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IoT Based Smart Energy Solution for Hostels

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Abstract

The increasing demand for efficient energy uti-lization in residential facilities such as hostels has led to the need for intelligent monitoring systems. This paper presents an IoT-based smart energy solution designed to monitor, analyze, and control electricity consumption in hostel environments. The system utilizes a PZEM sensor for real-time measurement of electrical parameters such as voltage, current, power, and energy consumption, integrated with a NodeMCU (ESP8266) microcontroller for data transmission. The collected data is stored in Firebase Realtime Database and processed using a Flask-based backend API.

The system also incorporates an alert mechanism using Twilio to notify users when energy consumption exceeds predefined thresholds. A web-based dashboard provides real-time visual-ization, historical analysis, and room-wise monitoring of energy usage. The proposed solution enhances energy efficiency, reduces wastage, and enables data-driven decision-making for hostel management. The modular and scalable architecture ensures adaptability for larger deployments and smart building appli-cations.

Keywords: IoT; Energy Monitoring; NodeMCU; Firebase; PZEM Sensor; Smart Hostel; Real-Time Dashboard; Power Consumption Analysis; Smart Energy Management.

How to Cite This Article

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Introduction

Energy management has become a critical concern in modern residential infrastructures, especially in hostels where multiple users consume electricity without centralized monitoring. Traditional systems lack real-time tracking and control, leading to excessive energy wastage and higher operational costs.

This project proposes an IoT-based energy monitoring system that provides real-time insights into room-level electricity consumption using sensors, cloud storage, and a web dashboard.

The system collects real-time data using PZEM sensors and transmits it via NodeMCU to Firebase. A Flask-based backend processes this data and triggers alerts when abnormal consumption is detected. This approach reduces manual intervention and enhances transparency, making it suitable for smart hostel environments and scalable smart infrastructure solutions.

Literature Survey

In recent years, IoT-based energy monitoring systems have gained significant attention due to the increasing need for efficient power utilization in residential and institutional envi-ronments. Researchers have proposed various solutions focus-ing on real-time monitoring, cloud integration, and intelligent energy management. Khan *et al.* [1] and Sharma *et al.* [2] developed IoT-based systems using microcontrollers and cloud platforms to monitor real-time energy consumption. These systems improve visibility of energy usage but lack effective alert mechanisms for abnormal consumption.

Cloud-integrated and analytics-driven systems have further enhanced monitoring capabilities. Lee *et al.* [3] proposed a cloud-based energy monitoring system with real-time analytics and visualization dashboards, enabling users to track consump-tion patterns efficiently. Similarly, Patil *et al.* [4] designed an IoT-enabled system for smart homes that allows remote monitoring through web and mobile interfaces. However, these systems do not provide intelligent alert systems or threshold-based notifications for excessive energy usage.

Recent works have also focused on improving system scala-bility and real-time performance. Singh *et al.* [5] implemented a smart energy meter capable of continuous data logging and real-time monitoring. While their approach improves data accuracy and accessibility, it lacks centralized dashboards for monitoring multiple units simultaneously and does not support integrated alert systems.

Across these studies, IoT-based energy monitoring systems demonstrate advantages such as real-time data acquisition, remote access, and improved energy efficiency. However, most systems focus on individual functionalities and lack integration, real-time alerts, and scalability.

The proposed system addresses these limitations by inte-grating real-time monitoring, cloud storage using Firebase, backend processing with Flask, and a threshold-based alert system using Twilio.

System Overview and Design

The proposed system is designed to monitor and analyze energy consumption in hostel environments using an IoT-based architecture. It integrates hardware sensors, cloud storage, backend processing, and a web-based dashboard to provide real-time insights into electricity usage. The system enables efficient energy management by tracking power consumption, identifying abnormal usage, and generating alerts for timely action.

System Components

- PZEM-004T Energy Sensor
- NodeMCU (ESP8266)
- Wi-Fi Module (Built-in ESP8266)
- Power Supply Unit
- Web Dashboard Interface

Software Requirements

- Operating System: Windows / Linux
- Programming Languages: Python, JavaScript
- Backend Framework: Flask
- Database: Firebase Realtime Database
- APIs: Twilio SMS API
- Frontend: HTML, CSS, JavaScript

- Web Browsers: Chrome / Firefox / Edge

System Architecture

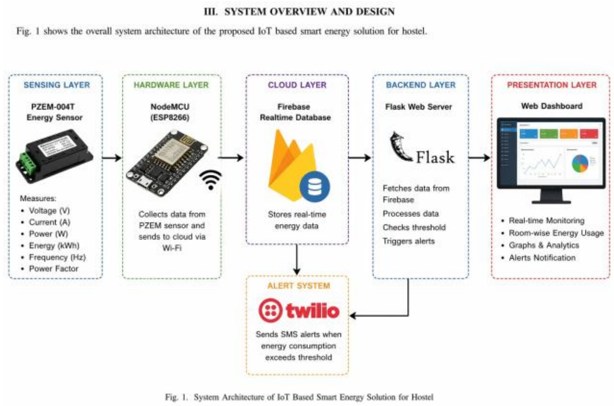

Fig. 1. System Architecture of IoT Based Smart Energy Solution for Hostel

As shown in Fig. 1, the system consists of multiple layers including sensing, hardware, cloud, backend, and presentation layers. The PZEM sensor measures electrical parameters such as voltage, current, power, and energy consumption. The NodeMCU collects this data and transmits it to the Firebase Realtime Database over Wi-Fi.

