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Research Article

A Hybrid IoT-Enabled Smart Home Automation System with Multi-Model Control and Human Presence Detection

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Abstract

This study suggests a comprehensive IoT-enabled smart home automation system that smoothly combines several control modalities with sophisticated human presence detection in an era where intelligent living environments are becoming increasingly important. This hybrid system offers a flexible and user-friendly platform for controlling home appliances such as lights and fans using Wi-Fi, Bluetooth, infrared (IR) remote control, and manual interfaces. The system's integration of human presence sensors enables context-aware automation, which dynamically modifies the linked appliances' operating status depending on occupancy. The multi-control technique guarantees high accessibility to accommodate a range of user preferences and scenarios by enabling users to interact via phones, physical switches, infrared remotes, or automatic triggers. Without sacrificing comfort, the presence-based automation feature proved highly successful in reducing idle energy consumption. Additionally, scalability is facilitated by the modular architecture, making it simple to add further sensors or devices in subsequent developments. This study demonstrates how IoT technology and cognitive sensing can be combined to construct flexible, energy-efficient smart homes that put user autonomy and environmental responsibility first. The suggested framework lays the groundwork for future studies in machine learning integration and improved sensor fusion by providing a workable design for next-generation home automation systems to maximize automation and personalization.

Keywords: *IoT, Energy Efficiency, Human Presence Detection, Smart Home Automation, Multi-Control Interface*

1. Introduction

Due to its ability to provide a “smarter” way of living through connectivity to a wide variety of household items (lights, fans, and so on), the Internet of Things (IoT), in conjunction with existing home automation systems, has made it possible for consumers to remotely operate their household appliances. Smart home automation is another excellent argument for the use of presence detection technologies. Advanced presence detection systems allow an appliance to shut down when no one is in the room and to turn on when someone enters the room, thus providing an energy-efficient solution as well as convenience (Asadullah & Raza, 2016).

Figure 1. IoT-based smart home automation

Despite their simplicity, traditional manual systems can sometimes fail to be the most reliable or efficient means of accomplishing a task. Intelligent sensing technologies provide solutions to the issues of human error and decision making, thereby affording individuals a more modern and sustainable means of managing their homes (Gunge & Yalagi, 2016).

1.1 IoT-Based Worldwide Control (ESP RainMaker)

One of the primary goals of the project is to enable remote access to home appliances from anywhere in the world. By using the ESP Rain Maker platform, users may connect their devices to the internet and control them with a smartphone application. This ensures that even when the user is not at home, appliances such as lights and fans can be quickly turned on or off. This objective highlights how important global connectivity, real-time monitoring, and user convenience are to modern smart home systems (Brush et al., 2011).

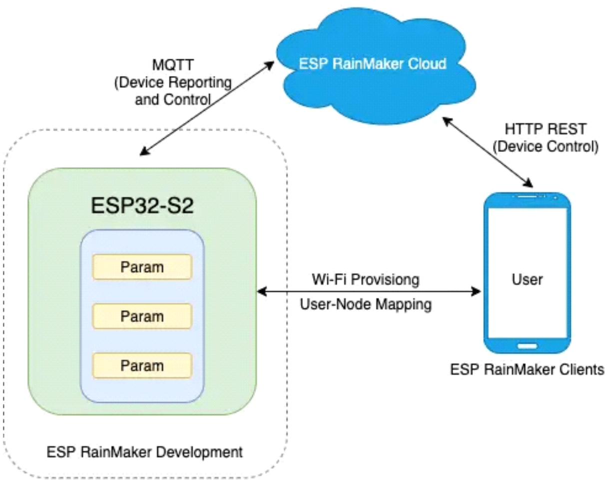

Figure 2. ESP RainMaker control architecture

1.2 Bluetooth-Based Local Control (MIT App Inventor)

Another aim is to create a local fail-safe in the event of internet loss, so that if the online service becomes inaccessible the consumer will still be able to use their devices. According to Gill et al. (2009), Bluetooth control provides an inexpensive means of locally operating devices while increasing the reliability of a system.

