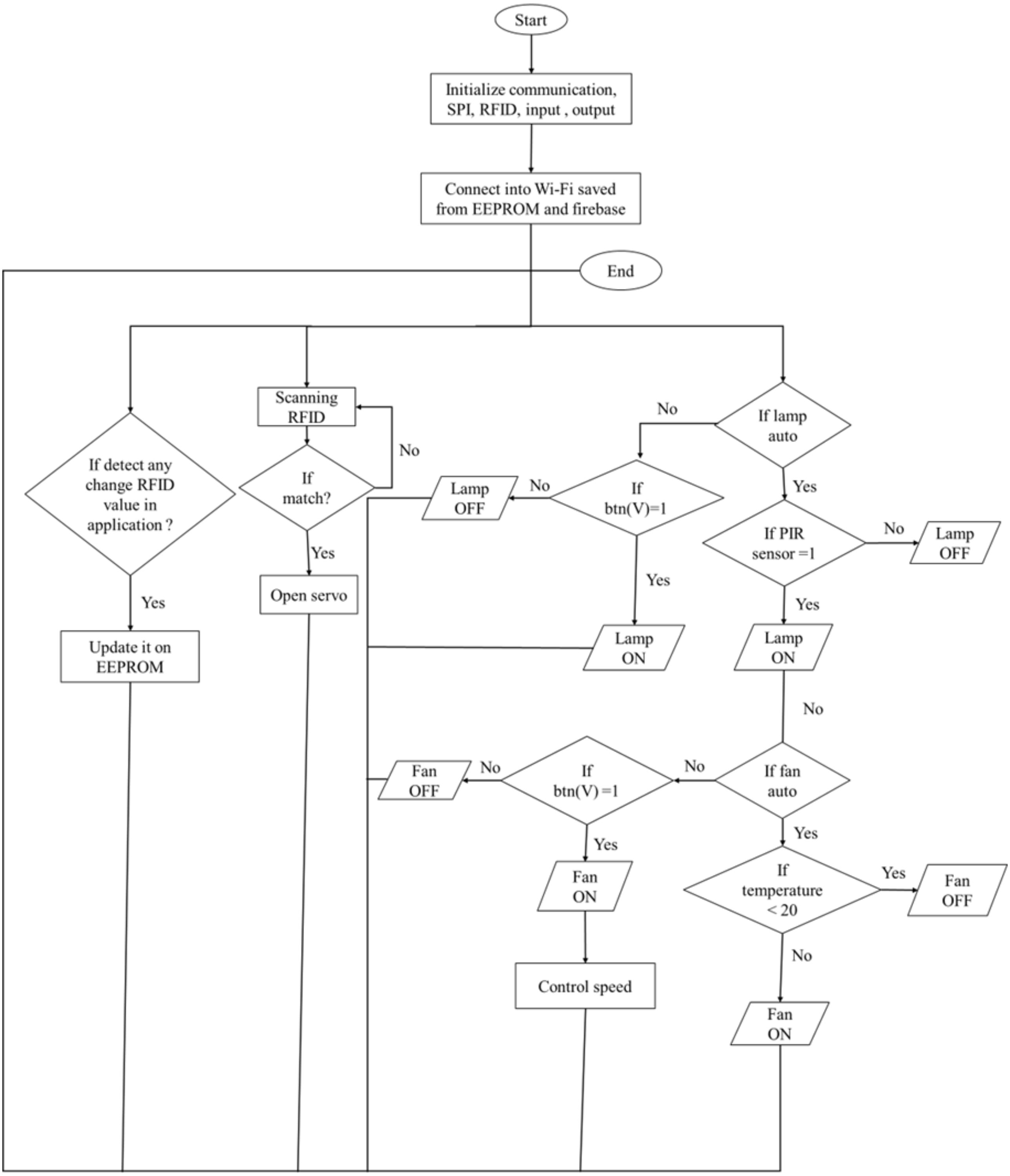


Fig. 3 *The process flow of the microcontroller ESP32 and Arduino Mega 2560*

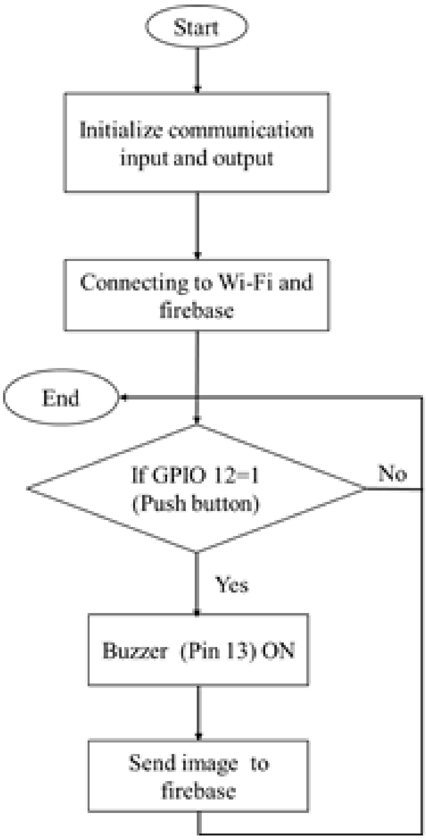


Fig. 4 *The process flow of the microcontroller ESP32 Camera*

