

Smart Environmental Monitoring with Blockchain Audit and ML Forecasting

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Abstract:

Environmental pollution and climate change have become critical global challenges, requiring accurate, secure, and real-time monitoring solutions. This paper presents a Smart Environmental Monitoring System that integrates Internet of Things (IoT) sensors, blockchain technology, and machine learning (ML) to provide a reliable and intelligent platform for environmental analysis. The proposed system continuously collects environmental parameters such as air quality, temperature, humidity, and sunlight intensity using IoT-based sensors. The collected data is securely stored using blockchain technology, ensuring data integrity, transparency, and protection against tampering. To enhance decision-making, machine learning algorithms are applied to analyze both real-time and historical data, enabling the prediction of environmental trends such as air pollution levels and climate variations. The system also provides a user-friendly dashboard for visualization, alerts, and reporting, helping authorities and individuals take preventive actions. By combining secure data management with intelligent forecasting, the proposed solution offers an efficient and scalable approach for environmental monitoring and sustainable development.

Key Words: Environmental Monitoring, IoT Sensors, Blockchain, Machine Learning, Air Quality Prediction, Smart Systems, Data Security, Forecasting.

I. INTRODUCTION

In recent years, environmental pollution and climate change have emerged as major global concerns affecting human health, ecosystems, and overall quality of life. Rapid industrialization, urbanization, and increasing emissions have significantly contributed to rising air pollution levels, temperature variations, and unpredictable weather patterns. These environmental issues demand continuous monitoring and timely analysis to ensure sustainable development and public safety. However, traditional environmental monitoring systems often rely on manual data collection or isolated sensing methods, which lack real-time capabilities, data reliability, and predictive intelligence.

To overcome these limitations, there is a growing need for an intelligent system that can not only monitor environmental parameters in real time but also ensure data security and provide future predictions. The integration of Internet of Things (IoT), blockchain technology, and machine learning offers a powerful solution to address these challenges. IoT enables continuous data collection through sensors that monitor parameters such as air quality, temperature, humidity, and sunlight intensity. However, ensuring the authenticity and integrity of this data remains a critical issue.

Blockchain technology provides a secure and tamper-proof mechanism for storing environmental data, ensuring transparency and trustworthiness. Each data transaction is recorded in a distributed ledger, preventing unauthorized modification and enabling reliable auditing. In addition, machine learning techniques enhance the system by analyzing historical and real-time data to identify patterns and forecast environmental trends such as pollution levels and climate changes. The proposed Smart Environmental Monitoring System combines these technologies into a unified platform. The system collects data through IoT sensors, secures it using blockchain, and applies machine learning algorithms to generate predictions and insights. A user-friendly dashboard allows users to visualize real-time data, access reports, and receive alerts when environmental conditions exceed safe thresholds. By integrating sensing, security, and intelligence, the proposed system provides a comprehensive and efficient solution for environmental monitoring. It supports

informed decision-making for authorities and individuals, contributing to improved environmental management and public health awareness.

II. LITERATURE SURVEY

Recent advancements in environmental monitoring systems have focused on integrating intelligent technologies such as Internet of Things (IoT), machine learning (ML), and blockchain to improve accuracy, reliability, and security. Several research studies have explored different aspects of these technologies for environmental analysis and prediction.

Z. Zhang [1] presented a comprehensive survey on air quality prediction using machine learning and deep learning techniques. The study compared traditional models such as Support Vector Machines and Random Forest with advanced models like Long Short-Term Memory (LSTM) and Convolutional Neural Networks (CNN). It highlighted challenges such as data inconsistency, sensor noise, and lack of interpretability, emphasizing the importance of preprocessing and feature selection for accurate predictions.

I. U. Ajakwe [2] investigated the integration of IoT and blockchain technologies for environmental monitoring systems. The research demonstrated how blockchain ensures data immutability, transparency, and secure sharing of sensor data. It also discussed practical challenges such as high transaction costs, latency, and scalability issues, suggesting the use of lightweight and permissioned blockchain networks for real-time applications.

M. M. Rahman [3] proposed a machine learning-based environmental monitoring system that utilizes sensor data for predicting air quality. The study emphasized the effectiveness of combining multiple environmental parameters such as temperature, humidity, and pollutant levels to improve prediction accuracy. It also highlighted the importance of real-time data processing and alert generation for early detection of hazardous conditions.

V. Kulkarni [4] introduced a decentralized approach using federated learning for air quality prediction. Instead of transferring raw data to a central server, the model is trained locally on edge devices and only model updates are shared. This approach enhances privacy, reduces communication overhead, and improves scalability in distributed sensor networks.

Other studies have focused on IoT-based environmental monitoring systems that provide real-time data collection but lack security and predictive capabilities [5][6]. While these systems are effective for monitoring, they often fail to ensure data integrity and do not support intelligent forecasting.

From the reviewed literature, it is evident that machine learning significantly improves prediction accuracy, while blockchain enhances data security and trustworthiness. However, most existing systems focus on either monitoring, security, or prediction individually. There is a lack of integrated systems that combine IoT sensing, secure data storage, and intelligent forecasting into a unified platform.

