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IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus

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ABSTRACT: Environmental sustainability has become a major concern for educational institutions due to increasing pollution levels, energy consumption, and climate change impacts. Traditional environmental monitoring systems lack real-time analytics and intelligent decision-making capabilities. This project proposes an IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus that enables real-time monitoring of environmental parameters such as temperature, humidity, air quality, and noise levels. Sensors are deployed across campus areas and connected to an ESP32 microcontroller for data acquisition and cloud transmission. The collected data is processed, analysed, and displayed on a smart dashboard that provides visual insights, anomaly alerts, and environmental trends. Threshold-based anomaly detection ensures early identification of abnormal environmental conditions. The system promotes energy efficiency, pollution control, and data-driven sustainability planning.

KEYWORDS: IoT, Environmental Monitoring, Smart Campus, ESP32, Real-Time Analytics, Smart Dashboard, Sustainable Development, Air Quality Monitoring, Threshold Detection, Cloud Integration.

I. INTRODUCTION

Environmental sustainability has become a critical concern in modern educational institutions due to increasing energy consumption, air pollution, and climate variability. University and college campuses function as small-scale urban environments where environmental conditions directly influence student health, academic performance, and overall well-being. Continuous monitoring of environmental parameters such as temperature, humidity, air quality, and noise levels is essential to maintain a safe and sustainable campus ecosystem.

Traditional environmental monitoring methods rely on manual inspection and periodic measurements, which are often inefficient, time-consuming, and incapable of providing real-time insights. The absence of continuous monitoring limits the ability of administrators to detect abnormal environmental conditions promptly and take corrective action. Therefore, there is a growing need for intelligent, automated systems capable of real-time environmental data acquisition and analysis. The advancement of Internet of Things (IoT) technology has enabled the development of distributed sensing systems that can collect, transmit, and process environmental data efficiently. By integrating low-cost sensors with microcontrollers and network communication modules, IoT-based systems offer scalable and energy-efficient monitoring solutions. This paper presents an IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus. The proposed system utilizes environmental sensors interfaced with ESP32 microcontrollers to capture real-time data related to temperature, humidity, air quality, and noise levels. The collected data is transmitted to a local server for processing, storage, and visualization through a web-based smart dashboard. The system supports anomaly detection and real-time alert generation to assist administrators in making data-driven sustainability decisions. The implementation of such an intelligent monitoring framework enhances environmental awareness, improves resource management, and contributes to the development of a smart and sustainable campus infrastructure.

II. LITERATURE SURVEY

This section presents an overview of existing research related to IoT-based environmental monitoring systems, smart campus sustainability models, local server-based data management, and anomaly detection techniques. Various research studies have focused on real-time environmental sensing, wireless communication, and dashboard visualization for institutional monitoring systems. The literature is classified based on sensing technologies, server

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architecture, data processing methods, and alert mechanisms. These studies address challenges such as delayed environmental monitoring, lack of centralized control, and inefficient campus sustainability management. The insights from these works guide the design and development of the proposed IoT-Based Environmental Analytics and Smart Dashboard System.

A. IoT-Based Environmental Monitoring

The application of IoT in environmental monitoring has been widely explored to enhance real-time data collection. In [1], a smart environmental monitoring system was developed using temperature and humidity sensors connected to a microcontroller. The collected data was transmitted to a centralized monitoring unit for visualization. The study demonstrated that IoT-based sensing improves environmental awareness and enables timely corrective actions.

In [2], an air quality monitoring system was proposed using MQ-series gas sensors to measure pollutant concentrations. The system used Wi-Fi modules to transmit data to a monitoring interface. The research emphasized the importance of continuous environmental data acquisition in maintaining healthy indoor and outdoor conditions.

B. Local Server-Based Monitoring Systems

Several studies have implemented IoT systems using local servers instead of cloud platforms to ensure better data privacy and reduced dependency on internet connectivity. In [3], a local web server-based environmental monitoring system was designed using a microcontroller and a local database. The system allowed users within the network to monitor environmental parameters through a browser-based dashboard.

Another research [4] proposed a campus monitoring system where sensor data was stored and processed within a local server environment. The study highlighted advantages such as improved data security, lower operational costs, and faster data access compared to cloud-based systems.

