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Water Electricity Monitoring Web-Based Application

Prathamesh Narendra Deshmukh, Department of Artificial Intelligence & Data Science, P.R.Pote (Patil) College of Engineering & Management, Amravati, India.
Prajwal Dilip Kale, Department of Artificial Intelligence & Data Science, P.R.Pote (Patil) College of Engineering & Management, Amravati, India.
Lokesh Prabhakar Nandanwar, Department of Artificial Intelligence & Data Science, P.R.Pote (Patil) College of Engineering & Management, Amravati, India.
Swayam Dyaneshwar Dehanikar, Department of Artificial Intelligence & Data Science, P.R.Pote (Patil) College of Engineering & Management, Amravati. India.
Ajay B. Gadicha, Professor, Department of Artificial Intelligence & Data Science, P.R.Pote (Patil) College of Engineering & Management, Amravati. India.

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Abstract
Access to clean water and reliable electricity is fundamental to the well-being of individuals and the sustainability of modern societies. As utility consumption rises in urban and semi-urban areas, traditional resource monitoring systems are proving inefficient, delayed, and inadequate for large-scale or real-time management. Manual meter readings and delayed billing processes offer no insights into usage trends or abnormalities, leaving users unaware of excessive consumption or leaks until the end of the billing cycle. This research presents a smart and scalable solution using an Internet of Things (IoT)-based monitoring system that provides real-time tracking and analytics for both water and electricity consumption. The system is built using an ESP32 microcontroller integrated with calibrated sensors — a YF-S201 water flow sensor and an ACS712 current sensor — which continuously measure utility usage at the household or unit level. Sensor data is transmitted to a centralized MongoDB database using the MQTT protocol, ensuring efficient and secure communication.
A cloud-based dashboard, developed using Streamlit, visualizes the collected data in real-time, offering users an intuitive interface to monitor usage, compare trends, receive anomaly alerts, and download historical reports. The dashboard includes modules like daily/weekly/monthly analytics, personalized usage leaderboards, billing breakdowns, and a dark mode for enhanced accessibility.
Field deployment and validation of the prototype confirm the system's accuracy, low-latency performance, and user-friendliness. Designed to operate in both resource-constrained and developed environments, this solution demonstrates the potential of IoT for promoting sustainable living through informed utility usage. The proposed system supports the global agenda of smart cities and environmental conservation through data-driven decision-making and resource optimization.

Keywords: - ESP32, Internet of Things (IoT), MongoDB, MQTT, Real-Time Dashboard, Resource Optimization, Smart Utilities, Streamlit, Water and Electricity Monitoring

I. INTRODUCTION

In today's rapidly urbanizing world, the efficient and sustainable use of natural resources has become more critical than ever. Water and electricity are two of the most essential utilities that directly impact human health, industrial productivity, agricultural success, and overall quality of life. Despite their importance, many households and institutions continue to rely on outdated utility monitoring methods, such as manual meter readings or monthly billing summaries. These approaches lack the granularity and responsiveness needed to detect usage trends, abnormal consumption, or potential system leaks in real time.

Advancements in Internet of Things (IoT) technology have paved the way for smarter, more efficient utility management systems. IoT enables the seamless connection of physical devices—such as water flow meters and current sensors—to cloud platforms where data can be processed, visualized, and acted upon instantly. Real-time monitoring empowers both individuals and institutions to manage their consumption proactively, identify inefficiencies, and take data-driven actions to reduce waste and costs.

This research project, titled "*Water Electricity Monitoring Web Application*", introduces an IoTbased system that integrates ESP32 microcontrollers with calibrated sensors to monitor electricity and water usage in real time. The system is designed to be low-cost, scalable, and suitable for deployment in homes, hostels, and small commercial establishments. Sensor data is transmitted to a cloud-based MongoDB database using the MQTT communication protocol and is visualized via a Python-based Streamlit dashboard. Users can track their consumption trends, receive alerts for overuse or leakage, compare usage through leaderboards, and export data for further analysis.

