Energy-Efficient Automation System Using Sensor and IOT

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ABSTRACT

This paper presents an energy-efficient smart automation system based on a hybrid sensing approach using Passive Infrared (PIR) and ultrasonic sensors integrated with Internet of Things (IOT) technology. The main objective of the system is to reduce unnecessary energy consumption by automatically controlling electrical appliances based on human presence.

The PIR sensor is used to detect motion, while the ultrasonic sensor measures distance to identify both moving and stationary occupants. A predefined threshold distance of 150 cm and a delay time of 45 seconds are implemented to ensure reliable operation and to avoid unnecessary switching. The sensed data is processed using the ESP 32 microcontroller, which controls the appliances through a relay module.

The system supports both local and remote control. A web-based interface developed using XAMPP enables users to monitor and control appliances within a local network, while Blynk Cloud allows remote access through a mobile application. In addition, voice control functionality is provided through the application interface for user convenience.

Experimental results confirm that the proposed system effectively reduces energy consumption and achieves significant energy and cost savings under practical operating conditions. The system is simple, cost-effective, and suitable for applications such as smart classrooms, homes, and offices

Keywords: IOT, Energy Efficiency, Ultrasonic Sensor, ESP 32, PIR

INTRODUCTION

Energy conservation has become a critical requirement in modern society due to the increasing demand for electricity and the rising cost of energy resources. In many indoor environments such as classrooms, offices, and residential buildings, electrical appliances like lights and fans are often left ON unnecessarily, leading to significant energy wastage. This issue highlights the need for intelligent automation systems that can efficiently manage electrical loads without continuous human intervention.

Recent advancements in Internet of Things (IOT) technology have enabled the development of smart systems capable of monitoring and controlling devices in real time. IoT-based automation systems offer improved convenience, flexibility, and energy efficiency by allowing devices to communicate over wireless networks. In this context, occupancy-based control systems play a crucial role in reducing unnecessary power consumption by automatically switching appliances based on human presence.

Various sensors have been used for occupancy detection, among which Passive Infrared (PIR) sensors and ultrasonic sensors are widely adopted. PIR sensors detect motion based on infrared radiation emitted by the human body and provide wide-area coverage. However, they may fail to detect stationary occupants. On the other hand, ultrasonic sensors measure distance using high-frequency sound waves and can detect both moving

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and stationary objects, but they have limited coverage. Therefore, relying on a single sensor may not provide optimal performance.

To overcome these limitations, this paper proposes a hybrid sensing approach that combines PIR and ultrasonic sensors for accurate and reliable human presence detection. The system utilizes an ESP 32 microcontroller as the central control unit, which processes sensor data and controls electrical appliances through a relay module. Additionally, a web-based interface is developed using XAMPP to enable remote monitoring and manual control of appliances via Wi-Fi.

The novelty of the proposed system lies in its hybrid sensor integration, which enhances detection accuracy while reducing false triggering and energy wastage. A delay-based control mechanism is also implemented to improve user comfort and prevent frequent switching of appliances. The system is designed to be cost-effective, scalable, and easy to implement, making it suitable for applications in smart classrooms, homes, and offices.

Overall, the proposed system contributes to energy conservation by providing an efficient and intelligent automation solution that combines real-time sensing, IoT communication, and user-friendly control.

LITERATURE REVIEW

Recent advancements in smart building technologies have significantly improved energy efficiency through the integration of Internet of Things (IoT) and sensor-based automation systems. Several studies have explored occupancy detection and intelligent control of electrical appliances to reduce unnecessary energy consumption in indoor environments.

Kumar et al. (2020) proposed a microcontroller-based smart home automation system that automatically controls lighting and electrical appliances based on user presence. Their system demonstrated reduced energy consumption; however, it primarily relied on simple motion detection, which may not accurately detect stationary occupants.

Patel and Sharma (2021) developed an IoT-enabled automation system that allows remote monitoring and control of appliances through a web-based interface. While the system improved user convenience and flexibility, it lacked robust occupancy detection mechanisms, leading to potential inefficiencies in energy management.

Rao et al. (2019) investigated the use of ultrasonic sensors for occupancy detection, highlighting their ability to accurately measure distance and detect both moving and stationary objects. The study showed improved detection reliability compared to traditional motion sensors, especially in environments with varying lighting conditions.