C. Smart Dashboard and Data Visualization

Data visualization plays a crucial role in environmental analytics. In [5], a real-time dashboard system was developed to display environmental parameters using graphical charts and tables. The system enabled administrators to monitor trends and identify abnormal variations.

Similarly, in [6], a web-based dashboard was integrated with an IoT monitoring system to provide real-time updates and historical trend analysis. The research showed that interactive dashboards improve decision- making and campus sustainability planning.

D. Threshold-Based Anomaly Detection

Anomaly detection techniques are essential for identifying abnormal environmental conditions. In [7], a threshold-based alert mechanism was implemented to detect high temperature and pollution levels. When sensor values exceeded predefined limits, the system generated warning notifications.

Another study [8] implemented rule-based environmental monitoring where alerts were triggered based on parameter thresholds. The research concluded that threshold-based detection is simple, efficient, and suitable for real-time campus monitoring systems.

E. Wireless Communication in Campus IoT Systems

Reliable wireless communication ensures stable data transmission between sensor nodes and servers. In [9], a Wi-Fi-based IoT monitoring system was designed for indoor environmental analysis. The system demonstrated stable data transmission with minimal latency.

In [10], an ESP32-based environmental monitoring system was developed to transmit sensor data to a local server. The study highlighted the efficiency of ESP32 in handling data acquisition, processing, and communication within a campus network.

III. PROPOSED SYSTEM

The IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus is designed to enhance environmental sustainability through real-time monitoring, local data processing, and intelligent visualization. The

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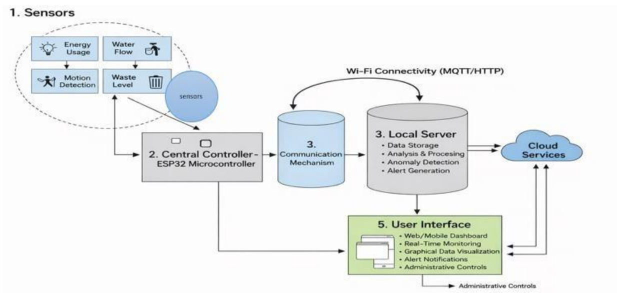
proposed system continuously monitors environmental parameters within the campus environment and provides meaningful insights to administrators for informed decision-making. Unlike cloud-dependent architectures, this system operates using a local server, ensuring improved data security, faster response time, and reduced dependency on external internet connectivity.

The system consists of three primary modules, namely the Sensing Module, the Processing and Storage Module, and the User Dashboard Module, each contributing significantly to the automation and optimization of environmental monitoring within the campus.



System Architecture

The Sensing Module is responsible for acquiring real- time environmental data from various campus locations. It integrates environmental sensors such as temperature and humidity sensors, air quality sensors, and noise detection sensors to continuously measure atmospheric conditions. These sensors are interfaced with the ESP32 microcontroller, which serves as the primary data acquisition unit. The ESP32 reads sensor values at regular intervals and ensures proper sampling and transmission of environmental parameters. The sensing mechanism enables continuous monitoring of environmental conditions, thereby providing accurate and up-to-date data for further processing.

The Processing and Storage Module functions as the backend of the system and operates through a local server environment. The ESP32 transmits the collected sensor data to the local server via Wi-Fi within the campus network. The local server stores both real-time and historical environmental data in a structured database for further analysis. The system performs data validation to eliminate abnormal or erroneous readings before storage. An environmental parameter calculation mechanism converts raw sensor outputs into meaningful values such as temperature in degrees Celsius, humidity percentage, air quality levels, and noise intensity. In addition, a threshold-based anomaly detection mechanism is implemented to identify unsafe environmental conditions. Whenever any parameter exceeds predefined safety limits, the system detects the anomaly and prepares an alert for administrative attention. By utilizing a local server architecture, the system ensures secure data handling, reduced operational costs, and reliable performance even in the absence of external cloud infrastructure.

The User Dashboard Module provides an interactive web-based interface hosted on the local server. The dashboard displays live environmental readings along with graphical representations of historical trends. It enables administrators to monitor variations in environmental parameters over time and identify patterns that may require corrective action. When abnormal environmental conditions are detected, the dashboard generates alert notifications to ensure immediate awareness. This module enhances transparency and facilitates proactive environmental management within the campus.