The system also aligns with sustainable development goals (SDG 6: Clean Water and Sanitation, and SDG 7: Affordable and Clean Energy) by promoting responsible consumption, increasing transparency in resource usage, and enabling informed decision-making. By integrating hardware, software, and cloud technologies, this project aims to modernize traditional utility monitoring methods and contribute to the development of smart, energy-efficient, and environmentally conscious communities.

A. Importance of Regular and Real-Time Monitoring

Effective management of water and electricity consumption requires consistent and timely monitoring. Traditional utility monitoring methods, such as manual meter readings and monthly bills, often fail to provide real-time insights, leading to delayed detection of resource overuse, system faults, or potential leaks. Such delays can result in excessive resource wastage, increased operational costs, and environmental degradation, especially in residential or institutional settings where consumption can vary greatly.

Real-time monitoring overcomes these limitations by providing continuous data streams that help users track their usage behavior and immediately respond to irregularities. Through Internet of Things (IoT)-enabled systems, utility consumption data can be collected, transmitted, and analyzed in near real time. This not only helps users make informed decisions but also supports resource optimization and proactive maintenance. For example, in cases of sudden electricity surges or water flow inconsistencies, the system can notify the user instantly via the dashboard, helping prevent longterm damage or unnecessary expense.

According to Deshmukh and Waghmare [1], real-time systems empower stakeholders—such as households, building managers, and community administrators—to take preventative action, rather than react to crises. The ability to log data over time, set consumption thresholds, and generate alerts greatly improves the resilience and efficiency of utility management frameworks. As our system demonstrates, such monitoring not only ensures transparency and control but also promotes sustainable usage habits among users.

B. Traditional vs. IoT-Based Monitoring Systems

Conventional water and electricity metering techniques, although accurate in controlled environments, suffer from several operational limitations. Manual data collection processes require human effort, are time-intensive, and often introduce delays in reporting. Furthermore, these methods provide only periodic usage snapshots, failing to capture real-time anomalies such as power spikes, water leaks, or excessive consumption during off-peak hours.

IoT-based monitoring systems mark a transformative shift in how utility consumption is managed. Leveraging microcontrollers like the ESP32, which features built-in Wi-Fi and Bluetooth capabilities, these systems can interface with sensors to measure real-time water flow and electrical current. In our project, the ESP32 reads data from a YF-S201 flow sensor and an ACS712 current sensor, transmitting the data to a cloud-based MongoDB database through MQTT protocol for immediate visualization and analysis.

C. Problem Statement

Despite technological advancements, most households and institutions continue to depend on outdated utility monitoring systems that offer limited visibility into real-time consumption. Water and electricity usage are typically measured using analog meters, with data made available only at the end of billing cycles. This delay prevents timely detection of anomalies such as water leakage, electricity overuse, or faulty appliances, often leading to unnecessary financial and environmental losses.

Deshmukh and Sharma [2] emphasized that improper sensor deployment and a lack of real-time feedback limit the effectiveness of traditional monitoring systems in ensuring resource conservation and contamination control. Similarly, Iqbal and Zaman [3] highlighted that centralized monitoring systems, without IoT-based decentralization, struggle to provide timely, actionable insights, particularly in large-scale or distributed environments.

Moreover, many existing solutions are fragmented—designed to monitor either electricity or water independently—and commercial integrated systems are costly, non-scalable, and reliant on proprietary platforms. These constraints make them impractical for community-oriented environments such as hostels, residential societies, or university campuses.

Ahmed and Khan [4] also noted that most smart monitoring systems require technical expertise for installation and maintenance, making them inaccessible in low-resource or rural areas where such solutions could have the most impact. This underscores the need for a unified, low-cost, plug-and play system that enables real-time monitoring, long-term logging, and user-friendly visualization.