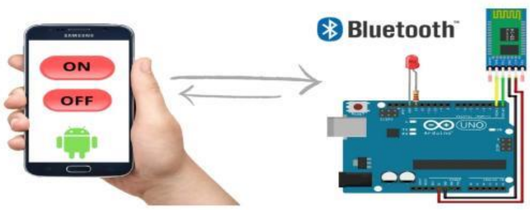

Figure 3. Bluetooth control app built with MIT App Inventor

1.3 Presence Detection and Automation (HLK-LD2410 Sensor)

One of the most inventive objectives of the project is the integration of the HLK-LD2410 human presence sensor. This objective directly promotes automation, energy efficiency, and intelligent living spaces (Withanage et al., 2014).

1.4 Enhancing Energy Efficiency, User Convenience, and Reliability

The system allows for the automatic switching off or on of electrical devices whenever a person enters or leaves the area in which the device has been placed, thereby enhancing the way living environments are currently managed (Sriskanthan et al., 2002).

2. Materials and Methods

2.1 Materials

The project design utilizes both hardware and software components. The hardware includes a microcontroller together with various sensors (for environmental observation), relay modules (electrical control), switches (user input), and a power supply. The complete list of materials is given in Table 1 (Jacobsson et al., 2016).

Table 1. List of components with specifications

S.N.	Component	Specification / model	Function	Unit
1.	Microcontroller	ESP32 dual-core, 240 MHz, Wi-Fi + Bluetooth	Central controller: processes all inputs and controls the relay modules for the appliances.	01
2.	ESP RainMaker app	Cloud-based IoT service	Provides worldwide remote control and monitoring of appliances via a smartphone app.	–
3.	HC-06 Bluetooth module	Classic Bluetooth, UART communication	Enables local wireless communication between the smartphone app and the ESP32.	01
4.	MIT App Inventor application	Custom Android app for Bluetooth communication	Provides the user interface for Bluetooth-based local control of appliances.	–
5.	IR remote	Standard TV/DVD remote	Allows traditional remote-based control of appliances.	01
6.	IR receiver	TSOP1838, 38 kHz IR receiver module	Detects IR signals from the remote and sends the decoded data to the ESP32.	01
7.	Human presence sensor	HLK-LD2410 wave-radar human presence sensor	Detects human presence/motion and triggers automatic ON/OFF of lights and fans.	01
8.	Relay module	4-channel, 5 V relay module	Acts as an electronic switch to control high-voltage appliances safely.	01
9.	Manual switches	Standard electrical switches	Provides fail-safe manual control of appliances in case of system failure.	06
10.	Power supply	5 V adapter	Supplies stable power to the ESP32 and the other modules.	01

2.2 Block Diagram

The ESP32 microcontroller is the central component of the overall architecture of the proposed hybrid smart home system. Because it is connected to all hardware modules and control interfaces, the ESP32 can handle user input, coordinate communication, and use relay switching to run the appliances. The connections between the components are depicted in the system block diagram (Figure 4), in which (A) is the ESP32 microcontroller, (B) the HLK-LD2410 sensor, (C) the HC-06 Bluetooth module, (D) the IR receiver, and (E) the relay module; the arrows indicate the data and power flow.

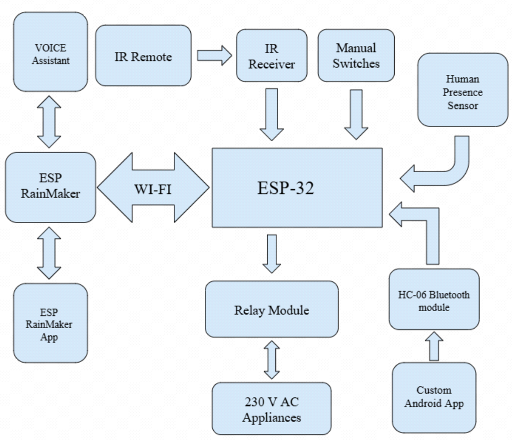

Figure 4. Block diagram of the hybrid smart home system

2.3 ESP32 as Central Controller Using Wi-Fi

The ESP32 microcontroller utilizes built-in Wi-Fi capabilities to become the primary controller of the home automation system, enabling wireless control and monitoring of many different types of appliances, such as four lights and four fans (Dey et al., 2016). The ESP32 enables a highly flexible and efficient smart home by allowing users to perform real-time monitoring and to communicate with other Internet of Things (IoT) devices using Hypertext Transfer Protocol (HTTP) standardization (FakhrHosseini et al., 2025).

