Smart Energy Management System Using ESP32 For Adaptive Fan Control And Voltage Anomaly Detection

[1]P. Selvamani, [2]Akilesh R, [3]Ajay Narayanan K, [4]Dhev S
Department of computer science engineering,
Sri Venkateswara college of Engineering,
Sriperumbudur, Tamil Nadu, India-602117

Abstract—Optimizing power consumption in a variety of applications, including HVAC, smart homes, and industrial systems, is imperative due to the growing demand for energy- efficient solutions. Significant energy waste from unnecessary motor operation frequently raises operating expenses and has an adverse effect on the environment. In order to overcome this difficulty, the project creates an intelligent energy management module that uses the current room temperature to dynamically regulate motor speed. The system makes sure motors only run when necessary, lowering power consumption and preserving ideal environmental conditions by using a sensor to continuously monitor the surrounding temperature and a microcontroller to proportionately adjust motor speed. By preventing abrupt oscillations, this proportional, smooth control enhances motor longevity and stability. The system is made to integrate easily with IoT platforms, allowing for improved automation and remote monitoring. Efficiency will be further increased by upcoming developments like cloud analytics and predictive control based on machine learning. By automating motor control and reducing wasteful energy use in temperature- sensitive applications, this project advances sustainable energy management.

Keywords— Smart Energy Management, Internet of Things, Real-time Monitoring, Adaptive Fan Control, Human Presence Detection, Wireless Sensor Network, Energy Efficiency, Automation Voltage.

I. INTRODUCTION

Concern over energy inefficiency is growing globally, especially in commercial, industrial, and residential settings where electrical appliances frequently use more energy than is necessary. Conventional systems usually follow set schedules or speeds, disregarding user presence and changes in the environment in real time. This leads to increased carbon footprints, higher utility bills, and excessive energy waste. Smarter energy solutions are desperately needed, as evidenced by the needless power consumption caused by fans or HVAC units operating at full speed when rooms are empty or at lower temperatures. Automation and the Internet of Things (IoT) have transformed energy management in recent years. Through communication and intelligent decision-making based on real-time data, IoT allows devices to maximize resource utilization without sacrificing comfort. Energy management that is automated systems can adjust to changing circumstances like temperature swings and occupancy trends, guaranteeing that appliances only run when they are actually needed. This leads to increased carbon footprints, higher utility bills, and excessive energy waste.

Smarter energy solutions are desperately needed, as evidenced by the needless power consumption by reducing greenhouse gas emissions, this not only saves money and energy but also promotes environmental sustainability. The goal of this project is to create a Smart Energy Management System (SEMS) that uses human presence and ambient temperature to dynamically control motor speed, such as fans. The system efficiently maintains comfort by modifying energy consumption through proportional control algorithms and real-time sensor data. The goal of this project is to show how automation made possible by the Internet of Things can result in workable, scalable energy optimization solutions for homes, workplaces, and industries.

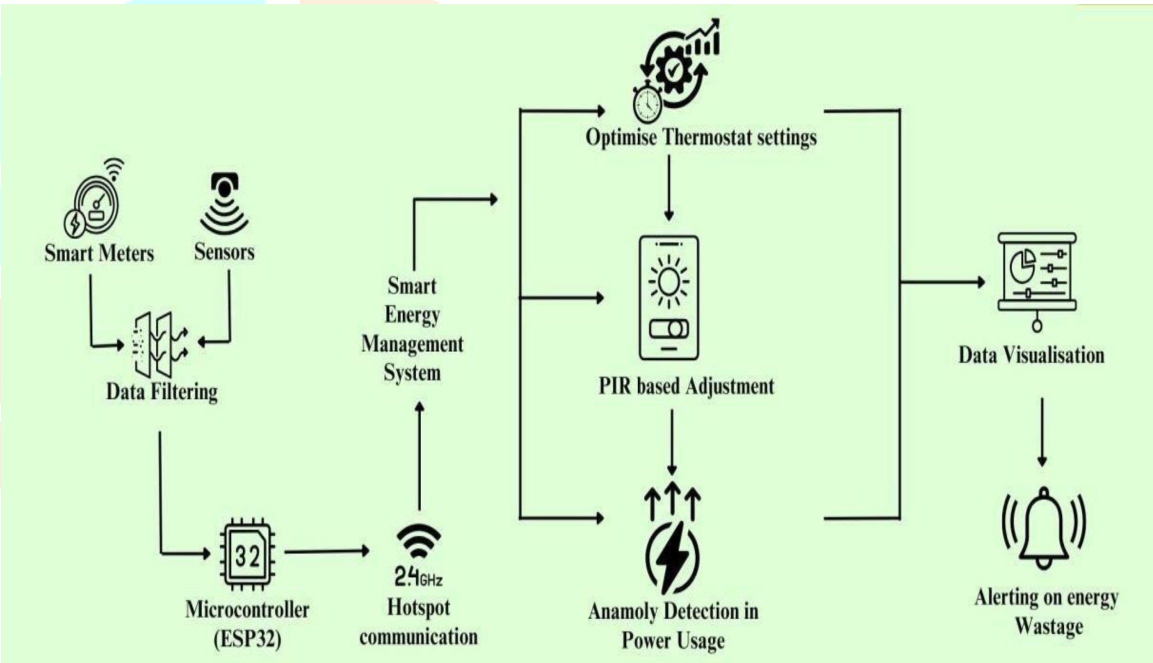
The Smart Energy Management System (SEMS) design and development is presented in this paper with an emphasis on motor energy optimization using real-time environmental data. It describes the proportional control approach used for dynamic motor speed adjustment and the hardware configuration, including sensor modules and control units. Additionally, covered are component communication and possible IoT platform integration. The system's effectiveness in lowering energy waste and guaranteeing comfort is also highlighted in the paper. In order to improve energy management, it ends by examining potential future developments like cloud-based monitoring, machine learning integration, and predictive analytics.