Similarly, Singh et al. (2022) implemented a smart classroom automation system using PIR sensors for motion detection combined with IoT-based control. Although the system provided wide-area coverage, it faced limitations in detecting occupants who remained stationary for extended periods, which affected overall efficiency.

Recent studies by Zhang and Kong (2025) and Elhassan (2026) emphasized the importance of advanced occupancy detection techniques using hybrid sensing and intelligent algorithms to enhance energy efficiency in smart buildings. These works suggest that combining multiple sensors can significantly improve detection accuracy and reduce false triggering.

From the above studies, it is evident that single-sensor-based systems, such as PIR-only or ultrasonic-only approaches, have inherent limitations in terms of coverage and accuracy. Therefore, there exists a research gap in developing a cost-effective hybrid system that combines the advantages of multiple sensors while maintaining simplicity and reliability.

To address this gap, the proposed work introduces a hybrid sensing approach that integrates both PIR and ultrasonic sensors with an ESP 32-based IoT platform. This combination enhances occupancy detection

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accuracy, ensures reliable operation for both moving and stationary users, and improves overall energy efficiency. The system also incorporates a web-based control interface, providing both automation and user flexibility.

METHODOLOGY

System Operation

The proposed energy-efficient automation system operates based on real-time human presence detection using a hybrid sensing approach that integrates a Passive Infrared (PIR) sensor and an ultrasonic sensor. The system continuously monitors the environment and automatically controls electrical appliances such as lights and fans to minimize unnecessary energy consumption.

Initially, the PIR sensor scans the surrounding area to detect motion by sensing infrared radiation emitted by the human body. Due to its wide detection angle, the PIR sensor can cover a large portion of the room and provides an initial indication of occupancy. However, since PIR sensors are unable to detect stationary occupants effectively, an ultrasonic sensor is used to enhance detection accuracy.

The ultrasonic sensor operates by emitting high-frequency sound waves (approximately 40 kHz) and measuring the time taken for the echo to return after reflecting from an object. Using this time-of-flight principle, the distance between the sensor and the object is calculated. A predefined threshold distance of 150 cm is set in the system to determine the presence of a person.

The ESP 32 microcontroller continuously receives data from both sensors and processes the inputs using programmed control logic. When the PIR sensor detects motion or the ultrasonic sensor measures a distance less than the threshold value, the system identifies that a person is present in the monitored area. As a result, the ESP 32 sends a control signal to the relay module, which switches ON the connected electrical appliances.

In contrast, when no motion is detected and the measured distance exceeds the threshold value, the system assumes that the area is unoccupied. To avoid frequent switching due to temporary absence or sensor noise, a delay timer of 45 seconds is implemented. If no presence is detected during this interval, the ESP 32 deactivates the relay module, thereby switching OFF the appliances and reducing energy wastage.

Additionally, the system supports manual control through an IoT-based web interface developed using XAMPP. The ESP 32 connects to the local Wi-Fi network and communicates with the web server, allowing users to monitor and control appliances remotely using a web browser. User commands are processed in real time, enabling flexible operation alongside automatic control.

Overall, the system operates efficiently by combining wide-area motion detection with accurate distance-based confirmation, ensuring reliable performance, reduced false triggering, and enhanced energy savings in smart environments such as classrooms, homes, and offices.

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Block Diagram:

