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IoT-Based Smart Campus Management System

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Abstract: In recent years, universities have been facing significant challenges related to inefficient energy usage and resource management. Large campuses consist of multiple buildings and facilities, each with varying energy demands, yet many institutions still rely on outdated management practices. These traditional approaches, which depend heavily on manual monitoring and control, are often inefficient, time-consuming, and susceptible to human error. As a result, unnecessary energy consumption occurs, operational costs increase, and environmental sustainability is negatively impacted. Furthermore, as campus infrastructures continue to expand, the complexity of managing energy resources also increases, making it even more difficult to maintain efficiency using conventional methods.

To address these challenges, this study proposes an advanced smart campus automation system based on Internet of Things (IoT) technology. The proposed system integrates multiple sensors to continuously monitor environmental parameters such as temperature, humidity, and air quality in real time. Based on the collected data, the system can automatically control electrical devices and optimize energy usage without human intervention. In addition, cloud-based platforms are used to store, analyze, and visualize data, enabling remote monitoring and better decision-making. The IoT framework allows seamless communication between devices, providing deeper insights into energy consumption patterns and helping to improve overall efficiency. By implementing such an intelligent system, institutions can reduce energy wastage, lower operational costs, and contribute to a more sustainable and environmentally responsible campus environment.

***Keywords* - Smart Campus, Internet of Things, Energy Efficiency, Automation System, Cloud Monitoring.**

I. INTRODUCTION

In the modern educational area, university campuses are evolving into large and complex infrastructures that consume a significant amount of energy for daily operations. Facilities such as classrooms, laboratories, corridors, and administrative buildings require continuous power for lighting, ventilation, and monitoring systems. However, in many institutions, these resources are still managed using conventional methods that rely on fixed schedules or manual control. Such approaches often fail to consider real-time occupancy and environmental conditions, resulting in unnecessary energy consumption and inefficient resource utilization. As energy costs continue to rise and environmental concerns become more critical, there is a growing need for intelligent systems that can manage campus resources in a more efficient and sustainable manner.

Recent advancements in the Internet of Things (IoT) have opened new possibilities for developing smart and connected environments. IoT technology enables the integration of sensors, microcontrollers, and cloud platforms to create systems capable of real-time data collection, communication, and automated decision-making. In the context of a smart campus, IoT can be used to continuously monitor environmental parameters such as temperature, humidity, air quality, light intensity, and occupancy. By analyzing this data, it becomes possible to control electrical devices dynamically, ensuring that energy is used only when required.

The work presented in this study builds upon the concept of IoT-based automation by designing a smart campus management system using an ESP32 microcontroller as the central processing unit. The system integrates multiple sensors, including a DHT11 sensor for temperature and humidity measurement, an MQ-135 sensor for air quality detection, a PIR sensor for occupancy sensing, and an LDR module for ambient light detection. These sensors provide continuous input to the controller, which processes the data and operates connected electrical loads such as lighting and ventilation systems through a relay module. The system supports both automatic and manual modes of operation, allowing users to control devices remotely through a cloud-based platform while also enabling autonomous decision-making based on predefined conditions.

In addition to real-time control, the proposed system incorporates cloud connectivity to store and visualize sensor data, enabling users to monitor system performance from remote locations. This feature not only improves accessibility but also allows for the analysis of usage patterns over time. By examining these patterns, institutions can gain valuable insights into energy consumption behavior and identify opportunities for further optimization. The integration of data logging and cloud-based dashboards enhances the overall functionality of the system, making it more practical for large-scale deployment.

Furthermore, this research emphasizes the role of intelligent automation in promoting sustainability within campus environments. By reducing unnecessary operation of electrical devices and optimizing their usage based on actual requirements, the system contributes to lowering overall energy consumption. This, in turn, can lead to a reduction in operational costs as well as a decrease in the environmental impact associated with excessive energy use. The proposed solution demonstrates how a low-cost, scalable, and easy-to-implement IoT-based system can significantly improve the efficiency of campus resource management

II. LITERATURE SURVEY

Kumar et al. (2023) proposed an IoT-based energy management system for campus environments using microcontroller platforms and wireless communication protocols. Their work demonstrated that automated monitoring of electrical loads can significantly reduce unnecessary energy consumption. However, their system required additional communication modules and separate processing units, which increased overall system complexity and cost. In contrast, the present work utilizes a compact ESP32-based architecture with inbuilt Wi-Fi capability, reducing hardware dependency and making the system more economical and easier to deploy.