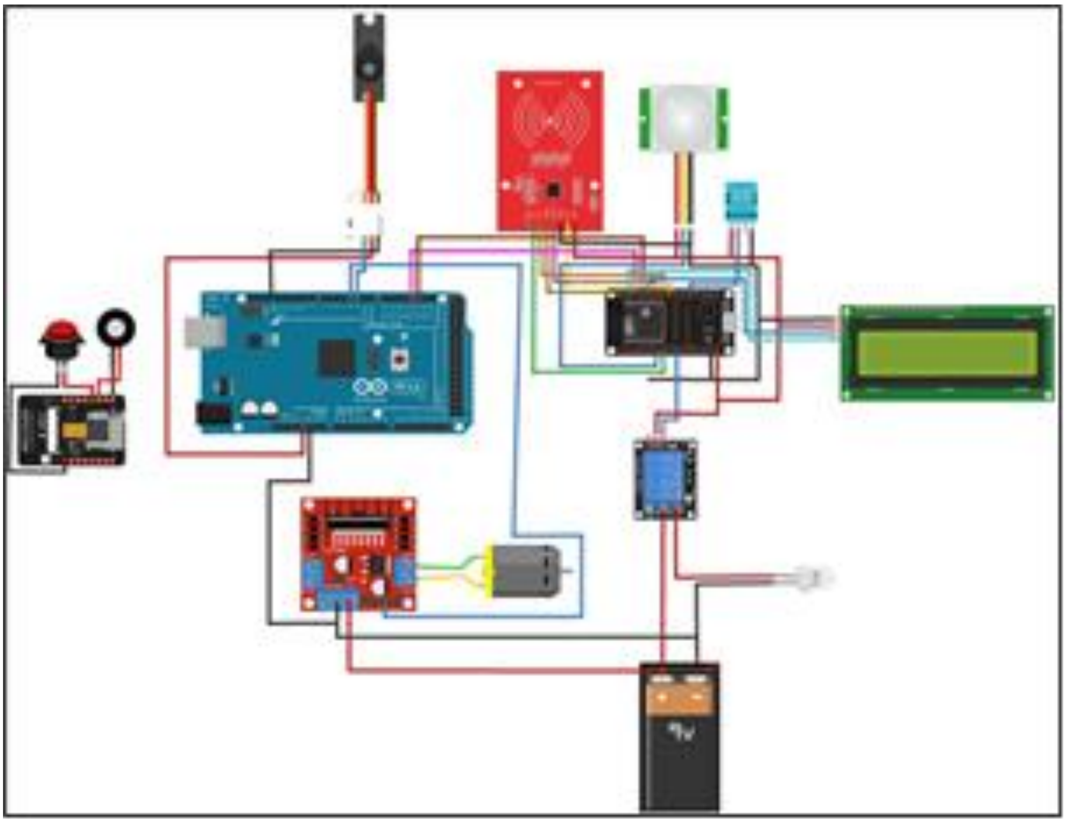


Fig. 5 *Circuit connection design for the system purpose*

3. Results and Discussion

This section presents the results and discussion of the IoT-Based Smart Home Automation System developed in this work.