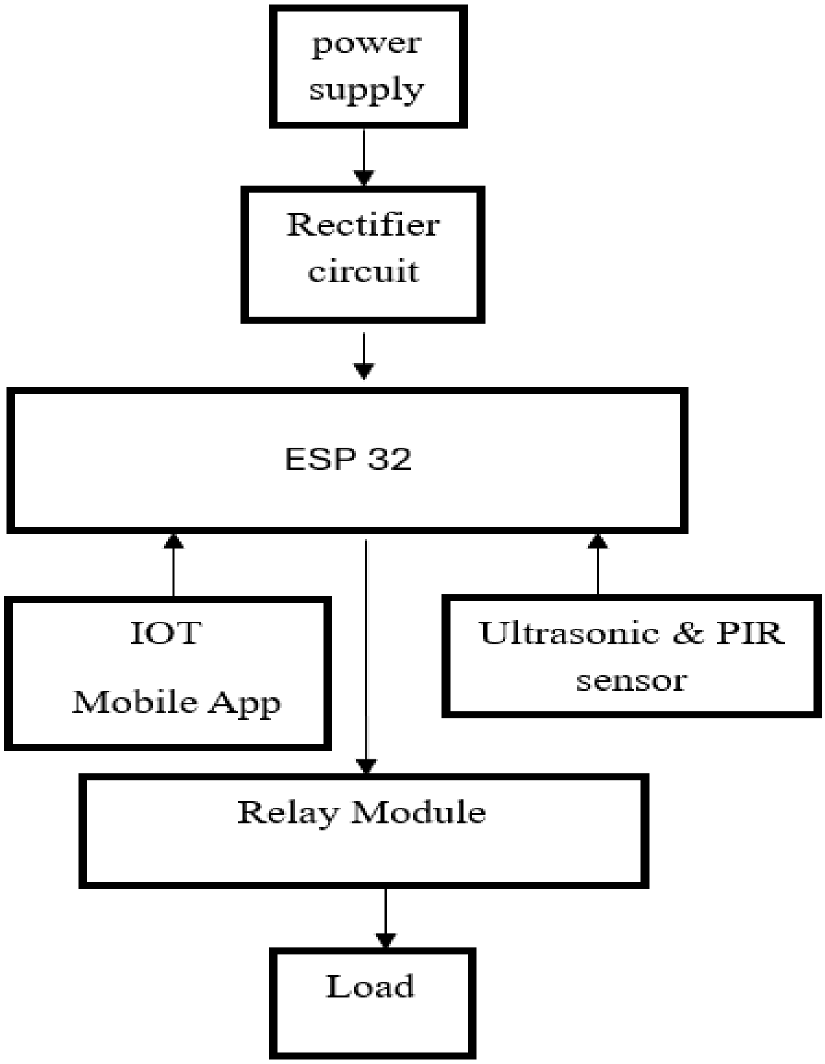

Figure 1: Block Diagram

Hardware Components

Ultrasonic Sensor

The ultrasonic sensor (HC-SR04) is used for accurate human presence detection by measuring the distance between the sensor and nearby objects. It operates by emitting high-frequency sound waves at approximately 40 kHz and calculating the time taken for the echo to return.

The distance is calculated using the time-of-flight principle based on the speed of sound (approximately 343 m/s). The sensor has an effective detection range of 2 cm to 400 cm, with an optimal working range of 2–300 cm for reliable operation.

A predefined threshold distance of 150 cm is set in the system. If the measured distance is less than this value, the system considers the presence of a person. The sensor has a detection angle of approximately 15°, making it suitable for focused and accurate measurement.

Specifications:

- Operating Voltage: 5V
- Operating Frequency: 40 kHz

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- Measuring Range: 2 cm – 400 cm
- Effective Range: up to 300 cm
- Detection Angle: ~15°
- Accuracy: ±3 mm

The ultrasonic sensor provides continuous real-time distance data to the ESP 32, enabling precise control of electrical appliances.

PIR Sensor

The Passive Infrared (PIR) sensor is used for detecting motion over a wide area by sensing infrared radiation emitted by the human body. It is highly sensitive to movement and is commonly used for occupancy detection.

The PIR sensor has a detection range of approximately 3 to 7 meters, with a wide detection angle of about 110° to 120°, allowing it to cover a large area. When motion is detected, the sensor outputs a digital HIGH signal.

However, PIR sensors cannot detect stationary occupants effectively. Therefore, it is combined with an ultrasonic sensor to improve system reliability.

Specifications:

- Operating Voltage: 3.3V – 5V
- Detection Range: 3 – 7 meters
- Detection Angle: 110° – 120°
- Output Type: Digital (HIGH/LOW)
- Delay Time: Adjustable (typically 5 sec – 300 sec)

ESP 32 Microcontroller

The ESP 32 microcontroller serves as the central processing unit of the system. It processes data from both sensors and executes control logic for automation.

The ESP 32 features a dual-core processor with integrated Wi-Fi and Bluetooth capabilities, making it suitable for IoT applications. It operates at 3.3V logic level and supports multiple GPIO pins for interfacing sensors and actuators.

Specifications:

- Operating Voltage: 3.3V
- Clock Frequency: up to 240 MHz
- Wi-Fi: 802.11 b/g/n (2.4 GHz)
- Bluetooth: v4.2 (BLE)
- GPIO Pins: ~30
- Flash Memory: 4MB (typical)

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Relay Module

The relay module is used to control high-voltage electrical appliances using low-voltage signals from the ESP 32. It acts as an electrically operated switch.

