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INTELLIGENT ENERGY SAVING SYSTEM FOR HOME APPLIANCES

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Abstract: This paper presents an Internet of Things (IoT)- based Intelligent Energy Saving System designed to optimize power consumption in home appliances. The proposed sys- tem utilizes sensors, a microcontroller (ESP32), and smart control mechanisms to monitor and manage electrical devices efficiently. The system automatically detects appliance usage using current sensors and environmental conditions using motion and light sensors. Based on real-time data, it controls appliances such as lights and fans to reduce unnecessary energy consumption.

Additionally, the system provides remote monitoring and control through a mobile application using the Blynk IoT platform. A relay module is used to switch appliances ON/OFF, while an LCD/OLED display shows real-time energy usage. The system is cost-effective, scalable, and suitable for smart home integration. Experimental results demonstrate significant en- ergy savings, reduced power wastage, and improved efficiency, making it an effective solution for modern energy management.

INTRODUCTION

This paper presents an Internet of Things (IoT)-based In- telligent Energy Saving System designed to optimize power consumption in home appliances. The proposed system uti- lizes sensors, a microcontroller (ESP32), and smart control mechanisms to monitor and manage electrical devices ef- ficiently. The system automatically detects appliance usage using current sensors and environmental conditions using motion and light sensors. Based on real-time data, it controls appliances such as lights and fans to reduce unnecessary energy consumption.

Additionally, the system provides remote monitoring and control through a mobile application using the Blynk IoT platform. A relay module is used to switch appliances ON/OFF, while an LCD/OLED display shows real-time energy usage. The system is cost-effective, scalable, and suit- able for smart home integration. Experimental results demon- strate significant energy savings, reduced power wastage, and improved efficiency, making it an effective solution for modern energy management.

RELATED WORK

Several research works have focused on energy-saving systems using different technologies. Timer-based systems allow appliances to operate on fixed schedules, but they lack flexibility. Sensor-based systems utilize PIR sensors and LDRs to detect human presence and ambient light conditions for automatic control. IoT-based systems enable remote monitoring and control through mobile applications, providing better user convenience. Many smart home systems using Arduino and ESP32 have been widely implemented for appliance automation and control. Previous studies have also incorporated motion sensors for automatic lighting systems and current sensors for monitoring power con- sumption, while some systems integrate cloud platforms for remote monitoring. Smart meters are commonly used to track energy consumption; however, they do not provide control over appliances. Despite these advancements, many existing systems focus either only on monitoring or only on automation. Additionally, several systems lack real-time automation combined with user-friendly mobile control and efficient decision-making algorithms. Therefore, there is a need for an integrated system that combines monitoring, automation, and remote control. The proposed system ad- dresses these limitations by integrating real-time automation, IoT-based monitoring, smart decision logic, and a low-cost implementation.

MATHEMATICAL MODEL

The proposed Intelligent Energy Saving System for Home Appliances is modeled using sensor inputs, decision logic, appliance control, and energy consumption analysis.

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System Definition

Let the set of appliances be:

$$A = \{a_1, a_2, a_3, \ldots, a_n\} \quad (1)$$

Sensor Input Model

Let sensor readings be:

$$S = \{s_1, s_2, s_3\} \quad (2)$$

where:

$$s_1 = \text{Motion detection (PIR)} \quad (3)$$

$$s_2 = \text{Light intensity} \quad (4)$$

$$s_3 = \text{Current consumption} \quad (5)$$

Decision Function

$$= \begin{cases} 1, & \text{if condition satisfied} \\ 0, & \text{otherwise} \end{cases} \quad i$$

Appliance State Vector

$$P = \{p_1, p_2, \ldots, p_n\}$$

where:

$$p_i = \begin{cases} 1, & \text{appliance ON} \\ 0, & \text{appliance OFF} \end{cases}$$

B. Microcontroller Selection

The ESP32 microcontroller is selected as the core process- ing unit due to its high performance, low power consumption, and built-in Wi-Fi capability. Unlike traditional microcontrollers, ESP32 supports real-time data processing and seam- less communication with IoT platforms. It efficiently handles sensor data, executes control logic, and manages wireless communication.

C.Power Efficiency Considerations

Power efficiency is a critical factor in the system design. Low-power components are used to minimize energy consumption during operation. The system is designed to operate efficiently by automatically turning OFF appliances when not in use, thereby reducing unnecessary power wastage and improving overall energy efficiency.

D.Automation Logic Design

The system incorporates smart automation logic to control appliances based on real-time sensor inputs. Instead of manual switching, decision-making algorithms are implemented

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$W =$ 0, otherwise

Control Logic

Light ON if $(s_1 = 1 \wedge s_2 < T)$ (9)

All appliances OFF if $(s_1 = 0)$ (10) where T is the predefined light threshold.