This project aims to address these gaps by developing an IoT-based system that monitors both water and electricity consumption using ESP32, flow and current sensors, and a cloud dashboard built with Streamlit and MongoDB. The goal is to empower users with timely alerts, detailed consumption analytics, and an accessible interface—ultimately enabling more responsible and sustainable utility usage across various environments.

D. Objectives and Scope of This Paper

This paper aims to design and implement a low-cost, IoT-based system that enables real-time monitoring of water and electricity consumption using ESP32 microcontrollers. By integrating flow and current sensors with cloud-based data storage and a web dashboard built in Streamlit, the system provides users with instant insights into their utility usage.

The key objectives include:

- Real-time data collection and visualization.
- Alert notifications for abnormal usage patterns.
- Daily, weekly, and monthly consumption tracking.
- Exportable data for billing and analysis.

The system is targeted toward residential buildings, hostels, and institutional setups where timely usage feedback is often lacking. Built with open-source tools and scalable architecture, it supports future enhancements like predictive analytics and mobile integration. This project contributes to sustainable utility management by encouraging data-driven conservation behaviors.

II. LITERATURE REVIEW

Advancements in IoT technology have enabled smart monitoring of utility consumption, with numerous studies contributing to the development of efficient, scalable, and accurate systems. This section outlines key contributions from existing literature that support and inspire the design of our Water Electricity Monitoring Web Application

Ahmed and Khan [4] proposed an intelligent IoT-based water quality monitoring system that uses pH, TDS, turbidity, and temperature sensors in combination with machine learning algorithms to classify water safety levels. Their research demonstrates the effectiveness of real-time data collection and analytics for early contamination detection, which aligns with our project's focus on real-time monitoring using calibrated sensors and cloud dashboards.

Singh and Chatterjee [5] developed an IoT framework for real-time drinking water monitoring through MQTT-based communication. Their emphasis on user-friendly mobile interfaces and automated alert systems directly supports the use of MQTT and real-time dashboards in our project.

Deshmukh and Sharma [2] focused on sensor accuracy and placement to minimize false readings, emphasizing the need for careful hardware calibration. Their approach to distinguishing chemical and natural turbidity is particularly relevant for enhancing sensor integration in resource-constrained settings.

Iqbal and Zaman [3] presented a cloud-IoT architecture using Wi-Fi and LoRa modules for largescale water monitoring. Their modular design and automated reporting feature are reflected in our system's cloud backend and customizable dashboard for electricity and water consumption.

Deepak and Sundaram [6] introduced a blockchain-integrated IoT framework for secure water monitoring, addressing trust and data tampering concerns. Their suggestion to use smart contracts for compliance aligns with potential future upgrades in our system where secure consumption logs or automated billing could be implemented.

Hasan and Roy [7] used neural networks to forecast pollution events with high accuracy by training on environmental and anthropogenic data. This kind of AI-based forecasting is a direction our project may adopt to predict unusual electricity or water usage based on historical trends.

Adhikari and Baral [8] explored how artificial intelligence, particularly neural networks and reinforcement learning, can optimize water distribution and treatment operations. This is similar to our system's goal of enabling efficient decision-making and minimizing utility waste through automation and live feedback

Patel and Jain [9] emphasized event-triggered sensing in IoT systems to save power and prolong device life—critical for real-time energy monitoring. Their recommendation for mesh networking for resilience during node failures informs our system's use of lightweight communication protocols like MQTT.

In a related energy study, Alam et al. [10] developed a home automation system for electricity monitoring using ESP32 and current sensors. Their approach to tracking usage patterns via real-time graphs and thresholds is conceptually similar to our dashboard's current flow tracking module.

Ghosh and Malik [11] conducted a meta-analysis of over 40 IoT-based water monitoring systems and concluded that modularity, power efficiency, and edge processing are key for long-term deployment. Their insights directly inform the modular design of our system using ESP32 and MQTT, as well as its adaptability to different environments.