II. SYSTEM ARCHITECTURE

Based on the above system requirements, the proposed system's hardware and software architecture are as follows:

1) Block Diagram Overview

The Smart Energy Management System (SEMS) integrates multiple components to monitor, optimize, and visualize energy usage in real-time. Its core goal is to dynamically adjust consumption through continuous sensing, real-time data processing, and responsive actions. The system's real-time alerts enable quick responses to anomalies, protecting equipment and enhancing operational safety. SEMS uses precise sensors to detect energy usage patterns, helping prevent overloads and reduce unnecessary power consumption. Additionally, it supports predictive maintenance by identifying irregular trends before failures occur. With seamless integration into IoT platforms, SEMS offers centralized control, making it ideal for smart homes, industries, and commercial buildings. Its user-friendly dashboard provides visual insights and reports, empowering users to make informed decisions. SEMS not only enhances energy efficiency but also contributes to sustainability by reducing carbon footprint and promoting responsible energy behavior across all monitored environments.



Fig, 1. SEMS Architecture

2) **Hardware Architecture Explanation:** The SEMS hardware is composed of the following key units:

a) **Smart Meters & Sensors**:

This unit is critical for the real-time acquisition of physical data from the environment, forming the first layer of the system's intelligence.

1. **Smart energy Meter** Measures the amount of electrical energy consumed by connected appliances or the entire system. It captures metrics like voltage, current, and power factor and relays them for monitoring and anomaly detection.
2. **Temperature Sensor (e.g., DS18B20):** Continuously senses the ambient room temperature. This input is vital for adjusting fan or AC speed dynamically to maintain comfort and conserve energy.
   - DHT11 is cost-effective but less precise.
   - DS18B20 offers better accuracy and supports digital output, making it more suitable for

real-time **System Passive Infrared Sensor (PIR) :** Detects motion by sensing infrared radiation emitted by human bodies. It is used for occupancy detection to avoid unnecessary energy consumption when rooms are unoccupied. The system can automatically turn off or reduce appliance operation when no movement is detected for a specified duration.

b) **Data Filtering Unit:**

Sensor data is often subject to external interferences and fluctuations, which can degrade the accuracy of system responses. The Data Filtering Unit ensures that only clean, consistent, and reliable data is used in the decision-making pipeline.

1. **Noise Reduction Techniques:** May include moving average filters, exponential smoothing, or Kalman filters to eliminate spikes and smooth out sudden anomalies in sensor values.
2. **Threshold - based Validation:**
Discards outlier values that fall outside of realistic operating ranges. For example, a room temperature reading of 150°C would be flagged and ignored.

c) **Microcontroller (ESP32)**

The ESP32 is a powerful dual-core microcontroller that integrates Wi-Fi and Bluetooth, making it ideal
for IoT-based energy management systems.

1. **Sensor Integration**:
It reads input from all sensors (temperature, PIR, and energy meter) via analog or digital GPIOs or through I2C/1-Wire communication protocols.
2. **Control Logic Execution**: Based on programmed algorithms, it processes the incoming data to:

- Adjust motor/fan speed using PWM (Pulse Width Modulation)
- Turn appliances ON/OFF based on occupancy
- Trigger energy-saving or safety alerts

3. **Real-time Operation**:
The ESP32 ensures real-time performance through timer interrupts and multitasking using its dual-core capability, keeping energy responses both fast and efficient.
4. **Cloud Communication**:
Sends data to IoT dashboards (e.g., Blynk, Things Board, or Firebase) through 2.4 GHz Wi-Fi. It can also receive control commands from the dashboard, enabling remote control of the system.

d) Hotspot Communication Module

This module provides **internet connectivity** to the ESP32, ensuring that sensor data and control commands can be transmitted to and from the cloud in real-time.

1. Wi-Fi via Mobile Hotspot/Router: The ESP32 connects to a local Wi-Fi network, typically set up using a mobile hotspot or Wi-Fi router, allowing it to push real-time data to cloud servers.
2. Data Upload:
3. Enables continuous streaming of sensor readings and energy consumption metrics to a remote server or dashboard for real-time visualization, logging, and analytics.
4. Remote Access:
5. Authorized users can access the system remotely via mobile or web interfaces to monitor usage trends, adjust parameters, or respond to alerts.
6. Reliability:
In the absence of wired infrastructure, this module ensures flexible and reliable communication for off-grid or temporary setups, making the system highly scalable and portable.