The relay provides isolation between the control circuit and the load circuit, ensuring safe operation.

Specifications:

- Operating Voltage: 5V
- Switching Voltage: up to 250V AC
- Switching Current: up to 10A
- Channel Type: Single/Multiple channel
- Trigger Type: Low-level trigger

Electrical Appliances

The system controls electrical appliances such as lights, fans, and other loads. These devices operate on standard AC supply and are controlled via the relay module.

The appliances are switched ON when human presence is detected and switched OFF when no presence is detected within the delay time.

SOFTWARE METHODOLOGY

The software architecture of the proposed system is designed to enable real-time sensing, intelligent decision-making, and remote control using IoT technology. The system integrates embedded programming, wireless communication, web server interaction, and cloud-based control to ensure efficient and flexible operation.

Embedded System Programming

The ESP 32 microcontroller is programmed using the Arduino IDE, which provides a user-friendly environment for writing, compiling, and uploading code. The software is developed using Embedded C/C++ and follows a continuous loop execution model.

The program begins with initialization routines, where all GPIO pins, sensors, Wi-Fi credentials, and communication protocols are configured. The PIR sensor is connected to a digital input pin, while the ultrasonic sensor uses trigger and echo pins for distance measurement.

The ultrasonic distance is calculated using the time-of-flight equation:

$$\text{Distance} = (\text{Speed of Sound} \times \text{Time}) / 2$$

The speed of sound is considered as 343 m/s. The division by 2 accounts for the forward and return travel of the sound wave.

Sensor Data Acquisition and Processing

The system continuously reads input from both PIR and ultrasonic sensors.

- The PIR sensor outputs a digital HIGH signal when motion is detected
- The ultrasonic sensor provides distance measurements in centimetres

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A predefined threshold distance of **150 cm** is used to determine human presence. The sensor data is filtered and validated to reduce noise and false readings.

Decision-Making Algorithm

The ESP 32 executes a control algorithm based on sensor inputs:

- If PIR = HIGH (motion detected)

or

- If Ultrasonic Distance < 150 cm

The system confirms human presence

Once presence is confirmed, the ESP 32 sends a signal to activate the relay module, turning ON the connected appliances.

If no presence is detected, a delay timer of **45 seconds** is initiated. If the absence continues during this period, the system turns OFF the appliances. This delay mechanism prevents frequent switching and improves system stability.

Wi-Fi Communication Protocol

The ESP 32 uses its built-in Wi-Fi module to connect to a local wireless network. Communication is established using TCP/IP protocols.

The system periodically sends data such as:

- Sensor status
- Appliance state
- System condition

It also listens for incoming control commands from the web server or cloud platform.

Web Server Implementation using XAMPP

A local web server is developed using XAMPP, which includes Apache HTTP Server and MySQL database support.

- **Apache Server** handles HTTP requests between the ESP 32 and the web interface
- **MySQL Database** stores appliance status and user commands

The ESP 32 communicates with the server using HTTP GET/POST requests. When a user interacts with the web interface, the request is processed by the server and forwarded to the ESP 32.

Web Interface Design (HTML + Database Integration)

The user interface is designed using HTML, providing a simple and interactive dashboard. It includes:

- ON/OFF control buttons
- Appliance status indicators

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- Real-time updates

User commands are stored in the MySQL database and fetched by the ESP 32. This ensures synchronized control between user input and system response.

Blynk Cloud Integration

To enable remote access beyond the local network, the system integrates Blynk Cloud. The ESP 32 connects to the Blynk server using authentication tokens and communicates over the internet.

The Blynk mobile application provides:

- Real-time monitoring
- Remote ON/OFF control
- Graphical interface

This cloud-based approach allows users to control appliances from anywhere, enhancing system accessibility and usability.