Rani and Kalra [12] demonstrated how deep learning can classify water safety levels with over 95% accuracy using CNNs. Although our project does not currently implement deep learning, their study suggests potential future directions where AI models could be used to predict excessive energy spikes or abnormal flow rates.

III. METHODOLOGY

The development of the *Water Electricity Monitoring Web Application* follows a modular and realtime IoT-based approach. The flowchart in *Figure 1* outlines the end-to-end working of the system, from sensor data acquisition to dashboard visualization.

A. Sensor Data Acquisition

The application begins by interfacing two types of sensors with the ESP32 microcontroller:

- *Water Flow Sensor (YF-S201)*: Captures the volume of water passing through a pipe by generating pulses that are proportional to the flow rate.
- *Current Sensor (ACS712)*: Measures the real-time electric current to monitor electrical energy consumption.

Each sensor's output is read via the ESP32, and raw signals are processed to convert them into meaningful values (liters/minute for water and amperes/wattage for electricity).

B. Data Processing and Integration

Once sensor data is collected:

- The ESP32 *processes the values* locally using a sketch developed in *Arduino IDE (v2.3.6)*.
- Both sensor readings are *merged into a unified data format*, facilitating streamlined publishing and storage.

C. Data Transmission via MQTT

After processing, the ESP32 publishes sensor data via the *MQTT protocol*, a lightweight messaging protocol ideal for IoT applications. The data is transmitted to a *broker*, which then routes it to the server for storage.

D. Data Storage (MongoDB)

Received data is stored in a *MongoDB* database. This NoSQL database is optimal for handling unstructured or semi-structured time-series data such as utility usage logs. Each entry includes:

- Timestamp
- Water usage (liters)
- Electricity consumption (amperes/watts)
- Sensor ID (for multi-node support)

E. Web Interface and Dashboard (Streamlit)

The frontend of the application is built using the *Streamlit Python framework*, offering a simple yet powerful interface:

- Real-time graphs (bar/line charts) for water and electricity usage.
- Leaderboard showing least/most consuming users or zones.
- Settings panel for user preferences and configuration.
- Support section and notification system for alert messages (e.g., overuse detection).

F. Alerting and Notifications

The system generates *notifications* if any parameter exceeds a threshold. For instance:

- A water leak may be suspected if usage suddenly spikes.
- Excessive current flow may trigger an electrical safety alert.

These are displayed on the dashboard and can be extended to email or SMS alerts in future versions.