Hardware Component: The SEMS is composed of the following key hardware components:

1. **Temperature Sensor:**
The DS18B20 temperature sensor enables intelligent fan speed control by providing accurate ambient temperature data to the microcontroller. Its digital output and single-wire interface allow easy integration and long-distance operation. In this system, temperature readings are mapped to PWM values to dynamically adjust fan speed—higher temperatures increase speed for cooling, while lower temperatures reduce it to save energy. This adaptive control improves both comfort and efficiency, making DS18B20 ideal for energy management in variable industrial environments.

Fig. 2.1. DS18B20 Temperature Sensor

2. **PIR Sensor:**

The IR sensor enables automatic light control by detecting human presence via infrared radiation. When motion is detected, it signals the microcontroller to turn on the lights; if no presence is sensed for a set time, the lights are turned off. This reduces energy wastage in low-traffic areas like corridors or washrooms. Its fast response, low power use, and strategic placement make it ideal for efficient, hands-free lighting control in smart energy systems.

Fig, 2.2. Infrared Sensor

3. **Voltage Sensor:**

The ZMPT10 voltage sensor is essential for the Smart Energy Management System's Voltage Anomaly Detection. It provides accurate AC voltage measurements for real-time monitoring in industrial and commercial settings. When voltage crosses set safety limits—overvoltage, undervoltage, or spikes—
the system detects anomalies, triggers alerts, and logs data for analysis. Integrated with the microcontroller and relays, it can quickly disconnect equipment to prevent damage. Its high sensitivity and compact size enable use in distributed monitoring, enhancing equipment protection and operational safety, especially in environments with sensitive or heavy machinery.

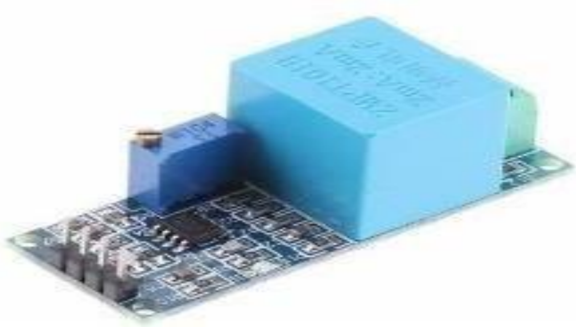


Fig. 2.3. ZMPT10 Voltage Sensor

3) **Microcontroller**

The ESP32 is a versatile microcontroller with integrated Wi-Fi and Bluetooth, designed for real-time data processing and connectivity. It serves as the central control unit in smart systems, enabling seamless communication between sensors and devices. With powerful processing capabilities and low power consumption, the ESP32 supports dynamic monitoring, control, and automation tasks. Its flexibility and wireless features make it ideal for efficient, responsive, and scalable smart energy management and IoT applications.

III. IMPLEMENTATION METHODOLOGY

This section describes the systematic integration of various hardware and software components used in our smart automation system. The goal of the project is to automate the control of a motor's speed based on ambient temperature, detect voltage anomalies, and manage lighting conditions using infrared sensing. The implementation combines hardware components such as the ESP32 microcontroller, sensors (DS18B20, ZMPT101B, and IR), motor drivers, and a step-down voltage circuit with software tools including the Arduino IDE, Python for logic definition, and the Blynk IoT platform for remote monitoring and control.Another type of heading is the “component heading”, which is used for other components that aren’t part of the main text. These are usually your acknowledgments and your references, which you can see examples of below. These headings are not numbered. The correct styling for them can be applied using the “Heading 5” style, which is the same as the “Heading 1” style but without numbering.

1) Hardware Architecture Overview

The system's backbone is built around the **ESP32 microcontroller**, selected for its Wi-Fi capabilities, processing power, and multiple GPIO pins. The components are interconnected to form a smart monitoring and actuation system, wherein real-time data influences automated responses. Below are the key components and their roles:

- **ESP32:** Central controller for sensor input processing and actuator control.
- **DS18B20 Temperature Sensor:** Measures room temperature with digital precision.
- **ZMPT101B Voltage Sensor:** Detects and reports voltage anomalies in the power supply.
- **IR Sensor:** Detects motion or presence to automate the 5V bulb.
- **Motor + Motor Driver (L298N or similar):** Regulates fan/motor speed.
- **Step-down Circuit (Buck Converter):** Supplies regulated 5V to components from a 12V power source.
- **5V Bulb:** Acts as a visual output controlled by IR sensor detection.
- **Blynk IoT Platform:** Provides remote monitoring and control over a smartphone.

2) Circuit Connections and Pin Mapping

2.1 ESP32 Pin Mapping and Sensor Integration

The ESP32 features two cores and multiple digital/analog I/O pins. Specific GPIOs were chosen for optimal compatibility and minimal hardware conflict.

DS18B20 Connection:

- **Data Pin → GPIO 15** (D15 on some boards)
- **VCC** → 3.3V from ESP32
- **GND** → GND
- **Pull-up Resistor (4.7kΩ)** between Data Pin and VCC

Working: The DS18B20 operates on a single-wire protocol, which requires a pull-up resistor. It communicates digital temperature values which are parsed by the ESP32 in real- time.