3.1 Prototype of The System

The prototype is an Internet of Things (IoT)-based smart home automation system that integrates an Arduino Mega, ESP32 microcontroller, and ESP32-CAM to regulate security, access, and environmental monitoring. The LCD shows whether the door is "Door Open" or "Door Closed." The RFID reader, which is coupled to the ESP32, operates a servo motor to unlock or lock the door. While a PIR sensor uses motion detection to turn on a lamp that is also powered by a 9V battery, a DHT11 sensor uses temperature and humidity readings to operate a fan that is driven by a 9V battery through a motor driver. Visitors can indicate their presence by using the button and buzzer on the ESP32-CAM, which doubles as a doorbell. Effective coordination of the fan and door lock functions is ensured via communication between the ESP32 and Arduino Mega. Fig.6 shows the prototype of the system.

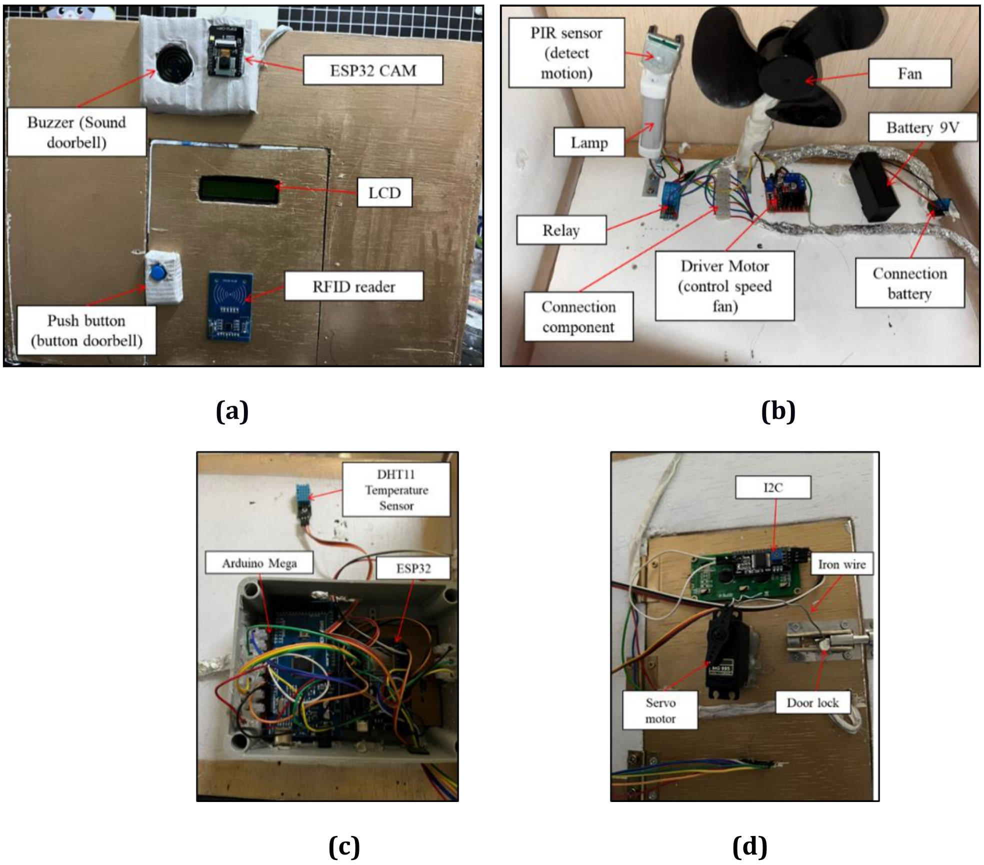


Fig. 6 *(a) front the door connection (b) lamp and fan connection (c) main controller and temperature connection (d) behind the door connection*