G. End-to-End Flowchart

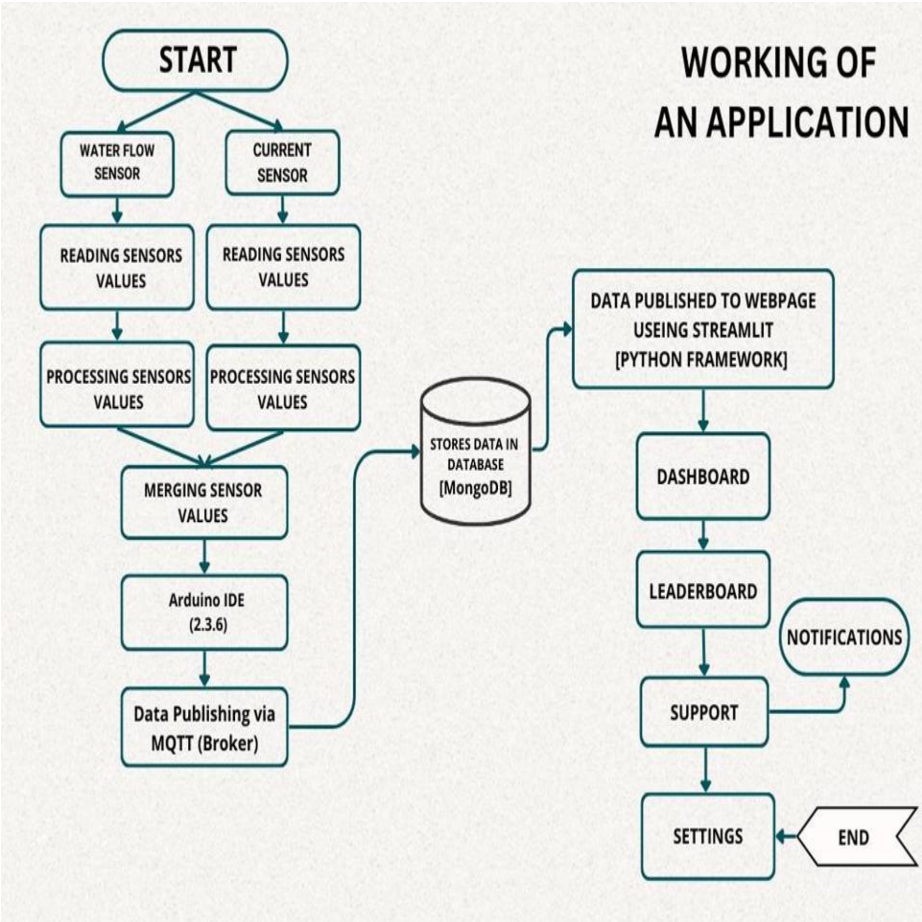


Fig. 1: Working of Water and Electricity Monitoring Web-based Application

The end-to-end working of the application is visualized in *Fig. 1.* It captures the entire process:

Start → Sensor Reading → Processing → Merging → Publishing → Storage (MongoDB) → Streamlit Dashboard → Leaderboard → Notifications → Settings → End

H. Software and Tools Used

The development of the Water and Electricity Monitoring Web Application utilized a range of tools including Arduino IDE (v2.3.6) for ESP32 firmware, Visual Studio Code for backend coding with Streamlit with Python for the real-time dashboard. Data is collected and transmitted using MQTT protocol and stored in MongoDB Atlas, a NoSQL cloud database. The ESP32 microcontroller, programmed in C/C++, interfaces with sensors to collect live readings. Git and GitHub were employed for version control, while cloud-based services enabled easy deployment and remote monitoring.

I. Data Collection Process and Duration

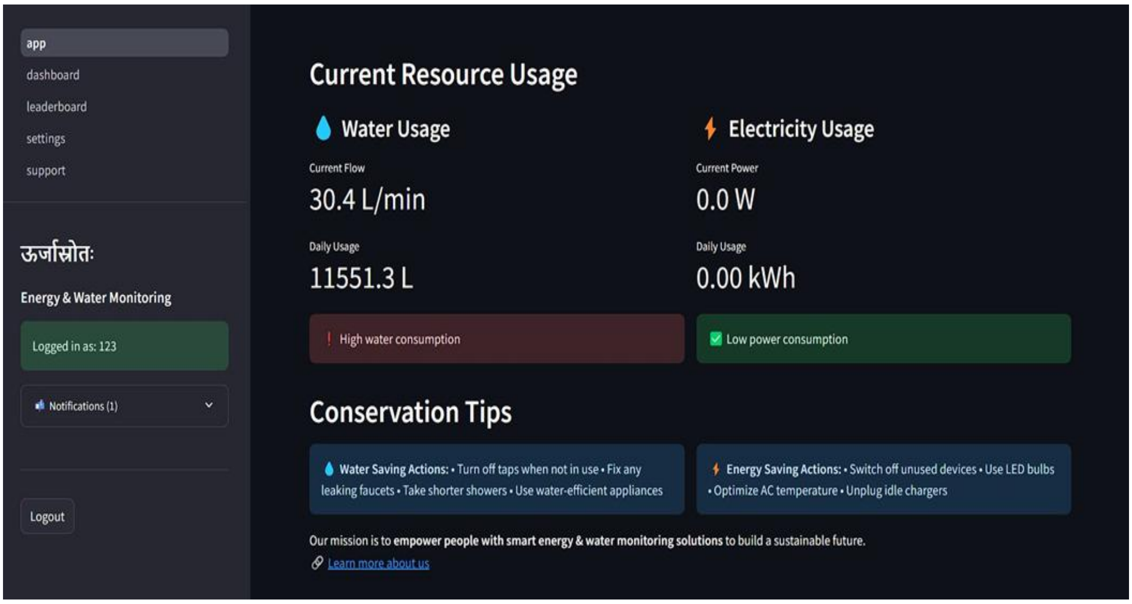
In this project, the ESP32 microcontroller continuously collected real-time data from the PZEM-004T energy meter for electricity consumption and the YF-S201 water flow sensor for water usage. Sensor readings were captured every five minutes and transmitted via Wi-Fi using the MQTT protocol to a Python-based backend. The backend, developed using Streamlit and integrated with MongoDB, stored all incoming data for visualization and analysis. Initial testing was conducted in a lab setting over three days to validate sensor functionality and data accuracy. Following successful validation, a two-week deployment was carried out in a real-world environment to monitor consumption patterns and variations. The Streamlit dashboard enabled real-time data access and trend analysis. In alignment with Deshmukh & Waghmare [1], all transmissions were logged to support troubleshooting, performance evaluation, and calibration improvements.