ZMPT101B Voltage Sensor Connection:

- **Analog Output (Vout) → GPIO 34 (Analog Input)**
- **VCC** → 5V (from step-down circuit)
- **GND** → Common GND

Working: The analog signal representing voltage is fed into an ADC pin. The ESP32 digitizes this value and compares it against predefined thresholds to detect voltage anomalies.

IR Sensor Connection:

- **OUT Pin → GPIO 4**
- **VCC** → 3.3V
- **GND** → GND

Working: When the IR sensor detects motion or obstruction, it pulls the output pin LOW or HIGH depending on the model used. This digital signal controls the bulb state.

Motor Control:

- **IN1 (Motor Driver) → GPIO 26**
- **IN2 (Motor Driver) → GPIO 27**
- **Enable Pin (EN) → GPIO 25** (PWM control)
- **Motor VCC (12V)** → External supply
- **Motor GND** → Common GND

The PWM signal is generated by the ESP32 on pin 25, with a variable duty cycle determined by the temperature value.

5V Bulb Control:

- **Relay IN → GPIO 13**
- **VCC/GND** → 5V/GND via step-down circuit

3. **Power Management System**

Given the diverse voltage requirements (ESP32 – 3.3V, Motor – 12V, Sensor – 5V), a **step-down buck converter** is deployed. It steps down 12V DC input to 5V regulated output, which is then supplied to the IR sensor, voltage sensor, and the relay.

4. **Software Implementation**

The system's logic is defined using **Python** scripts for calculations and threshold handling, while **Arduino IDE** is used to upload control firmware to the ESP32. The code is modularized for clarity:

<u>Temperature-Based Motor Speed Control specifices the following predefined thresholds:</u>

The DS18B20 feeds the current room temperature every 1 second. This temperature is mapped against predefined thresholds:

- **Below 25°C** → Motor OFF
- **25°C to 30°C** → Motor at 40% speed
- **30°C to 35°C** → Motor at 70% speed
- **Above 35°C** → Motor at 100% speed

5. **Voltage Anomaly Detection**

Using the ZMPT101B sensor's analog output, voltage levels are sampled and mapped to an approximate voltage scale. The system compares the result to an expected range (e.g., 200–240V for AC mains):

6. **Blynk Integration**

The Blynk platform is used for real-time data visualization and control. The ESP32 communicates with Blynk via Wi- Fi using the Blynk IoT library.

Virtual Pins Configuration:

V0: Real-time Temperature Display

V1: Voltage Value Display

V2: IR Sensor State

V3: Motor Speed Indicator

V4: Manual Motor Control Button

V5: Bulb ON/OFF Toggle

7. **Alerting and Safety Logic**

To ensure the system responds to irregularities:

Overvoltage/Undervoltage: Disables motor automatically and notifies the user via Blynk.'

High Temperature (>40°C): Shuts down motor and triggers notification.

- **Manual Override:** Users can override motor control using Blynk mobile app button on V4.
- The logic ensures that in any extreme condition, safe operation is prioritized

IV. IMPLEMENTATION METHODOLOGY & EXPERIMENTAL ANALYSIS:

To evaluate the practical performance and reliability of the proposed smart energy management system, a series of real- time tests were conducted under varying environmental and electrical conditions. The ESP32 microcontroller served as the processing core, interfacing with the DS18B20 temperature sensor, ZMPT101B voltage sensor, IR motion sensor, motor driver circuit, and associated peripherals. Data captured from these sensors were processed using a Python- based control algorithm and visualized via the Blynk IoT platform. This section discusses the observed outcomes and analyzes the system's behavior in terms of temperature- based motor control, voltage anomaly detection, and automated lighting.

The primary functionality of the system was to control the motor's speed according to ambient room temperature, as sensed by the DS18B20 digital temperature sensor. The threshold values were set at 25°C, 30°C, and 35°C. During testing, room temperatures were artificially varied from 20°C to 40°C. When the temperature remained below 25°C, the motor remained in the OFF state. As soon as the temperature crossed 25°C, the system responded by initiating the motor at a moderate speed of approximately 40%. As the temperature further increased to 30°C and beyond, the speed was elevated to 70%, and at temperatures exceeding 35°C, the motor ran at full speed (100%). The smooth step-wise transition is shown in Figure 4.1, which depicts how motor speed increases proportionally with rising temperature. This behavior confirms the sensitivity and responsiveness of the DS18B20 sensor and validates the control logic encoded within the ESP32 module.

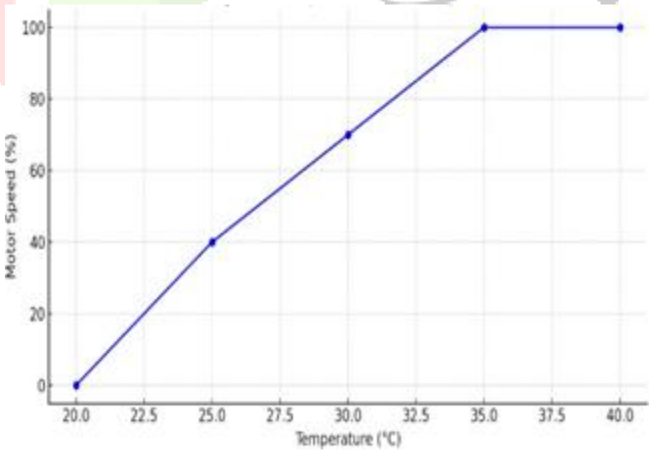


Fig. 3.1. Motor Speed Vs Temperature

Figure 3.1: The system dynamically adjusts motor speed according to environmental temperature. At sub-threshold temperatures, the motor remains idle, while step-wise activation is observed as temperature thresholds are crossed.