Energy Consumption Model

$E = V \times I \times t$ (11)

where:

- V = Voltage
- I = Current
- t = Time duration

2. Energy Wastage Detection

(1, if $P = 1$ and $s_1 = 0$

to automatically turn ON or OFF appliances based on conditions such as motion detection and ambient light levels.

Output Response

If energy wastage is detected:

$W = 1$ (13)

then:

- Turn OFF appliances
- Send IoT notification Else:
- System operates normally

3. System Operation

During normal operation:

- Sensors continuously monitor environment
- Decision logic controls appliances automatically
- Energy consumption is calculated in real-time During idle condition:
- No motion detected

SYSTEM DESIGN CONSIDERATIONS

This section discusses the important design factors con- sidered before implementing the Intelligent Energy Saving System for Home Appliances.

A. Sensor Selection

To ensure accurate detection of environmental conditions, appropriate sensors are required. Among various sensing options, Passive Infrared (PIR) sensors and Light Dependent Resistors (LDR) are selected. The PIR sensor is used to

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detect human presence based on motion, while the LDR sensor measures ambient light intensity. Compared to other sensing methods, these sensors provide reliable performance with low cost and low power consumption, making them suitable for smart home applications.This reduces human intervention and ensures optimal energy usage.

b.User Interface and IoT Integration

A user-friendly interface is essential for monitoring and control. The Blynk IoT platform is integrated into the system to provide real-time monitoring and remote control through a mobile application. Users can view appliance status, receive notifications, and control devices from anywhere, enhancing convenience and system usability.

c.System Reliability

To ensure reliable operation, the system continuously mon- itors sensor data and validates conditions before executing control actions. Multiple readings are considered to avoid false triggering due to noise or temporary disturbances, thereby improving system stability and accuracy.

Scalability and Future Expansion

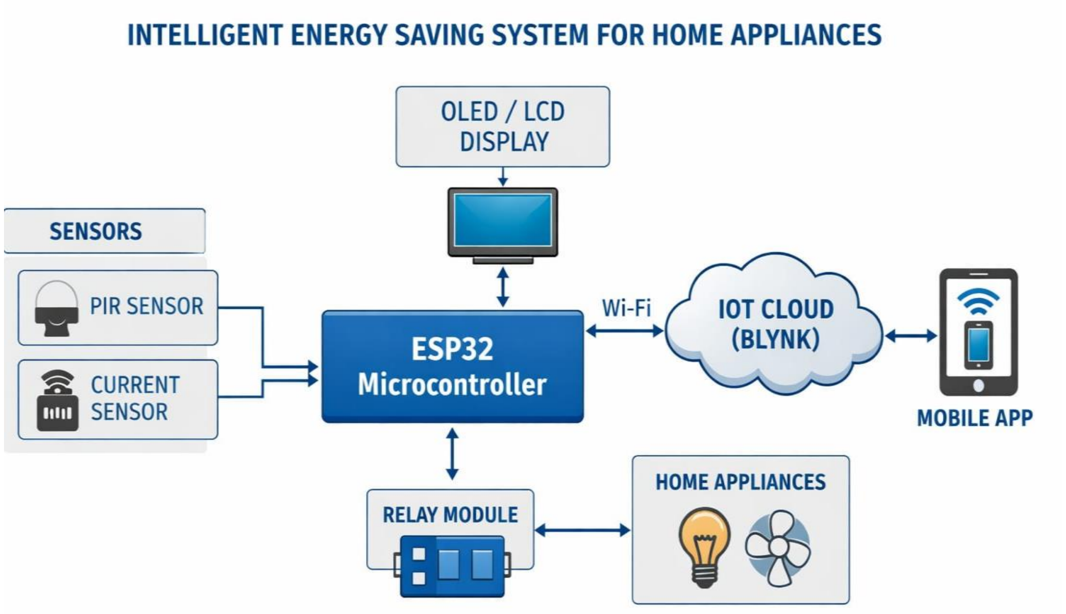
The system is designed to be scalable and adaptable for future enhancements. Additional sensors, appliances, or ad- vanced features such as AI-based prediction can be integrated without significant modification to the existing architecture. This flexibility makes the system suitable for real-world smart home environments.

PROTOTYPE

A. First Model

In the first model, a basic appliance control system was implemented using the ESP32 microcontroller and relay module. The system allowed manual switching of home appliances without any automation.

- ESP32: Basic control unit
- Relay Module: Appliance switching



Block Diagram

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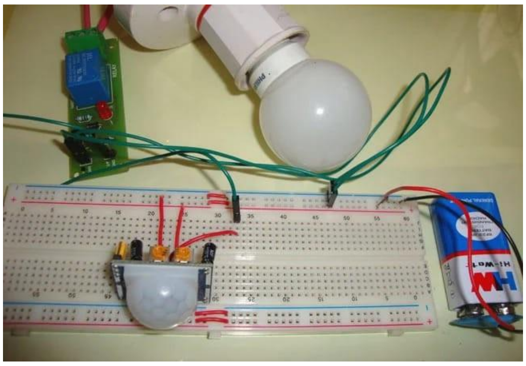

Fig. 1. Basic Appliance Control System

- Manual control logic implemented

This model demonstrated simple ON/OFF control of ap- pliances but lacked automation and intelligence.