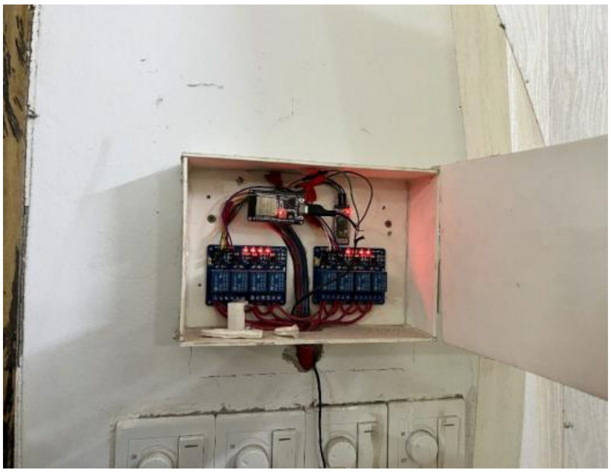

Figure 5. Home automation system using built-in Wi-Fi. Blue lines denote Wi-Fi communication pathways.

2.4 IoT Control Implementation

The use of IoT controls provides the ability for remote monitoring and control of equipment via an internet connection. In summary, the technology allows users to operate their appliances in a smarter, more efficient, and more user-friendly manner (Dhumpati et al., 2025).

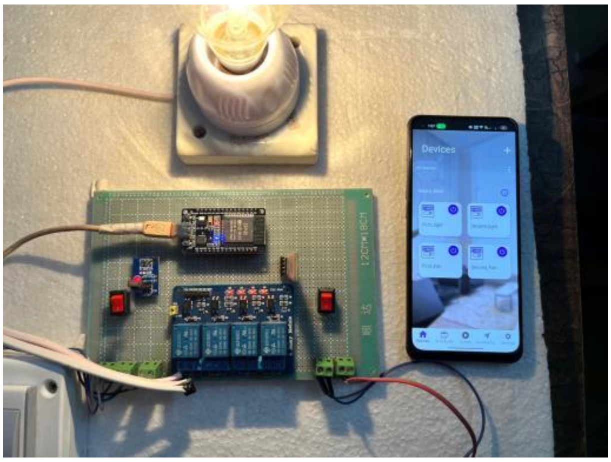

Figure 6. Home automation with ESP RainMaker

2.5 Mobile Application Development for Bluetooth Communication (MIT App Inventor)

The mobile app is used to control four fans and four lights using Bluetooth technology and was created using MIT App Inventor. Additionally, for fans that allow speed control, a speed-level command can be entered by adding sliders (Mahendran et al., 2025). To facilitate successful communication with the Bluetooth controller, a simple predefined communication protocol is used. Finally, the app may continue to be enhanced and updated in response to user feedback by adding further features or increasing usability (Simwaba & Shabiyemba, 2025). Four buttons were created in the app interface, labelled *Light 1*, *Light 2*, *Fan 1*, and *Fan 2*.

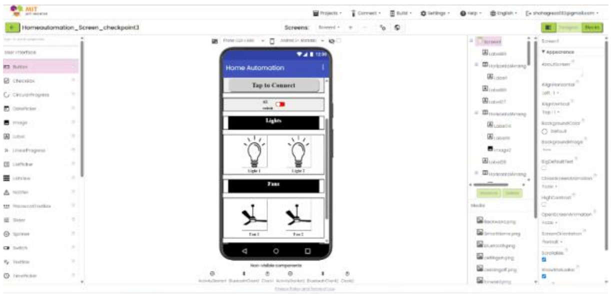

Figure 7. MIT App Inventor during creation of the customized Bluetooth app

2.6 IR Remote Control Implementation

The system incorporates an infrared (IR) remote control mechanism to offer a conventional and user-friendly control alternative. For appliance switching, the relay module remained attached to the ESP32 GPIO pins (Fakhruldeen et al., 2025). The Arduino IDE and the IRremote library were used to program the ESP32 to record and decode the IR codes. Specific appliance control functions were then associated with the decoded IR codes (Ayeni & Adesoba, 2025).