Patel et al. (2022) focused on indoor environmental monitoring using gas sensors to evaluate air quality in educational buildings. Their study highlighted the importance of continuous monitoring, especially in crowded classrooms where air quality tends to degrade. However, their approach was limited to data observation and did not include automated control mechanisms. This limitation is addressed in the proposed system by integrating relay-based actuation, enabling automatic responses such as activating ventilation systems when air quality exceeds defined thresholds.

Sharma et al. (2022) developed an IoT-enabled remote monitoring system using cloud platforms for real-time visualization of environmental data. While their system provided effective remote access and user-friendly dashboards, it relied heavily on continuous internet connectivity for operation and control. In comparison, the proposed system incorporates both local processing and cloud integration, ensuring that essential control actions can still be executed even with limited network availability.

Jaber et al. (2021) introduced a smart parking management system using sensor networks to detect vehicle presence and optimize space utilization on campus. Their work demonstrated how IoT can improve user convenience and reduce congestion. However, the system was application-specific and did not address broader resource management challenges. The present study extends the use of IoT beyond a single application by integrating multiple functionalities such as environmental monitoring, lighting control, and energy optimization within a unified framework.

Antonescu et al. (2020) discussed the concept of smart campuses through the integration of IoT devices, emphasizing the importance of interconnected systems for improving operational efficiency. Their research highlighted the benefits of combining different subsystems, but it lacked practical implementation details and cost considerations. The proposed system overcomes this gap by presenting a low-cost, hardware-based prototype that demonstrates real-time functionality and practical feasibility.
Verma et al. (2023) implemented a sensor-based automation system for controlling lighting and appliances using predefined threshold conditions. Although their system was simple and easy to implement, it lacked scalability and flexibility for larger environments. This issue is addressed in the current work by incorporating cloud-based monitoring and modular design, allowing the system to be expanded for larger campus deployments.

Alam et al. (2024) explored machine learning-based smart building systems for predictive energy management. Their approach improved efficiency through data-driven decision-making but introduced higher computational requirements and system complexity. In contrast, the proposed system adopts a simpler rule-based control mechanism combined with real-time sensing, ensuring reliable performance without the need for intensive computation.

III. AIM AND OBJECTIVE

Aim

Our main goal is to create an Internet of Things-based campus management system. This system will help us manage our resources better and make our campus more sustainable. We want to use the Internet of Things to make our campus more efficient and comfortable. We will use sensors and other devices to monitor the environment and make sure everything is working properly.

Objective

The primary aim of this research is to design and develop an efficient IoT-based smart campus management system that improves energy utilization and supports sustainable operations. The specific objectives of the study are as follows:

1. Reduce energy consumption across campus facilities
The system aims to minimize unnecessary usage of electrical devices by implementing automated control strategies based on real-time environmental conditions and occupancy.

2. Develop a real-time environmental monitoring system
The project focuses on continuously tracking parameters such as temperature, humidity, air quality, and human presence using multiple sensors.

3. Implement intelligent automation using sensor data
The system is designed to automatically control devices like lighting and ventilation based on inputs from sensors, thereby reducing manual intervention and improving efficiency.

4. Enhance user comfort within campus environments
By maintaining optimal temperature, air quality, and lighting conditions, the system ensures a comfortable and healthy environment for students and staff.

5. Integrate cloud-based monitoring and control
The use of an IoT platform enables remote access to real-time data, allowing users to monitor system performance and manually control devices when required.

6. Design a user-friendly interface for system interaction
The project includes the development of an intuitive dashboard that allows easy visualization of sensor data and control of connected devices.

7.Ensure accessibility and ease of use
The system is intended to be simple, reliable, and accessible to a wide range of users without requiring advanced technical knowledge.

8.Minimize energy wastage through occupancy-based control
Motion detection is used to ensure that electrical devices operate only when spaces are occupied, reducing unnecessary power consumption.

9.Support sustainable campus development
The system contributes to reducing the overall carbon footprint by optimizing energy usage and promoting environmentally responsible practices.

10.Develop a low-cost and scalable solution
The proposed system is designed to be economically feasible and adaptable for deployment across multiple buildings within a campus.