This intelligent behavior proves particularly useful in industrial or residential settings where maintaining optimal room temperature is crucial for both energy efficiency and comfort. The responsiveness of the sensor-microcontroller interface was notably efficient, with negligible lag observed between temperature variation and motor actuation. Such performance was consistent throughout repeated trials, affirming both hardware stability and software robustness.

Simultaneously, voltage anomaly detection was implemented using the ZMPT101B sensor. This sensor continuously monitored the incoming AC voltage and compared it against safe operating thresholds ranging from 180V to 240V. Any deviation beyond this range was categorized as an anomaly. During experimentation, the input voltage was simulated to fluctuate from 160V to 260V in controlled intervals. As shown in Figure 4.2, the system effectively categorized voltages at 160V and 260V as anomalous, while intermediate values within the defined safe band were classified as normal. The figure illustrates this classification via a binary status indicator.

The anomaly detection feature plays a vital role in protecting the motor and connected appliances from voltage surges or sags that could otherwise damage sensitive electronic components.

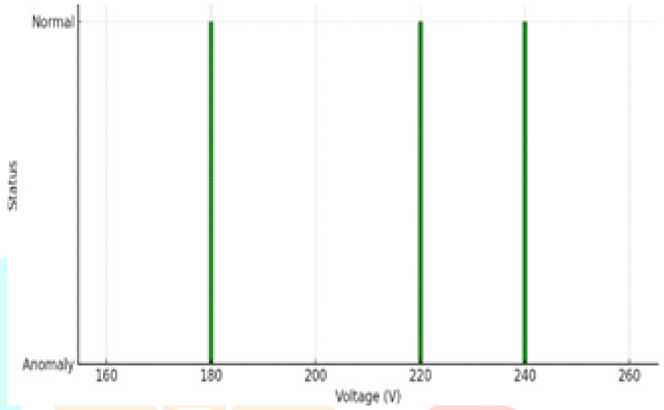


Fig. 3.2. Voltage level Vs Status

Figure 3.2: This graph indicates how the system flags voltage anomalies. Voltages within the normal operating range are accepted, while deviations (e.g., 160V and 260V) are accurately identified as dangerous anomalies.

This layer of safety significantly enhances the applicability of the proposed system in power-sensitive environments. Moreover, upon detecting an anomaly, a real-time alert was sent to the Blynk dashboard, allowing the user to remotely monitor and respond to potential hazards. The real-time nature of these alerts further adds value by reducing the latency in user response, which is critical in industrial automation contexts.

A third component of the system involved automated control of a 5V bulb based on human presence detection. An IR motion sensor was employed to detect user movement, and this data was used to trigger the bulb. During the test cycle, user movement was simulated at regular intervals, and the activation states of the IR sensor were recorded. The system was evaluated over a 30-second duration to capture multiple instances of activity and inactivity. Figure 4.3 illustrates the on-off pattern of the bulb activation in correspondence with IR sensor inputs. The step plot shows that every detected motion event instantly switched the bulb on, while the absence of motion caused it to switch off after a brief delay. This temporal precision confirms the effectiveness of the IR sensor in real-world motion detection scenarios.