Figure 8. IR remote control communication setup

2.7 Manual Switch Integration

The system is designed to allow each appliance to be controlled both automatically and manually, so that the appliance can be operated directly by the user without having to use a wireless communication link.

Figure 9. Controlling the device with the manual switch setup

2.8 Human Presence Detection Automation

Automatically detecting when someone is in an area involves developing a solution based on sensors or cameras. The initial step in developing an automated human presence detection capability is to determine which type of device is to be used to sense when people are nearby.

2.9 Hybrid Smart Home System

The various control interfaces — Wi-Fi, Bluetooth, infrared remote control, manual switches, and human presence sensors — were integrated in order to make use of current technologies and to identify gaps in their integration. The system was then tested in a controlled environment, and information was gathered on energy efficiency, user responsiveness, and overall system performance (Raghu et al., 2025).

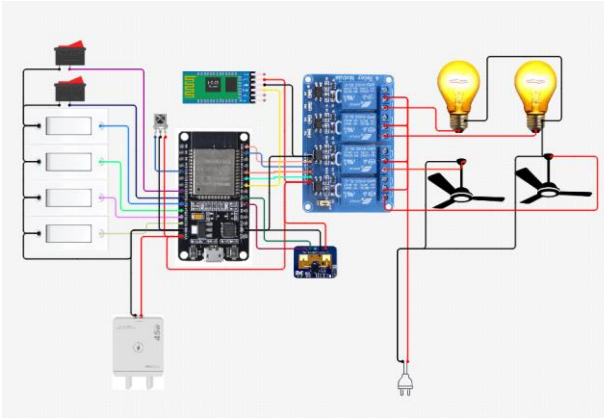

Figure 10. Hybrid smart home automation circuit diagram

3. Results and Discussion

This section presents the outcomes of the hybrid smart home system deployment. The results demonstrate the ability of the system to operate reliably in a range of scenarios and confirm the successful integration of the several control strategies (Chaudhary et al., 2025). Cloud connectivity was made possible by integrating the RainMaker libraries into the code. The relay module, which in turn controlled the associated appliances such as lights and fans, was configured to be operated by the GPIO pins of the ESP32 (Prasad, 2025).

3.1 IoT Control Implementation (ESP RainMaker)

The RainMaker application allowed the user to enter the Wi-Fi network SSID and password and to securely transmit the credential information to the ESP32, so that the ESP32 could connect to the Wi-Fi network and join the RainMaker cloud (Lunial et al., 2025).