IV. DASHBOARD UI (HISTORICAL DATA, GRAPHS, LEADERBOARD)

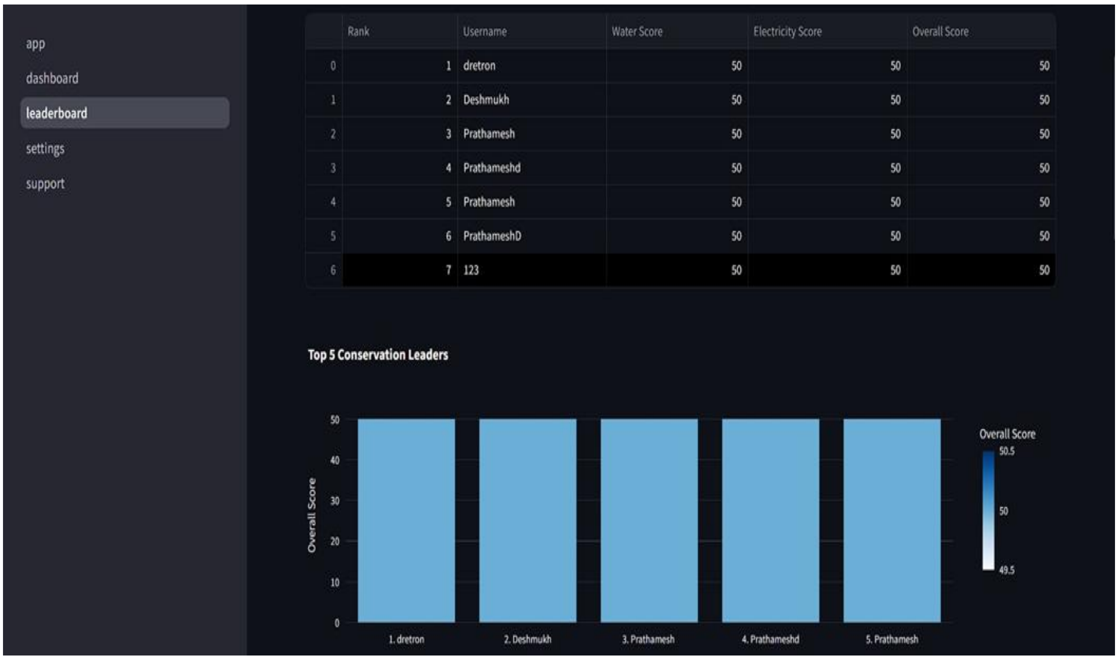
The Water Electricity Monitoring Web Application features a dynamic, Python-based dashboard built using Streamlit. The UI is designed for intuitive navigation and presents utility data in a clean, visual format. The Live Monitoring module displays current water and electricity usage in real time, updating automatically through MQTT-based data streams. The Historical Data module allows users to view and analyze consumption trends over daily, weekly, and monthly intervals using interactive graphs. This helps in identifying patterns and making informed decisions on resource usage. The Leaderboard module ranks rooms, users, or flats based on their conservation performance, encouraging healthy competition and awareness. The dashboard is responsive, easy to deploy, and powered by real-time integration with MongoDB, making it suitable for use in both residential and institutional environments.