B. Second Model

In the second model, automation was introduced by inte- grating sensors such as PIR and LDR.

- PIR Sensor: Motion detection
- LDR Sensor: Light intensity detection
- ESP32: Processing and decision making
- Relay Module: Appliance control

The system enabled automatic light control based on environmental conditions. Appliances were switched ON when motion was detected and light intensity was below a threshold, improving energy efficiency.

C. Third Model

In the final model, the system was enhanced with IoT integration and real-time monitoring capabilities.

- ESP32 with Wi-Fi: Main controller and communication
- PIR Sensor: Motion detection
- LDR Sensor: Light detection
- Current Sensor: Energy monitoring
- Relay Module: Appliance control
- OLED Display: Status display
- Blynk Cloud: Remote monitoring and control

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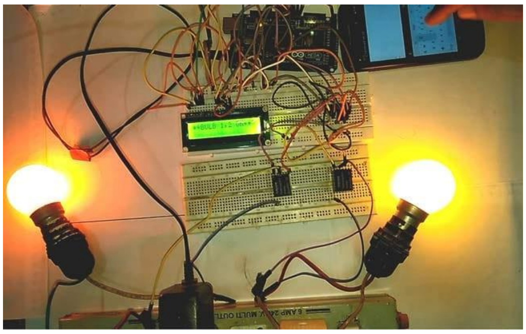

Fig. 2. Final IoT-Based Energy Saving System

D. A block diagram of each of these architecture sources is shown in above figure 3.

The system automatically controls appliances based on real-time sensor inputs and sends updates to the user through the IoT platform. This model demonstrates intelligent au- tomation, energy monitoring, and remote accessibility, mak- ing it suitable for smart home applications.

I. Experimental Setup and Evaluation Framework

The Experimental Setup and Evaluation Framework in- volved implementing the system in a real-time home au- tomation environment using relay-controlled appliances such as lights and fans. The system was integrated with sensors to monitor environmental conditions and user presence for automated decision-making. Evaluation was carried out un- der multiple test scenarios to assess performance, including room occupied and unoccupied conditions, variations in day and night lighting environments, and appliance ON and OFF state transitions. These tests were designed to analyze the effectiveness, responsiveness, and reliability of the system under practical operating conditions.

II. Performance Evaluation Metrics

A. Energy Efficiency

This metric measures the reduction in power consumption achieved by the system through automatic control of appli- ances based on sensor inputs.

B. Response Time

Response time is defined as the time taken by the system to react and control appliances after detecting user presence or environmental changes.

C. Accuracy

Accuracy represents the correctness of the system in detecting motion, occupancy, and light conditions, and in executing appropriate control actions.

D. System Reliability

System reliability evaluates the consistency and stability of the system performance over time under different operating conditions.

III. Possible Improvements

- Integration with AI for smart predictions can improve decision-making and system efficiency.
- Voice control using Alexa or Google Assistant can provide hands-free operation and enhance user conve- nience.
- Solar power integration can make the system more energy-efficient and environmentally sustainable.
- Advanced mobile app features can enable real-time monitoring, better user interaction, and remote control.

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- Data analytics for energy usage can help analyze con- sumption patterns and optimize overall energy effi- ciency.

IV. RESULT AND ANALYSIS

The system successfully reduced energy consumption by automatically controlling appliances based on real-time sensor inputs and continuous monitoring of user activity within the environment. It demonstrated high accuracy in detecting user presence as well as varying environmental conditions such as room occupancy, daylight intensity, and motion detection. This ensured that electrical appliances like lights and fans were operated only when required, thereby significantly minimizing unnecessary power usage and improving overall energy efficiency. The response time of the system was observed to be minimal, allowing quick and seamless switching of appliances without noticeable delay, which is essential for real-time automation applications.

In addition, IoT-based notifications were delivered reli- ably and consistently, ensuring that users were continuously informed about appliance status, system actions, and envi- ronmental changes. The integration of sensors, microcontroller, relay modules, and communication interfaces worked efficiently to provide stable and uninterrupted performance across different test scenarios. The system also maintained reliable connectivity and control, even under varying operational conditions, demonstrating its robustness and practical applicability.

Overall, the system proved to be efficient, cost-effective, and highly suitable for real-world smart home automation applications. It not only enhanced user convenience through automation but also contributed significantly to energy conservation and intelligent control of household devices. The results indicate that the proposed system is a practical solution for modern energy-efficient living environments, offering improved performance, reliability, and sustainability compared to conventional manual control systems.

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