The overall system workflow operates in a continuous and automated cycle. Initially, environmental sensors collect real-time data from designated campus areas. The ESP32 processes and transmits the data to the local server for storage and analysis. The server evaluates the incoming data, checks for threshold violations, and updates the dashboard accordingly. If any parameter exceeds safe limits, the system triggers an alert notification. After processing, the system resets for the next monitoring cycle, ensuring uninterrupted and continuous environmental tracking.

Through the integration of IoT sensing technology, local server-based analytics, and intelligent dashboard visualization, the proposed system enhances campus sustainability. It minimizes manual monitoring efforts, improves environmental awareness, and supports data-driven decision- making for sustainable campus development.

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The proposed IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus is organized into multiple functional modules to ensure systematic data acquisition, processing, storage, and visualization. Each module performs a specific task in the overall environmental monitoring architecture and contributes to the efficient operation of the system.

The Data Acquisition Module is responsible for sensing and collecting environmental parameters from different locations within the campus. Environmental sensors such as temperature and humidity sensors, air quality sensors, and noise sensors are deployed to measure atmospheric conditions continuously. These sensors are interfaced with the ESP32 microcontroller, which reads sensor outputs at regular intervals. The ESP32 converts analogy and digital sensor signals into meaningful data values suitable for transmission. The accuracy and reliability of environmental monitoring largely depend on the performance of this module.

The Processing Module plays a critical role in managing and preparing the collected data for storage and analysis. The ESP32 performs preliminary data filtering to remove invalid or unstable readings before transmitting the information to the local server. This module ensures that only validated and structured environmental data is forwarded for further processing. It also formats the data into structured packets suitable for network transmission within the campus infrastructure.

The Communication Module enables data transmission between the ESP32 microcontroller and the local server. Wi-Fi communication is used to transmit environmental data through the campus network. The communication mechanism ensures stable and low-latency data transfer, allowing real- time environmental updates on the dashboard. Reliable wireless connectivity is essential to maintain continuous data flow and prevent loss of environmental readings.

The Storage Module is implemented on a local server that stores real-time and historical environmental data in a structured database. This module maintains records of environmental parameters over time, enabling trend analysis and sustainability assessment. Unlike cloud-based systems, the use of a local server enhances data privacy, reduces operational costs, and ensures accessibility even when external internet connectivity is unavailable.

The Analytics Module performs environmental parameter evaluation and anomaly detection. The system implements a threshold-based detection mechanism to identify abnormal environmental conditions. When sensor values exceed predefined safety limits, the system classifies the condition as critical and prepares an alert notification. This module supports proactive environmental management by enabling early detection of unsafe conditions.

The Dashboard Module provides an interactive web- based interface hosted on the local server. It displays real-time environmental data along with graphical representations of historical trends. The dashboard enables administrators to monitor temperature variations, humidity fluctuations, air quality levels, and noise intensity within the campus. It also displays alert notifications when abnormal conditions are detected. This module enhances decision-making by presenting environmental data in a clear and user- friendly format.

Together, these modules form an integrated environmental monitoring system that ensures continuous data acquisition, secure storage, intelligent analysis, and effective visualization. The modular architecture improves system scalability, maintainability, and operational efficiency while supporting sustainable campus development.

IV. MODULE DESCRIPTION

1. Sensing Module:

DHT22, MQ135 and Sound Sensor: These sensors form the core of the sensing module. The DHT22 sensor measures temperature and humidity levels within the campus environment by detecting atmospheric variations and converting them into calibrated digital signals. The MQ135 sensor is used to monitor air quality by detecting harmful gases and pollutants present in the surroundings. The sound sensor measures ambient noise levels to evaluate environmental comfort and detect excessive noise conditions. These sensors are deployed at selected campus locations and continuously collect environmental data. The sensed values are transmitted to the ESP32 microcontroller for further processing and analysis.

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2. Processing Module:

ESP32 Microcontroller: The ESP32 acts as the primary processing unit of the system. It receives environmental data from the connected sensors and performs initial data validation and formatting. The ESP32 converts raw sensor signals into meaningful environmental parameters such as temperature in degrees Celsius, humidity percentage, air quality readings, and noise levels. It also prepares structured data packets for transmission to the local server. The ESP32 is chosen for its integrated Wi-Fi capability, sufficient processing power, and energy-efficient operation, making it suitable for real-time environmental monitoring applications.