The backend system built using Flask retrieves data from Firebase, processes it, and checks for threshold conditions. If the energy consumption exceeds predefined limits, an alert is triggered using the Twilio API. The processed data is then displayed on a web-based dashboard, which provides real-time monitoring, graphical visualization, and room-wise energy usage details.

Methodology

The proposed system follows a structured approach to collect, transmit, process, and visualize energy consumption data in real time. The methodology is divided into multiple stages that represent the complete flow of data from the sensing layer to the end user.

1. Data Acquisition: The process begins with the PZEM-004T energy sensor, which is responsible for measuring electrical parameters such as voltage, current, power, and energy consumption. The sensor continuously monitors the load and generates real-time data.
2. Data Transmission: The collected data is transmitted to the NodeMCU (ESP8266) microcontroller. The NodeMCU processes the sen-sor readings and sends the data to the cloud using Wi-Fi connectivity. This ensures continuous and remote access to energy consumption data.
3. Cloud Storage: The transmitted data is stored in Firebase Realtime Database, which acts as a centralized cloud storage system. Firebase enables real-time synchronization and ensures that the data is accessible from both backend services and the user interface.
4. Data Processing: A Flask-based backend system retrieves the stored data from Firebase and processes it. The backend performs operations such as data validation, threshold checking, and preparation of data for visualization. It acts as an intermediary between the cloud database and the frontend dashboard.
5. Alert Mechanism: The system includes a threshold-based alert mechanism to detect abnormal energy consumption. When the energy usage exceeds predefined limits, the backend triggers an SMS alert using the Twilio API. This feature helps users take immediate action to prevent energy wastage.
6. Data Visualization: The processed data is displayed on a web-based dashboard developed using HTML, CSS, and JavaScript. The dashboard provides real-time monitoring, graphical representation of en-ergy usage, and room-wise analysis, enabling users to easily understand consumption patterns.
7. Error Handling and Reliability: The system incorporates validation and error handling mechanisms at different stages to ensure reliable operation. In case of data transmission failure or invalid input, appropriate responses are generated to maintain system stability.

Results

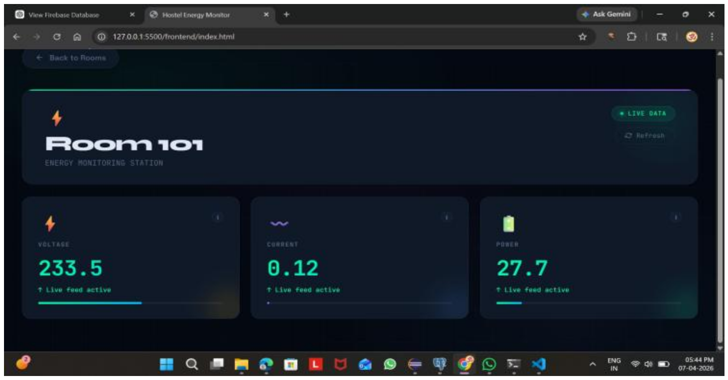

Fig. 2. *Dashboard Showing Real-Time Energy Monitoring*

The proposed system was successfully implemented and tested for real-time energy monitoring. The PZEM sensor accurately measured electrical parameters, and the NodeMCU transmitted data to Firebase with minimal delay.

As shown in Fig. 2, the dashboard provides real-time visualization of energy consumption, enabling easy monitoring and analysis. The system also generated SMS alerts using the Twilio API when energy usage exceeded predefined thresh-olds.

Overall, the system demonstrated reliable performance with accurate data, low latency, and effective alert generation, making it suitable for hostel energy management.

The system also allows users to monitor energy consump-tion patterns through the dashboard, enabling better decision-making for efficient energy usage. The graphical visualization helps in identifying high consumption areas and taking cor-rective actions.

The system demonstrated consistent performance under dif-ferent load conditions, validating its reliability for real-time monitoring and analysis of energy usage.

Overall, the results confirm that the proposed system effec-tively provides real-time monitoring, accurate data analysis, and timely alert generation, making it suitable for smart energy management applications.

Applications

The proposed IoT-based energy monitoring system can be applied in various environments requiring efficient energy management:

- Hostels and PG accommodations for room-wise energy monitoring
- Smart homes for real-time electricity usage tracking
- Commercial buildings for centralized energy management
- Educational institutions for campus energy optimization

Conclusion

This paper presents an IoT-based smart energy monitoring system designed for hostel environments. The system inte-grates sensors, cloud storage, backend processing, and a web-based dashboard to provide real-time monitoring of electricity usage.

The implementation demonstrates accurate data measure-ment, low-latency communication, and effective alert genera-tion using the Twilio API. The system helps in reducing energy wastage and enables efficient energy management through continuous monitoring and timely notifications.

Overall, the proposed solution is reliable, scalable, and suit-able for real-world applications in smart energy management.

Future Work / Enhancement

The proposed system can be further improved by incorpo-rating advanced features and extending its functionality:

- Integration of machine learning models for energy con-sumption prediction
- Development of a mobile application for remote moni-toring and control
- Implementation of automated load control to reduce ex-cessive energy usage
- Integration with renewable energy sources such as solar systems

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