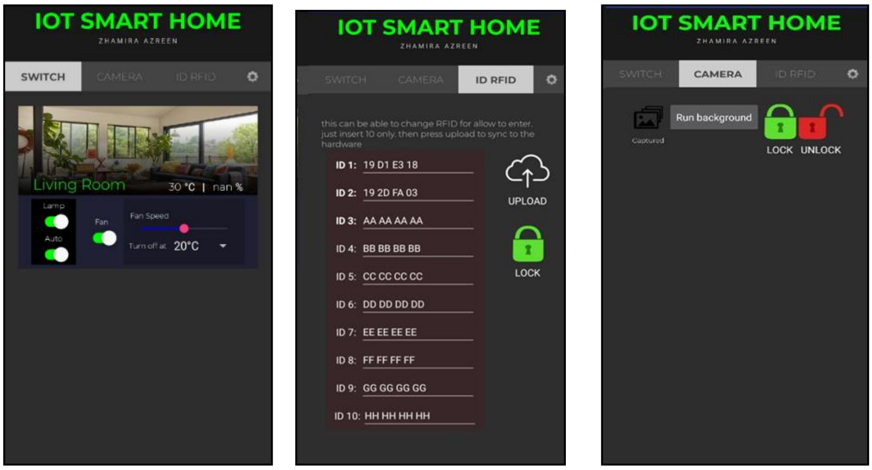
3.2 Time Data Visualization Firebase

The IoT application for the Smart Home Automation System uses Firebase as a backend for real-time data storage and synchronization. It enables seamless communication between hardware components (ESP32, Arduino Mega, sensors, and actuators) and the system, storing the status of devices such as fans, lamps, cameras, and door locks. Features include switches for manual on/off control and automated fan and lamp operations based on sensor data. Firebase's real-time database ensures users can monitor and control devices instantly, ensuring efficient management and status updates.

The Firebase data zone interface, shown in Fig. 7, manages and displays data from the IoT application, including temperature readings from the DHT11 sensor, images from the ESP32 camera, and the status of devices like fans, lamps, and door locks. It also tracks RFID data for door access control. This centralized platform ensures seamless data storage, synchronization, and efficient management of all connected devices.

Fig. 7 *Data zone for user applications interface*

The user interface of the mobile app, which is seen in Fig. 8, enables control of the smart home system, which includes motion sensor-based lamp activation, an auto-switch for temperature-based fan control, and switches for manual lamp and fan control. It offers RFID-based door access and shows current temperature and humidity values. For security monitoring, the camera feature takes pictures with timestamps. All linked devices are managed effectively thanks to this user-friendly interface.



a) **b)** **c)**

Fig. 8 *a) Lamp and fan switch & b) RFID ID and lock door & c) Picture capture and lock/unlock picture*

3.3 ESP32 Camera with Doorbell Testing

Fig. 9 shows that when the doorbell button is pressed, the buzzer rings and the camera capture a picture of the person. This setup enhances the doorbell system by capturing images for security and remote monitoring, making the system smarter. The image is uploaded and displayed in the IoT application for real-time access.

3.4 Fan Control by Motor Driver Speed and Temperature Testing

In this system, the buzzer sounds and the camera takes an image of the individual when the doorbell button is pressed (Fig. 10). The output of the camera is shown on the serial monitor in Fig. 11, verifying that the picture was taken. By taking pictures for security and remote monitoring, this configuration improves the doorbell system and makes it more intelligent. For real-time access, the image is uploaded and seen in the IoT application.

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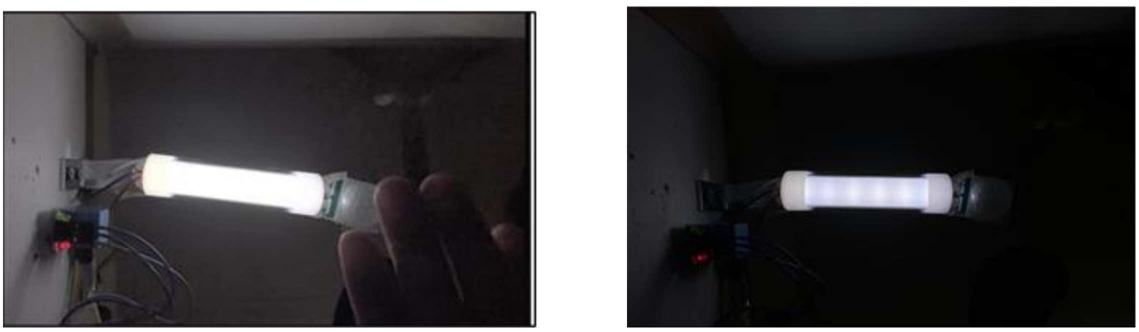
Fig. 9 Image captured in the IoT application

Fig. 10 *Fan control by 50 speeds when the temperature is more than 20°C*

3.5 Lamp Detect Movement and Manual Control Testing

The IoT app enables manual or automatic control of the lamp via a PIR sensor. The sensor, tested in a bedroom, detected motion up to 7 meters, turning the lamp on. Beyond this range, the lamp remained off. Users can flexibly manage the lamp for convenience and efficiency.