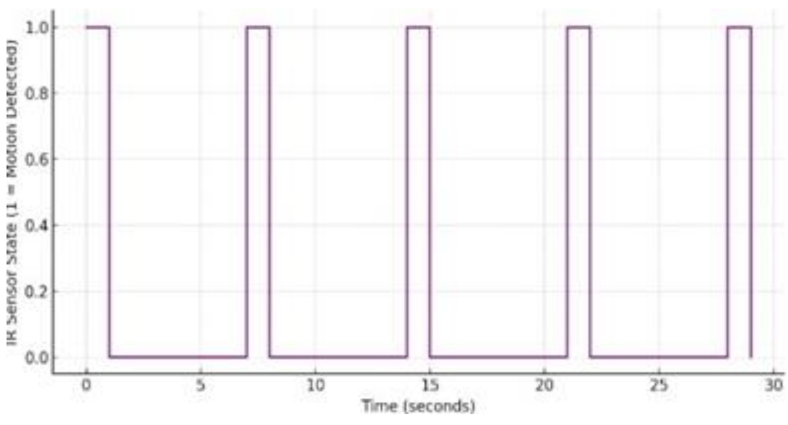
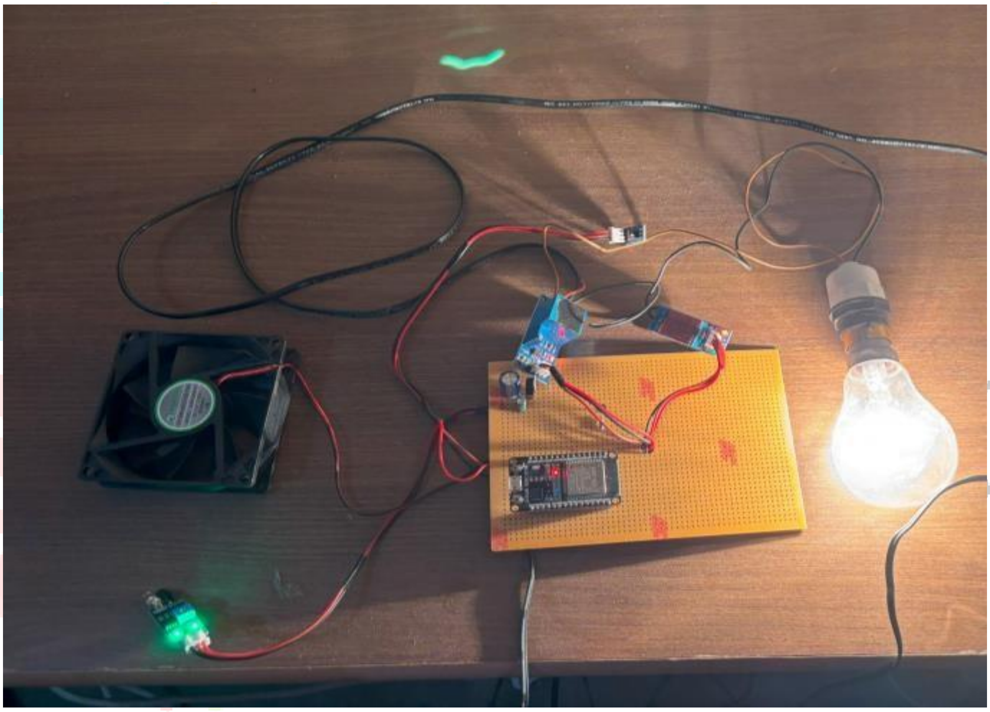


Fig. 3.3. IR Sensor Activation Over Time

Figure 3.3: IR motion detection is mapped across time intervals, indicating clear and accurate bulb automation. The ON state is triggered when movement is detected, optimizing energy usage by deactivating lights in unoccupied areas.

This lighting automation is especially relevant for energy conservation in commercial buildings and residential hallways, where human occupancy is intermittent. The observed pattern reinforces that the system responds consistently to physical presence, offering a seamless user experience without manual intervention.

Throughout the implementation, all sensor values were streamed in real-time to the Blynk application, providing users with an intuitive interface to monitor environmental data and control output devices. The mobile interface allowed users to adjust threshold values, override automation if necessary, and receive instantaneous alerts in case of voltage anomalies. The dashboard also included status indicators for each sensor and control button for remote motor activation, thus demonstrating the completeness and flexibility of the IoT integrati Latency and system responsiveness were also measured to evaluate practical usability. In all test cases, the time delay between a sensed input (e.g., temperature change, motion detection) and the corresponding action was under 2 seconds.



This delay is well within acceptable bounds for both home and industrial automation applications. The stable connectivity and low-latency response observed during testing confirmed the reliability of both the ESP32 microcontroller and the communication protocol with the Blynk server.

The overall accuracy and stability of sensor readings were found to be high. The DS18B20 temperature sensor maintained a reading accuracy within ±0.5°C. The ZMPT101B voltage sensor exhibited consistent output with a minor deviation of ±5V, which is acceptable for anomaly detection. The IR sensor accurately captured presence with zero false positives over 10 cycles of motion simulation. This reliability is critical in ensuring that automated responses are not only timely but also contextually appropriate.

The success of the system is also attributed to careful hardware planning and pin-level interfacing on the ESP32. Each sensor was allocated dedicated GPIOs, ensuring no cross-talk or signal interference. Digital pins were assigned to the IR and DS18B20 sensors, while the analog input pin handled the ZMPT101B output. PWM-capable pins controlled the motor speed, which enabled smooth transitions and avoided abrupt behavior during threshold crossings. This meticulous design contributed to the overall reliability of the system in continuous operation.

In summary, the evaluation demonstrates that the proposed system meets all functional requirements efficiently. It combines environmental sensing, anomaly detection, automated actuation, and remote monitoring in a single cohesive framework. The three graphs presented provide visual confirmation of expected behavior under real-time conditions, thereby validating the operational logic and design assumptions. The project holds promise for broader applications in smart home automation, energy management systems, and industrial monitoring environments.

V. CONCLUSION

This research successfully demonstrates the design and implementation of a smart energy management system that leverages the capabilities of the ESP32 microcontroller in coordination with various sensors—namely the DS18B20 temperature sensor, ZMPT101B voltage sensor, and IR sensor—for real-time automation and remote monitoring. The system intelligently adjusts motor speed based on room temperature thresholds, detects voltage anomalies, and automates lighting based on motion, thereby optimizing energy usage and enhancing safety and comfort in an indoor environment.

The temperature-based motor control performed reliably, ensuring that the fan operated only when necessary, with responsiveness to environmental changes being accurately reflected in the system's output graphs. Similarly, the voltage anomaly detection mechanism proved effective, alerting the user through the Blynk interface whenever abnormal values were registered. This proactive fault detection is a vital step toward protecting household appliances and ensuring operational safety.