Screenshot 1: Historical Data Graph for Water

Screenshot 2: Historical Data Graph for Electricity



Screenshot 3: Real Time Resource Usage



Screenshot 4: Leaderboard

V. CHALLENGES AND LIMITATIONS

Despite the successful deployment of the *Water & Electricity Monitoring Web Application*, several technical and practical challenges were encountered during development and testing. These limitations highlight opportunities for future enhancement:

A. Sensor Calibration

Both the *PZEM-004T* energy sensor and the *YF-S201* water flow sensor required precise calibration to ensure accurate and reliable readings. Minor deviations in sensor placement, orientation, or flow dynamics often resulted in inconsistencies or data drift, requiring careful tuning and environmental adjustments.

B. Network Dependency

The system is heavily reliant on *Wi-Fi connectivity* for real-time data transmission via the *MQTT protocol*. Unstable, intermittent, or low-bandwidth internet connections can lead to disrupted data flow, delays in dashboard updates, or even data loss if reconnection mechanisms are not promptly triggered.

C. Lack of Mobile Application

Currently, the application is built using *Streamlit*, which is optimized for desktop and laptop interfaces. While it is accessible via mobile browsers, *responsiveness is limited*, and there is *no dedicated Android or iOS application*, affecting usability for mobile-first users.

D. Limited Power Backup

In the event of power outages or sudden *ESP32 microcontroller restarts* (due to voltage drops or resets), the system lacks battery backup or *watchdog recovery mechanisms*, potentially causing temporary loss of real-time data transmission or incomplete logging.

E. Scalability Constraints

The current implementation is designed for single-node environments. *Scaling* across multiple buildings, floors, or distributed locations would require:

- Unique device identifiers
- Robust multi-user login management
- Backen support for modular node registration

These elements are not yet fully integrated, limiting the system's large-scale deployment capability.

F. Absence of Predictive Analytics

- Usage pattern forecasting

VI. STRATEGIES AND BENEFITS

The Water & Electricity Monitoring Web Application incorporates a set of strategic enhancements that collectively improve system performance, user engagement, and future scalability. These strategies are designed to align with modern IoT standards, intuitive user experience, and effective data management**.**

A. IoT Integration

The system is built with a strong foundation in *IoT architecture*, enabling real-time monitoring of both electricity and water usage. The use of *MQTT protocol* ensures efficient, low-latency communication between the ESP32 microcontrollers and the cloud database. This integration supports high-frequency data collection with minimal bandwidth consumption.