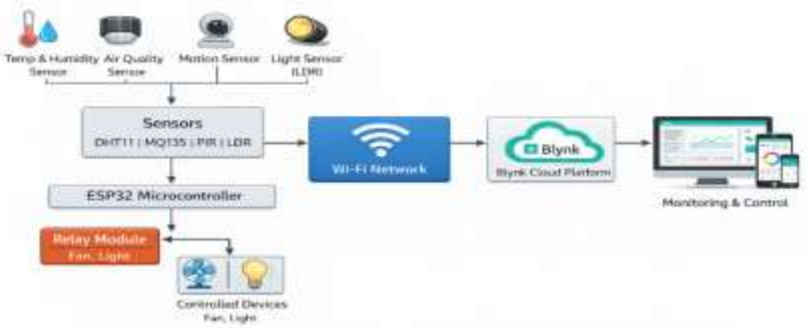

Figure 1: Block Diagram of IoT-Based Smart Campus Management System

IV. PROJECT REQUIREMENTS

Hardware Components

1. ESP32 Microcontroller

The ESP32 serves as the central processing unit of the system. It is a powerful microcontroller equipped with a dual-core processor and built-in Wi-Fi and Bluetooth capabilities. These features allow the device to handle multiple tasks simultaneously, including sensor data acquisition, data processing, and communication with cloud platforms.

In this project, the ESP32 reads input signals from all connected sensors through its GPIO pins and executes control logic based on predefined conditions. It also transmits real-time data to the cloud dashboard for remote monitoring. The use of ESP32 eliminates the need for additional communication modules, making the system more compact, cost-effective, and efficient.

2. DHT11 Temperature and Humidity Sensor

The DHT11 sensor is used to measure ambient temperature and relative humidity within the campus environment. It provides digital output, which simplifies data acquisition and reduces the need for complex signal conditioning.

In the proposed system, temperature readings are used to control the operation of cooling devices such as fans. When the temperature exceeds a predefined threshold, the system activates the corresponding relay to maintain a comfortable indoor environment. Humidity data further helps in understanding environmental conditions and ensuring occupant comfort.

3. MQ-135 Air Quality Sensor

The MQ-135 sensor is responsible for monitoring indoor air quality by detecting the presence of gases such as carbon dioxide, ammonia, and other pollutants. It outputs an analog signal that is converted into digital form using the ADC of the ESP32.

This sensor plays a crucial role in maintaining a healthy environment. When the detected air quality level crosses a specified limit, the system automatically triggers ventilation mechanisms through relay control. This helps in improving air circulation and reducing the impact of harmful gases in enclosed spaces.

4. PIR Motion Sensor

The Passive Infrared (PIR) sensor is used to detect human presence by sensing variations in infrared radiation within its range. It provides a digital output signal indicating motion detection.

In this system, the PIR sensor is primarily used for occupancy-based lighting control. When movement is detected, the system switches ON the lights automatically. If no motion is detected for a certain period, the lights are turned OFF to avoid unnecessary energy consumption. This significantly contributes to energy conservation.

5. LDR (Light Dependent Resistor) Module

The LDR module is used to measure ambient light intensity. It helps in determining whether a space is naturally illuminated or requires artificial lighting.

By combining LDR data with PIR sensor input, the system ensures that lights are turned ON only when both motion is detected and the surrounding environment is dark. This dual-condition logic further improves energy efficiency by preventing unnecessary usage of lighting during daytime.

6. Relay Module (4-Channel)

A 4-channel relay module is used to interface low-voltage control signals from the ESP32 with higher voltage electrical appliances. Each relay acts as an electrically operated switch, allowing safe control of devices such as lights and fans.

In the proposed setup, relays are used to control a DC bulb and a fan, representing lighting and ventilation loads. The relay module provides electrical isolation between the control circuit and load circuit, ensuring safety and reliability during operation. Additional relay channels are available for future expansion.

7. Power Supply System

The system is powered using a 12V battery, which provides energy to the relay module and connected loads such as the fan and bulb. A regulated power supply is used to step down the voltage to suitable levels (5V and 3.3V) required for the ESP32 and sensors.

Proper voltage regulation ensures stable operation of all components and protects them from damage due to voltage fluctuations. The use of a battery backup also enables uninterrupted operation during power outages.

8. Connecting Components and Supporting Hardware

Additional components such as breadboards, jumper wires, and voltage regulators are used to establish proper electrical connections between all modules. A common grounding system is maintained to ensure accurate signal transmission and stable system performance.

These supporting components, although simple, are essential for organizing the circuit, simplifying assembly, and enabling easy troubleshooting during system development and testing.

Software Components

1. Arduino IDE

The firmware for the ESP32 microcontroller is developed using the Arduino Integrated Development Environment (IDE). This platform provides a simple and flexible interface for writing, compiling, and uploading code to the microcontroller.

The Arduino IDE supports the ESP32 through dedicated libraries, allowing easy configuration of Wi-Fi connectivity, sensor interfacing, and GPIO control. It also offers a wide range of built-in and third-party libraries, which simplifies the integration of sensors such as DHT11, MQ-135, and PIR. The use of Arduino IDE makes the development process efficient and accessible, even for users with limited programming experience.