(a) (b)

Fig. 11 *(a) Sensor detects the movement & (b) Manual switch with lamp ON*

The PIR sensor test demonstrates its ability to recognize motion and activate the lamp. While Fig. 11(b) displays manual IoT control, Fig. 11(a) demonstrates motion detection turning on the lamp. Real-time feedback from the system guarantees precise motion-based lamp regulation for increased efficiency.

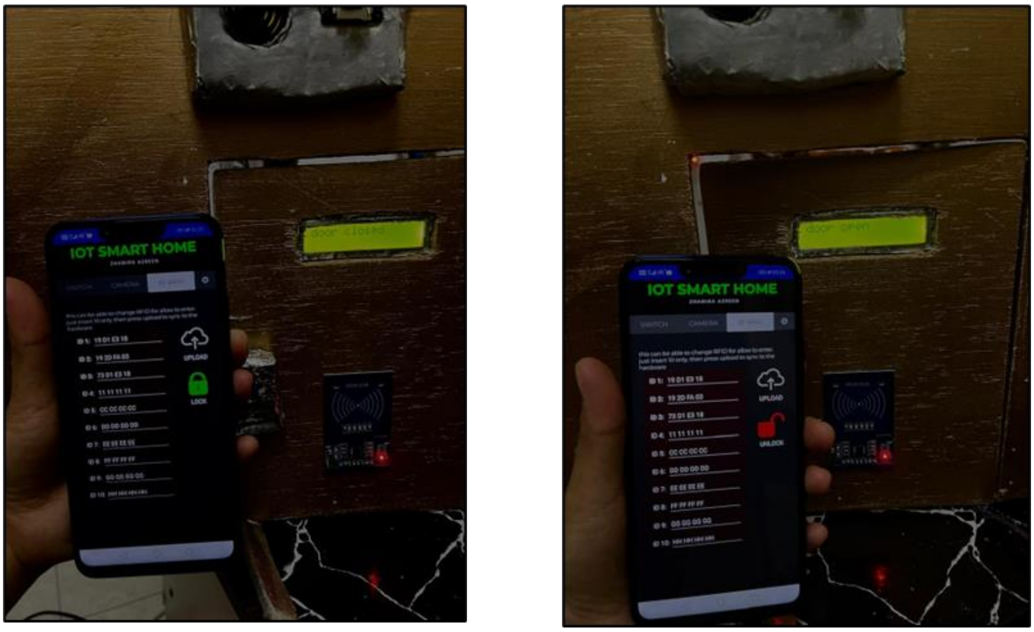
3.6 Door Lock with RFID and Manual Door Lock Testing

The RFID-based door lock system unlocks the door when valid card IDs, such as 19 D1 E3 18 or 19 2D FA 03, are recognized. The servo motor rotates 30 degrees to open the door. The IoT application can also be used to manually operate the door for added versatility. When no RFID card is identified, the "Door Closed" message appears in Figure 12 (a). When a valid card is identified, the LCD displays "Door Open" (Fig. 12(b). The technology ensures secure entry by confirming card IDs and displays the door's status.

(a) (b)

Fig. 12 *(a) No RFID card detects and LCDs "door closed" & (b) RFID detects card and LCDs "door open"*

Fig.13 shows the door lock system in two states. In Fig. 13(a), when the door is locked manually, the LCDs "Door Closed." In Fig. 14(b), when the door is unlocked manually, the LCD shows "Door Open." This system allows the door to be locked or unlocked using a manual switch in the IoT application.



(a) (b)

Fig. 13 *(a) Door Lock manual and LCDs "door closed" & (b) Door unlock manual and LCDs "door open"*

4. Conclusion

The IoT-Based Smart Home Automation System is designed to control and monitor equipment such as fans, lamps, and doors. The system uses components such as the ESP32 microcontroller, sensors, and actuators to automate operations such as temperature-based fan control, PIR-detected lamp operation, and RFID-enabled door locking. An ESP32 camera improves security by capturing photos surrounding the door. The device additionally employs a buzzer and a servo motor for feedback and door lock control. The system demonstrates automation for home management, security, and energy saving through wireless communication and remote control via an IoT application.

Acknowledgment

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the paper's publication.

Author Contribution

The authors attest to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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