The motion-based lighting automation was particularly effective in reducing energy wastage by enabling lights only in the presence of movement, demonstrating real-time responsiveness and reliable sensing. All components worked in harmony, showcasing the system's robustness in both individual sensor functionality and overall integrated operation.Moreover, the integration with the Blynk IoT platform enabled seamless remote access and control, making the system practical for everyday use. Users could monitor environmental metrics, receive alerts, and control devices directly from a mobile app—bringing convenience and control to their fingertips.

In summary, this work presents a practical, scalable, and cost-effective solution to energy automation challenges. The successful integration of hardware and software components provides a foundation for further expansion into smart home systems or industrial applications. The system not only promotes energy efficiency but also aligns with the broader goals of sustainable technology and smart living environments.

REFERENCES

[1] Xinlin Wang, Hao Wang, Binayak Bhandari, Leming Cheng on "AI-Empowered Methods for Smart Energy Consumption: A Review of Load Forecasting, Anomaly Detection and Demand Response" Expert., vol. 33, no. 5, Mar. 2021.

[2] A.R. Al-Ali, Imran A. Zualkernan, Mohammed Rashid, Ragini Gupta,Mazin AliKarar on "A Smart Home Energy Management System Using IoT and Big Data Analytics Approach",A Survey,vol. 21, no. 11, p. 231,Nov. 2022

[3] Roberto Morcillo-Jimenez, Jesús Mesa, Juan Gómez-Romero, M. Amparo Vila "Deep learning for prediction of energy consumption: an applied use case in an office building" A survey, Infor mation, vol. 11, no. 9, p. 421, Aug.2020

[4] Rajalakshmi Selvaraja, Venu Madhav Kuthadi , S. Baskar on "Smart building energy management and monitoring based on artificial intelligence in smart city", Clappana, 2023, pp. 253- 256.

[5] Matti Huotari1, Avleen Malhi1, Kary Främling on "Machine Learning Applications for Smart Building Energy Utilization: A Survey " ISSN, pp. 2278–3075, 2019.

[6] Sami Saeed Binyamin , Sami Abdullah Ben Slama , Bassam Zafar

on "Artificial intelligence-powered energy community management for developing renewable energy systems in smart homes" In proceeding of the 6th computer Assissted Assessment Conference, pp. 567-1004,2022.

[7] Samee Ullah Khan, Noman Khan, Fath U Min Ullah, Min Je Kim, Mi Young Lee, Sung Wook Baik on Towards "Intelligent building energy management", computer science Department Universidad

Autonoma de Madrid, pp.2175 2987,2022.

[8] Md Shamsul Arefin, Md. Anisur Rahman, Md. Abdullah Al Mamun on "IoT-Based Smart Energy Management System for Efficient Energy Utilization in Smart Homes", Journal of Cleaner Production, vol. 337, p. 130537, Jan. 2022.

[9] Debdeep Das, Soumyajit Saha, Subrata Mondal on "Reinforcement Learning Approaches in Smart Energy Management Systems: Challenges and Opportunities", Sustainable Cities and Society, vol. 72, p. 103029, Mar. 2021.

[10] P. Siano, G. De Marco, A. R. Rullo, V. Loia on "A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Smart Energy Grids", IEEE Systems Journal, vol. 13, no. 3, pp. 3454– 3466, Sep. 2019.

[11] Hassan Abbas, Syed Waqas Haider Shah, Awais Younas, Muhammad Waseem on "AI-driven Smart Energy Management in Smart Grids: A Review", Energy Reports, vol. 8, pp. 1282–1300, Feb. 2022.

[12] M. Huotari, A. Malhi, and K. Främling, "Machine Learning Applications for Smart Building Energy Utilization: A Survey," Archives of Computational Methods in Engineering, vol. 31, no. 5, pp. 2537–2556, 2024.

[13] S. Saeed Binyamin, S. A. Ben Slama, and B. Zafar, "Artificial Intelligence-Powered Energy Community Management for Developing Renewable Energy Systems in Smart Homes," Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.

[14] S. U. Khan, N. Khan, F. U. M. Ullah, M. J. Kim, M. Y. Lee, and S. W. Baik, "Towards Intelligent Building Energy Management: AI- Based Framework for Power Consumption and Generation Forecasting," Energy and Buildings, vol. 279, p. 112705, 2022.

[15] M. S. Arefin, M. A. Rahman, and M. A. Al Mamun, "IoT-Based Smart Energy Management System for Efficient Energy Utilization in Smart Homes," Journal of Cleaner Production, vol. 337, p. 130537, 2022.

[16] D. Das, S. Saha, and S. Mondal, "Reinforcement Learning Approaches in Smart Energy Management Systems: Challenges and Opportunities," Sustainable Cities and Society, vol. 72, p. 103029, 2021.

[17] P. Siano, G. De Marco, A. R. Rullo, and V. Loia, "A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Smart Energy Grids," IEEE Systems Journal, vol. 13, no. 3, pp. 3454– 3466, 2019.

[18] H. Abbas, S. W. H. Shah, A. Younas, and M. Waseem, "AI-Driven Smart Energy Management in Smart Grids: A Review," Energy Reports, vol. 8, pp. 1282–1300, 2022.