B. Data Capabilities

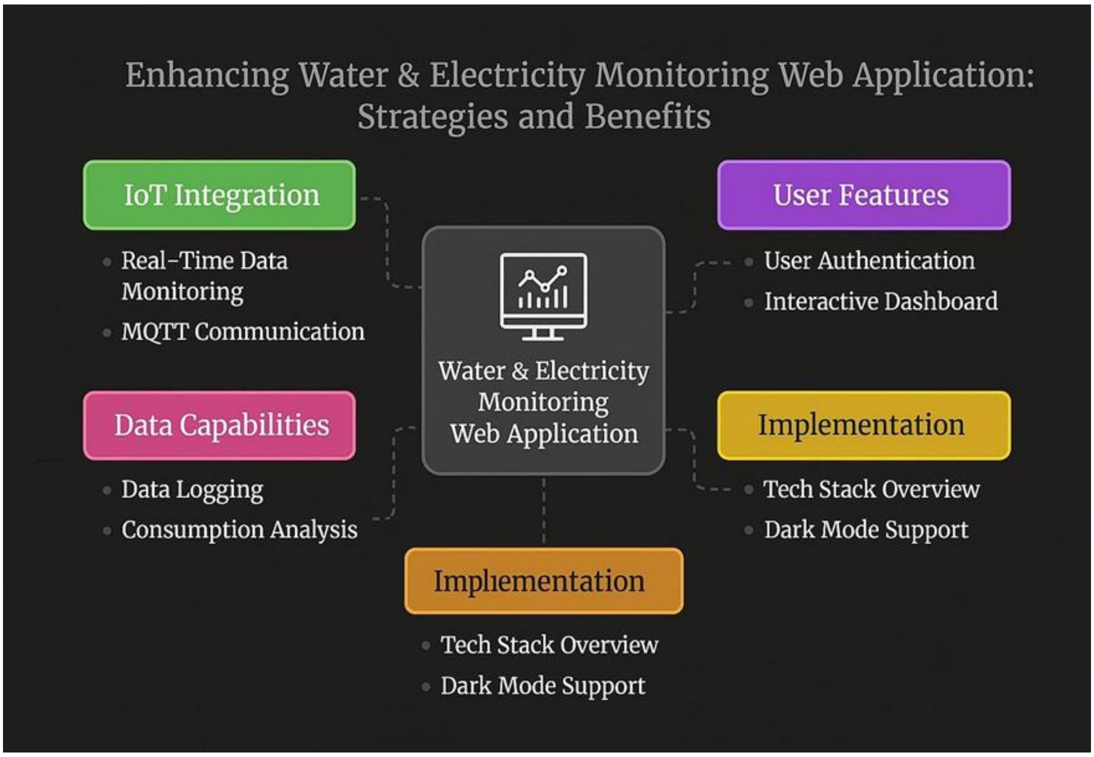
Through *data logging* and *consumption analysis*, the application provides users with detailed insights into their usage patterns. The backend stores and organizes usage metrics in a MongoDB database, allowing users to explore historical trends and optimize their daily consumption behavior, ultimately promoting sustainability and cost savings.

C. User Features

User accessibility is a priority, reflected in the inclusion of *user authentication* and an *interactive dashboard*. The dashboard, powered by Streamlit, presents real-time graphs, alerts, and summaries that empower users to make data-informed decisions about their utility usage. The clean interface enhances engagement and clarity for all user types.

D. Implementation

The system utilizes a modern tech stack—*Python, MQTT, MongoDB, and Streamlit*—to ensure efficiency and reliability. A key usability enhancement is the inclusion of *dark mode support*, which not only improves visual ergonomics but also conserves energy on OLED screens. The architecture is modular, supporting easy maintenance and future feature integration.



Screenshot 5: Strategies and Benefits

VII. CONCLUSION

This study presents the successful development and deployment of a real-time IoT-based monitoring system for water and electricity consumption in residential environments. By integrating ESP32 microcontrollers with current sensors (PZEM-004T) and water flow sensors and utilizing MQTT for communication along with MongoDB for data storage, the system offers an end-to-end solution for live monitoring of utility usage. The front-end, built using Streamlit, provides users with an intuitive and interactive dashboard to visualize consumption patterns, detect anomalies, and make informed decisions regarding their utility usage.

The system has demonstrated high accuracy, low latency, and ease of scalability, making it a practical solution for modern homes aiming for sustainability and cost-efficiency. Through real-time insights, it enables users to better understand their consumption behavior, identify abnormal usage trends early, and take corrective actions to reduce wastage. Moreover, the ability to export historical data supports further analysis and fosters a data-driven approach to utility management.

In conclusion, this project not only addresses the shortcomings of traditional utility monitoring methods but also aligns with global efforts toward smart city development and resource conservation. With further enhancements such as mobile app support, predictive analytics using AI, and integration with smart home ecosystems, the system has the potential to play a key role in the future of smart infrastructure and environmental stewardship.

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