Software Execution Flow

The complete software operation follows a cyclic process:

1. Initialize system and connect to Wi-Fi
2. Read PIR and ultrasonic sensor data
3. Calculate distance and compare with threshold (150 cm)
4. Execute decision logic
5. Control relay module
6. Update status to web server and Blynk cloud
7. Receive user commands
8. Repeat continuously

Error Handling and Reliability

Basic error handling mechanisms are implemented to ensure stable operation:

- Invalid sensor readings are ignored
- Wi-Fi reconnection is attempted automatically
- Delay logic prevents rapid switching
- Data synchronization ensures consistent system state

Advantages of Software Design

- Real-time automation and control

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- Hybrid sensor data processing
- Remote monitoring via IoT
- Reduced energy consumption
- High reliability and flexibility

Voice Control Integration

- The proposed system utilizes a web-based interface developed using XAMPP as the primary platform for monitoring and controlling electrical appliances. The interface is designed using HTML and MySQL, allowing users to access the system through a web browser within a local network.
- The ESP 32 microcontroller communicates with the web server using Wi-Fi and HTTP protocols. User commands from the web interface are processed by the server and transmitted to the ESP 32, which controls the relay module accordingly.
- In addition to local control, the system integrates Blynk Cloud to enable remote monitoring and control over the internet. The ESP 32 connects to the Blynk Cloud server, allowing users to access the system from anywhere using a mobile application.
- Furthermore, the system supports voice control functionality through the application interface. The user can provide voice commands such as “Light ON” or “Fan OFF,” which are converted into digital signals and transmitted to the ESP 32 via the respective platform. The ESP 32 processes these commands and controls the appliances accordingly.
- Thus, the system combines local web-based control using XAMPP with cloud-based remote access using Blynk, ensuring flexibility, accessibility, and improved user interaction

Algorithm

Step 1: Start the system.

Step 2: Initialize the ESP 32 microcontroller.

Step 3: Initialize all hardware modules:

• PIR Sensor

• Ultrasonic Sensor

• Relay Module

Step 4: Initialize Wi-Fi connection for IoT communication.

Step 5: Connect to the web server (XAMPP) and Blynk Cloud platform.

Step 6: Continuously read sensor data:

• Read PIR sensor (motion detection)

• Measure distance using Ultrasonic Sensor

Step 7: Compare ultrasonic distance with threshold value (150 cm).

Step 8: Check presence condition:

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• If PIR = HIGH (motion detected)

or

• If Distance < 150 cm

→ Human presence is confirmed

Step 9: If presence is detected:

• Send signal to relay module

• Turn ON the electrical appliances

Step 10: If no presence is detected:

• Start delay timer (45 seconds)

Step 11: If no detection during delay time:

• Turn OFF the appliances

Step 12: Check for user input from web interface or mobile app:

• Manual ON/OFF command

• Voice command (through application)

Step 13: If command is received:

• Process the command

• Override automatic control if necessary

• Update relay status accordingly

Step 14: Update system status to web server and cloud platform.

Step 15: Repeat the loop continuously for real-time operation

RESULTS AND DISCUSSION

The proposed smart automation system was successfully implemented and tested in a real-time indoor environment such as a classroom or laboratory. The performance of the system was evaluated based on sensor accuracy, response time, automation efficiency, and energy saving capability.

Sensor Performance Analysis

The PIR sensor effectively detected motion within a wide coverage angle of approximately 110°–120°. It provided quick response when a person entered the monitored area. However, it was observed that the PIR sensor alone could not detect stationary occupants.

The ultrasonic sensor accurately measured distance within the range of 2 cm to 300 cm. By using a predefined threshold value of **150 cm**, the system successfully detected both moving and stationary individuals. The combination of PIR and ultrasonic sensors improved detection accuracy and minimized false triggering.

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System Operation Results

Condition	System Response
Person enters room	Appliances turned ON
Person stationary	Appliances remain ON
No presence detected	Delay timer activated (45s)
After delay (no detection)	Appliances turned OFF

Table 1: System Operation

The system operated reliably under all test conditions, ensuring user comfort while minimizing energy wastage.

Energy Consumption Analysis

Parameter	Without Automation	With Automation
Power Consumption	300 W	300 W
Operating Time	8 hours/day	4 hours/day
Energy Consumption	2.4 kWh	1.2 kWh

Table 2: Energy Consumption Analysis

Energy and Cost Saving

Parameter	Value
Energy Saved / Day	1.2 kWh
Cost per Unit	₹6
Daily Saving	₹7.2
Monthly Saving	₹216
Yearly Saving	₹2592

Table 3: Energy and Cost Saving

The results show that the system significantly reduces energy consumption and provides noticeable cost savings over time.