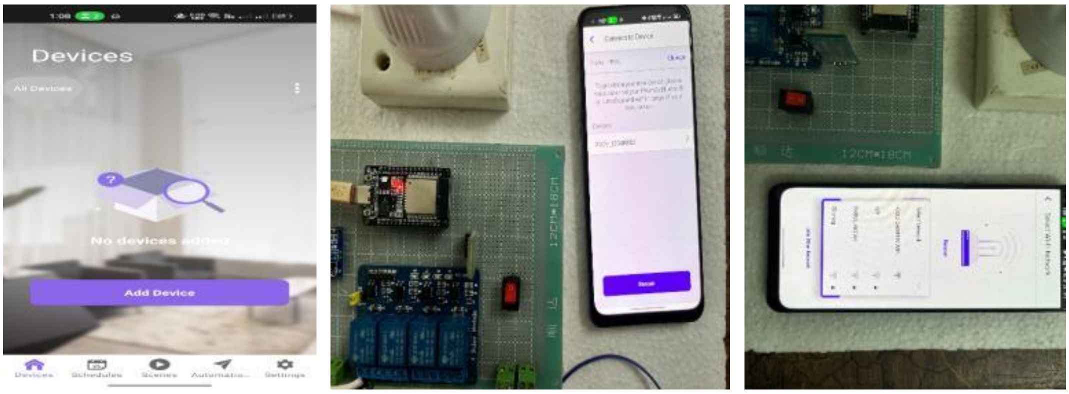

Figure 11. Connecting the device to Wi-Fi

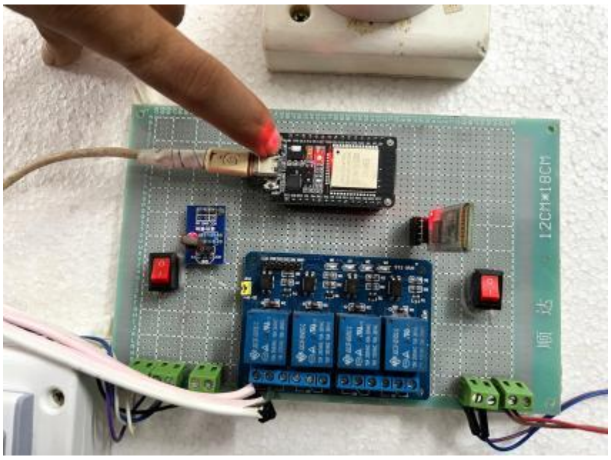

Figure 12. Pressing the reset button to reset the Wi-Fi credentials

Once linked, the ESP32 was shown as a controlled device by the ESP RainMaker mobile application. The user could then transmit commands via the app, such as “Light ON” or “Fan OFF”.

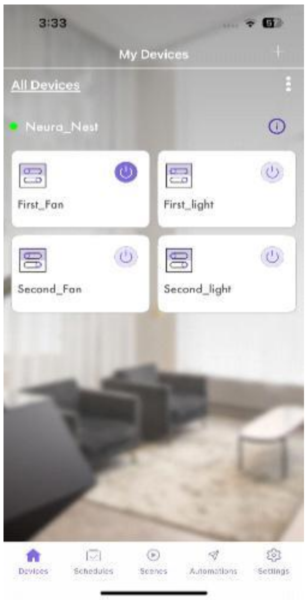

Figure 13. ESP RainMaker app interface

This capability makes the smart home system considerably more convenient than requiring every user to set up a personal configuration on the ESP32 device (Garg et al., 2025).

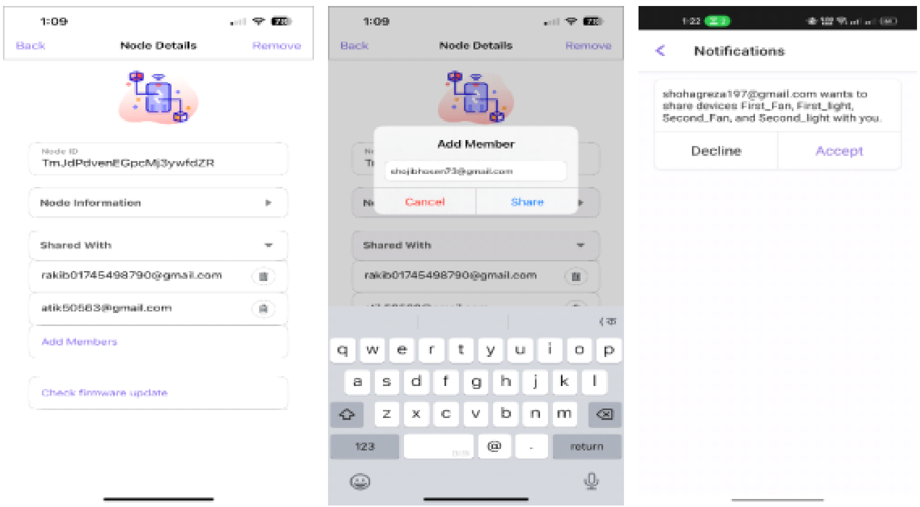

Figure 14. Adding a user in ESP RainMaker

3.2 Bluetooth Control Implementation

The Bluetooth control system ensures local appliance operation even in the absence of internet connectivity. A custom Android application was developed using MIT App Inventor, and the ESP32 and the smartphone were connected via the HC-06 Bluetooth module. The ESP32 received commands through UART serial communication and used them to drive the relay module (Ravinder Kumar, 2025).