2. Embedded C / Arduino Programming

The system logic is implemented using Embedded C through the Arduino framework. The program is structured around a continuous execution loop that performs three primary tasks: reading sensor data, processing conditions, and controlling output devices.

Sensor readings are collected at regular intervals and compared against predefined threshold values. Based on these conditions, the program decides whether to activate or deactivate connected appliances through relay control. The code also includes timing functions to manage delays, avoid rapid switching, and ensure stable system behavior. This approach ensures reliable and real-time automation without the need for complex algorithms

3. Blynk IoT Platform

The Blynk IoT platform is used to enable cloud connectivity and remote monitoring of the system. It acts as an interface between the ESP32 hardware and the end user by providing a mobile-based dashboard.

Sensor data such as temperature, humidity, air quality, and motion status is transmitted from the ESP32 to the Blynk cloud using Wi-Fi communication. The platform displays this data in real time using widgets such as gauges, graphs, and indicators. Users can also send commands from the mobile application to control devices manually, allowing flexibility in system operation.

4. Wi-Fi Communication Protocol

Wireless communication is a key component of the system, enabling data exchange between the ESP32 and the cloud platform. The ESP32 connects to a local Wi-Fi network and uses standard communication protocols to transmit sensor data and receive control commands.

This wireless setup allows real-time monitoring without the need for physical connections, making the system more flexible and scalable. It also supports remote access, enabling users to monitor and control the system from any location.

5. Data Logging and Storage (JSON Format)

The system includes a data logging mechanism to store sensor readings for future analysis. Sensor data is formatted into a structured format such as JSON (JavaScript Object Notation), which allows easy storage and retrieval.

Data can be stored locally within the ESP32 memory or transmitted to the cloud for long-term storage. This feature enables the analysis of historical trends, helping in understanding usage patterns and improving system efficiency over time.

7. Dashboard Interface Design

A user-friendly dashboard is created within the Blynk application to display real-time system data. The interface includes visual elements such as gauges for temperature, indicators for humidity, and graphs for air quality trends.

The dashboard is designed to be intuitive and easy to use, allowing users to quickly understand system status and interact with connected devices. Notification features can also be included to alert users when certain parameters exceed safe limits

V.RESULT AND DISCUSSION

The proposed IoT-based smart campus management system was implemented and evaluated under different environmental conditions to assess its performance and reliability. The system successfully performed real-time monitoring by collecting data from temperature, humidity, air quality, and motion sensors. The ESP32 microcontroller processed this data efficiently and controlled connected devices through the relay module with a response time of less than one second. The temperature-based control mechanism operated effectively, where the fan was automatically activated when the temperature exceeded the predefined limit and turned OFF when conditions normalized. Similarly, the occupancy-based lighting system functioned accurately using the PIR sensor, ensuring that lights were switched ON only when motion was detected. The addition of the LDR module further improved efficiency by allowing lighting control based on ambient light conditions, thereby avoiding unnecessary energy consumption during daylight hours. The system also demonstrated stable communication with the cloud platform, enabling continuous monitoring and remote access through a user-friendly dashboard.

The air quality monitoring feature provided valuable insights into indoor environmental conditions, with the system responding appropriately when pollutant levels increased by activating ventilation mechanisms. The integration of cloud-based monitoring allowed users to observe real-time data and manually control appliances when required, adding flexibility to the system. From an energy efficiency perspective, the automated control strategies significantly reduced unnecessary power usage, achieving an estimated energy saving of approximately 20–30% compared to conventional systems. Although minor limitations such as sensor stabilization time and occasional false motion detection were observed, these did not significantly affect overall performance. The results indicate that the developed system is reliable, cost-effective, and suitable for smart campus applications, offering an efficient solution for energy management and environmental monitoring while contributing to sustainable development.

VI. CONCLUSION

This study presents the design and implementation of an IoT-based smart campus management system for improving energy efficiency and environmental monitoring. The system successfully integrates sensors with an ESP32 microcontroller to monitor temperature, humidity, air quality, and occupancy in real time, and automatically controls electrical devices based on these conditions. The results demonstrate reliable performance, quick response, and effective reduction in unnecessary energy consumption.

The use of cloud-based monitoring enables remote access and improves system usability, while occupancy-based and condition-based control strategies help optimize resource utilization. Overall, the proposed system offers a cost-effective and practical solution for developing sustainable and energy-efficient campus environments. With further improvements, it can be expanded for large-scale smart campus applications.

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