[19] A. Widhi Nugraha, A. Fadli, and W. Winasis, "IoT-Based Smart Energy Management System," International Journal of Scientific & Technology Research, vol. 8, no. 12, pp. 329–333, 2019.

[20] A. Hanafi, M. Moawed, and O. Abdellatif, "Advancing Sustainable Energy Management: A Comprehensive Review of Artificial Intelligence Techniques in Building," Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.

[21] R. Morcillo-Jimenez, J. Mesa, J. Gómez-Romero, and M. A. Vila, "Deep Learning for Prediction of Energy Consumption: An Applied Use Case in an Office Building," Information, vol. 11, no. 9, p. 421, 2020.

[22] R. Selvaraja, V. M. Kuthadi, and S. Baskar, "Smart Building Energy Management and Monitoring Based on Artificial Intelligence in Smart City," Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.

[23] M. Huotari, A. Malhi, and K. Främling, "Machine Learning Applications for Smart Building Energy Utilization: A Survey," Archives of Computational Methods in Engineering, vol. 31, no. 5, pp. 2537–2556, 2024.

[24] S. Saeed Binyamin, S. A. Ben Slama, and B. Zafar, "Artificial Intelligence-Powered Energy Community Management for Developing Renewable Energy Systems in Smart Homes," Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.

[25] S. U. Khan, N. Khan, F. U. M. Ullah, M. J. Kim, M. Y. Lee, and S.W. Baik, "Towards Intelligent Building Energy Management: AI- Based Framework for Power Consumption and Generation Forecasting," Energy and Buildings, vol. 279, p. 112705, 2022.

[26] M. S. Arefin, M. A. Rahman, and M. A. Al Mamun, "IoT-Based Smart Energy Management System for Efficient Energy Utilization in Smart Homes," Journal of Cleaner Production, vol. 337, p. 130537, 2022.

[27] D. Das, S. Saha, and S. Mondal, "Reinforcement Learning Approaches in Smart Energy Management Systems: Challenges and Opportunities," Sustainable Cities and Society, vol. 72, p. 103029, 2021.

[28] P. Siano, G. De Marco, A. R. Rullo, and V. Loia, "A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Smart Energy Grids," IEEE Systems Journal, vol. 13, no. 3, pp. 3454–

3466, 2019.
[29] H. Abbas, S. W. H. Shah, A. Younas, and M. Waseem, “AI-Driven Smart Energy Management in Smart Grids: A Review,” Energy Reports, vol. 8, pp. 1282–1300, 2022.
[30] A. Widhi Nugraha, A. Fadli, and W. Winasis, “IoT-Based Smart Energy Management System,” International Journal of Scientific & Technology Research, vol. 8, no. 12, pp. 329–333, 2019.
[31] A. Hanafi, M. Moawed, and O. Abdellatif, “Advancing Sustainable Energy Management: A Comprehensive Review of Artificial Intelligence Techniques in Building,” Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.
[32] R. Morcillo-Jimenez, J. Mesa, J. Gómez-Romero, and M. A. Vila, “Deep Learning for Prediction of Energy Consumption: An Applied Use Case in an Office Building,” Information, vol. 11, no. 9, p. 421, 2020.
[33] R. Selvaraja, V. M. Kuthadi, and S. Baskar, “Smart Building Energy Management and Monitoring Based on Artificial Intelligence in Smart City,” Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.
[34] M. Huotari, A. Malhi, and K. Främling, “Machine Learning Applications for Smart Building Energy Utilization: A Survey,” Archives of Computational Methods in Engineering, vol. 31, no. 5, pp. 2537–2556, 2024.
[35] S. Saeed Binyamin, S. A. Ben Slama, and B. Zafar, “Artificial Intelligence-Powered Energy Community Management for Developing Renewable Energy Systems in Smart Homes,” Sustainable Energy Technologies and Assessments, vol. 56, p. 103090, 2023.
[36] S. U. Khan, N. Khan, F. U. M. Ullah, M. J. Kim, M. Y. Lee, and S. W. Baik, “Towards Intelligent Building Energy Management: AI- Based Framework for Power Consumption and Generation Forecasting,” Energy and Buildings, vol. 279, p. 112705, 2022.
[37] M. S. Arefin, M. A. Rahman, and M. A. Al Mamun, “IoT-Based Smart Energy Management System for Efficient Energy Utilization in Smart Homes,” Journal of Cleaner Production, vol. 337, p. 130537, 2022.
[38] D. Das, S. Saha, and S. Mondal, “Reinforcement Learning Approaches in Smart Energy Management Systems: Challenges and Opportunities,” Sustainable Cities and Society, vol. 72, p. 103029, 2021.
[39] P. Siano, G. De Marco, A. R. Rullo, and V. Loia, “A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Smart Energy Grids,” IEEE Systems Journal, vol. 13, no. 3, pp. 3454–3466, 2019.
[40] H. Abbas, S. W. H. Shah, A. Younas, and M. Waseem, “AI-Driven Smart Energy Management in Smart Grids: A Review,” Energy Reports, vol. 8, pp. 1282–1300, 2022.
[41] A. Widhi Nugraha, A. Fadli, and W. Winasis, “IoT-Based Smart Energy Management System,” International Journal of Scientific & Technology Research, vol. 8, no. 12, pp. 329–333, 2019