The mobile app reliably shows the ON/OFF status of each appliance in real time, because each time the ESP32 alters a relay state in response to a Bluetooth command the updated status is concurrently transferred to the ESP RainMaker cloud.

Figure 15. Connecting the custom app with the Bluetooth module

Figure 16. Real-time ON/OFF status of the appliances in the custom app

3.3 IR Remote Control Implementation

An IR remote control mechanism is built into the system to allow a traditional, user-friendly method of controlling the equipment. The remote allows the equipment to be controlled by a standard TV/DVD remote control, which is familiar and comfortable for a large number of users, especially elderly users. The button mapping is as follows:

i. Remote Button 1 → Light 1 ON/OFF

ii. Remote Button 2 → Light 2 ON/OFF

iii. Remote Button 3 → Fan 1 ON/OFF

iv. Remote Button 4 → Fan 2 ON/OFF

By comparing the received code with predetermined values stored in the software, the ESP32 determined which relay channel to activate.

Figure 17. Controlling the device with the IR remote

3.4 Manual Switch Integration

This method offers a reliable fallback without compromising the convenience of conventional switching.

Figure 18. Controlling the device with the manual switch

3.5 Human Presence Detection Automation

The sensor is attached to the ESP32 via UART/GPIO interfaces and is capable of detecting motion and human presence in a defined area. Every time a relay state changes as a result of presence detection, the ESP32 also updates the ESP RainMaker cloud, to guarantee that the mobile app accurately displays the ON/OFF status of the appliances in real time (Anubha et al., 2025).

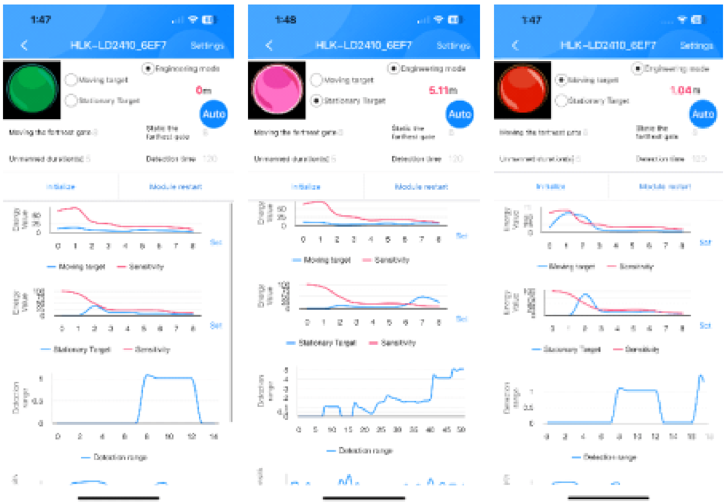

Figure 19. Controlling the device with the human presence sensor over the 5 m detection range

3.6 Comparative Advantages of the Proposed System

The proposed system uniquely integrates multiple control methods — manual switching, mobile apps, infrared remotes, and autonomous decision making — into a single cohesive platform. Unlike systems limited to a single control method, this system adapts to human presence, optimizing automation and energy savings. It ensures seamless device interoperability and rapid response by efficiently managing data and control. These combined features enhance the flexibility, intelligence, and practicality of the system, making it well suited to modern households in comparison with other hybrid smart home solutions.

4. Conclusion

This study offers a reliable and flexible Internet of Things (IoT)-enabled smart home automation system that improves both user experience and energy efficiency. In addition to providing a workable architecture for contemporary smart homes, this work lays the groundwork for future studies into advanced sensor integration and machine learning-driven customization, which will produce more intelligent, more flexible, and more ecologically conscious living spaces.

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Author Contributions

Research concept and research design – Md. Hedaytul Alom and Hasibur Rahman; materials and data collection – Md. Hedaytul Alom and Md. Jobaer Hossain Shojib; data analysis and interpretation – Md. Rakib Hossen and Most. Ferdousy Akhter; literature search and writing of the article – Hasibur Rahman and Md. Hedaytul Alom; critical review and article editing – Most. Ferdousy Akhter and Md. Rakib Hossen; final approval – all authors.

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