3. Communication Module:

Wi-Fi Module (Built-in ESP32 Wi-Fi): The built-in Wi- Fi capability of the ESP32 is utilized to establish communication between the sensing unit and the local server. This module enables real-time transmission of environmental data through the campus network. The communication system ensures stable and low-latency data transfer, allowing continuous monitoring and instant dashboard updates. Reliable wireless connectivity is essential to maintain uninterrupted environmental data flow within the monitoring system.

4. Storage and Analytics Module:

Local Server and Database: The local server functions as the backend of the system and is responsible for storing and managing environmental data. It maintains a structured database that records both real-time and historical sensor readings. The server performs data processing and implements a threshold-based anomaly detection mechanism to identify abnormal environmental conditions. When sensor values exceed predefined safety limits, the system generates alerts for administrative action. By utilizing a local server instead of cloud infrastructure, the system ensures enhanced data security, reduced operational costs, and independence from external internet services.

5. Dashboard Module:

Web-Based Smart Dashboard: The dashboard module provides a user interface for real-time environmental monitoring and visualization. It displays current environmental parameters along with graphical representations of historical trends. The dashboard allows campus administrators to analyse temperature variations, air quality levels, humidity changes, and noise intensity patterns. It also presents alert notifications when abnormal environmental conditions are detected. This module improves transparency and supports data-driven sustainability management within the campus.

6. Power Module:

Regulated Power Supply Unit: The system operates using a stable regulated power supply to ensure continuous functioning of the ESP32 and connected sensors. Proper voltage regulation is essential to maintain accurate sensor readings and reliable communication. For future enhancements, the system can be extended with energy-efficient solutions such as solar power integration and battery backup to support sustainable and uninterrupted environmental monitoring.

V. IMPLEMENTATION AND RESULT

The IoT-Based Environmental Analytics and Smart Dashboard System for Sustainable Campus was implemented using ESP32 as the primary microcontroller, integrated with environmental sensors for real-time data acquisition. The system was designed to monitor temperature, humidity, air quality, and noise levels across selected campus locations. The DHT22 sensor was used to measure temperature and humidity, the MQ135 sensor was deployed for air quality monitoring, and a sound sensor was utilized to measure ambient noise levels. The ESP32 microcontroller collected sensor readings at predefined intervals and transmitted the data to a local server through the built-in Wi-Fi module.

The local server was configured to receive, store, and process environmental data within the campus network. A structured database was created to maintain both real-time and historical environmental records. The server implemented data validation techniques to eliminate unstable readings before storage. A threshold-based anomaly detection mechanism was configured to identify unsafe environmental conditions. Whenever sensor values exceeded predefined safety limits, the system generated alert notifications on the dashboard interface.

A web-based smart dashboard was developed and hosted on the local server to provide real-time visualization of environmental parameters. The dashboard displayed live sensor readings along with graphical representations of historical trends, enabling administrators to analyse environmental variations over time. The interface was designed to update dynamically as new data was received from the ESP32. The dashboard also included an alert panel to notify users about abnormal environmental conditions such as high temperature, poor air quality, or excessive noise levels.

System testing was conducted under different environmental conditions to evaluate performance and reliability. The DHT22 sensor demonstrated stable temperature and humidity measurements with minimal deviation under controlled conditions. The MQ135 sensor successfully detected variations in air quality levels when exposed to changes in surrounding air composition. The sound sensor responded accurately to fluctuations in ambient noise levels. Data transmission between the ESP32 and the local server was achieved with low latency, ensuring near real-time dashboard updates.

The implementation results indicate that the system effectively performs continuous environmental monitoring within the campus environment. The threshold-based detection mechanism successfully identified abnormal environmental conditions and generated timely alerts. The use of a local server ensured improved data privacy, faster response time, and uninterrupted monitoring without reliance on external cloud infrastructure.

Overall, the developed system demonstrated reliability, accuracy, and efficiency in supporting sustainable campus management. The integration of IoT sensing technology, local server analytics, and smart dashboard visualization provides a practical and scalable solution for environmental monitoring applications.

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