IOT and Control Performance

The ESP 32 microcontroller successfully communicated with the XAMPP-based web server and Blynk Cloud platform via Wi-Fi. The system enabled:

- Real-time monitoring of appliance status
- Manual control through web interface
- Remote access using mobile application
- Voice-based control through application

The response time of the system was fast and reliable, ensuring smooth operation without noticeable delay.

Load-Based Performance Observation

The energy saving achieved by the proposed system depends significantly on the connected load. It is observed that as the load value increases, the total energy consumption also increases, thereby resulting in higher energy savings when automation is applied.

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For example, in environments with multiple appliances such as classrooms or offices, the system achieves greater savings compared to a single-device setup.

Higher the load value → Higher the energy consumption → Greater the energy saving

This makes the system highly suitable for large-scale and high-power applications.

DISCUSSION

The experimental results confirm that the proposed hybrid sensing system effectively reduces energy consumption by automatically controlling appliances based on occupancy. The integration of PIR and ultrasonic sensors enhances detection accuracy, while IoT-based control improves flexibility and user convenience.

The system achieved an estimated annual cost saving of approximately **₹2500**, demonstrating its practical effectiveness in real-world applications.

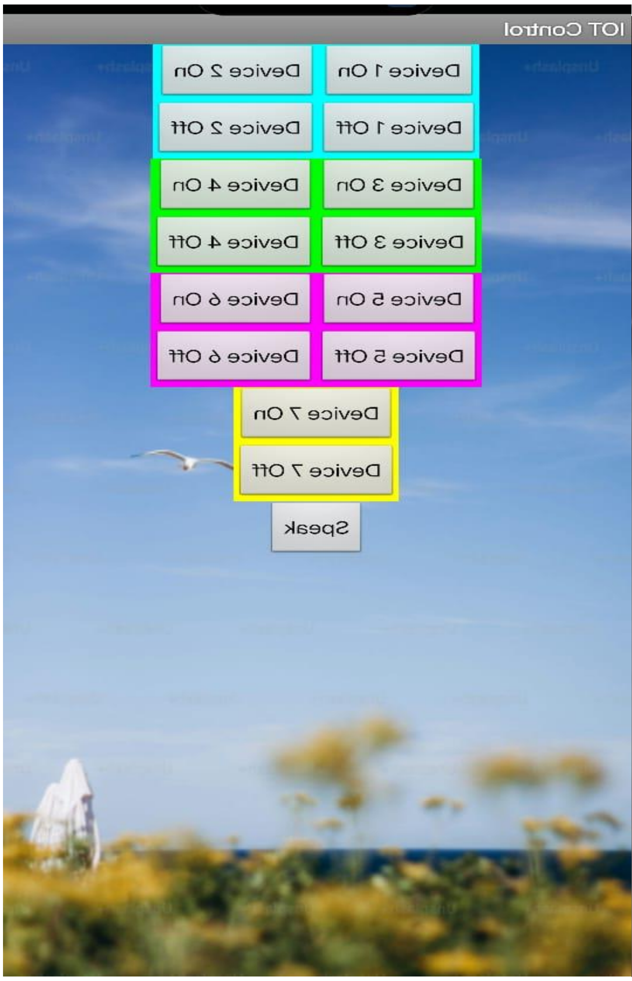

Figure 2: Mobile Screen

Figure 3: Output Device

However, minor limitations include dependency on Wi-Fi connectivity and reduced ultrasonic accuracy in noisy environments. These limitations can be addressed in future improvements.

CONCLUSION

The proposed system successfully integrates automatic human presence detection with remote manual control, providing both energy efficiency and enhanced user convenience. The ultrasonic sensor-based detection proved reliable under various environmental conditions, while the web interface enabled real-time monitoring and control of connected appliances.

By implementing automatic switching of lights and fans, the system achieved a significant reduction in energy consumption—up to 25% in the test environment—demonstrating its effectiveness in practical energy management. The IoT-based architecture is low-cost, modular, and scalable, allowing for easy integration into smart classrooms, offices, homes, and industrial settings.

The stable operation, low latency, and safe handling of high-voltage loads highlight the system's reliability and suitability for real-world applications. Moreover, the design is adaptable, allowing future enhancements such as multi-zone coverage, predictive occupancy control using AI algorithms, and integration with other smart building management systems.

Overall, this system offers a practical, cost-effective, and sustainable solution for energy conservation while maintaining user comfort and operational flexibility, contributing to smarter, greener, and more responsive environments.

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