The proposed system addresses these gaps by integrating IoT, blockchain, and machine learning into a single framework. This combination ensures real-time monitoring, secure data handling, and accurate environmental predictions, making the system more reliable and efficient for practical applications.

III. METHODOLOGY

A. Dataset Description

The proposed Smart Environmental Monitoring System utilizes real-time and historical environmental data collected through IoT-based sensors. Unlike traditional systems that rely on a single parameter, this system incorporates multiple environmental attributes such as air quality index (AQI), temperature, humidity, and sunlight intensity to provide a comprehensive analysis.

The dataset consists of continuous sensor readings collected from deployed IoT devices such as NodeMCU and environmental sensors. Air quality parameters include pollutant concentrations such as particulate matter (PM_{2.5}, PM₁₀), while temperature and humidity sensors capture atmospheric conditions. Sunlight intensity

sensors provide additional environmental context. These data points are transmitted to a central system via communication protocols such as MQTT or HTTP.

In addition to real-time data, historical environmental data is stored and used for training machine learning models. This combination of real-time and historical data enables accurate prediction and trend analysis of environmental conditions.

B. Data Preprocessing

Data preprocessing is a critical step to ensure the quality, consistency, and reliability of the collected sensor data before it is used for analysis and prediction.

Initially, raw sensor data is validated to remove noise, missing values, and inconsistent readings. Outliers caused by sensor errors or environmental disturbances are detected and filtered using statistical techniques. The data is then normalized to ensure uniformity across different parameters, which improves machine learning model performance.

For blockchain integration, data is structured into secure transactions where each record is hashed before being stored on the blockchain network. This ensures that any modification in the data can be detected, maintaining data integrity.

Additionally, time-series formatting is applied to the dataset to preserve temporal relationships between environmental parameters. This is essential for forecasting models that depend on sequential data patterns.

C. Feature Selection and Analysis

Feature selection plays a vital role in improving model accuracy and reducing computational complexity. The system identifies key environmental parameters that significantly influence prediction outcomes. Important features include air quality indicators (PM2.5, PM10), temperature fluctuations, humidity levels, and sunlight intensity. These parameters are analyzed to understand their correlation with environmental conditions and pollution trends.

Statistical methods and correlation analysis are used to eliminate redundant or less significant features. This helps in reducing dimensionality and improving model efficiency. The selected features are then used as inputs for machine learning models to predict environmental conditions.

By focusing on relevant features, the system ensures accurate forecasting while maintaining computational efficiency.

D. System Architecture

1. The proposed system follows a modular and layered architecture to ensure scalability, efficiency, and reliability.
2. **Data Collection Layer** IoT sensors continuously monitor environmental parameters such as air quality, temperature, humidity, and sunlight intensity. These sensors are connected to microcontrollers like NodeMCU or Arduino.
3. **Communication Layer** Sensor data is transmitted to the central system using communication protocols such as MQTT or HTTP. Secure transmission is ensured using encryption mechanisms like SSL/TLS.
4. **Blockchain Layer** The collected data is stored in a blockchain network, ensuring immutability and transparency. Each data entry is recorded as a block, preventing unauthorized modifications and enabling secure auditing.
5. **Data Processing Layer** The incoming data is cleaned, normalized, and processed for analysis. This layer prepares the data for machine learning models.
6. **Machine Learning Layer** Machine learning algorithms analyze the processed data to identify patterns and predict future environmental conditions such as pollution levels and temperature changes.
7. **Visualization Layer** A user-friendly dashboard displays real-time data, predictions, alerts, and reports. This helps users and authorities make informed decisions.
8. This layered architecture ensures smooth data flow from sensors to end users while maintaining security and efficiency.

E. Workflow of the System

The workflow of the proposed system follows a structured sequence of operations:

1. Environmental data is continuously collected through IoT sensors.
2. The collected data is transmitted securely to the central server.
3. Data is validated, cleaned, and preprocessed for analysis.
4. Processed data is stored on the blockchain to ensure security and integrity.

5. Machine learning models analyze the data and generate predictions.
6. The system identifies abnormal conditions such as high pollution levels.
7. Alerts and notifications are generated for users and authorities.
8. Results are displayed on a dashboard with real-time insights and forecasts.

This workflow ensures real-time monitoring, secure data handling, and intelligent prediction, making the system efficient and reliable for environmental management.

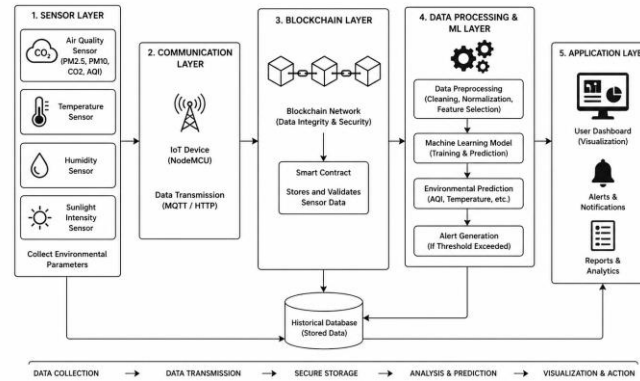


Fig 1: System architecture

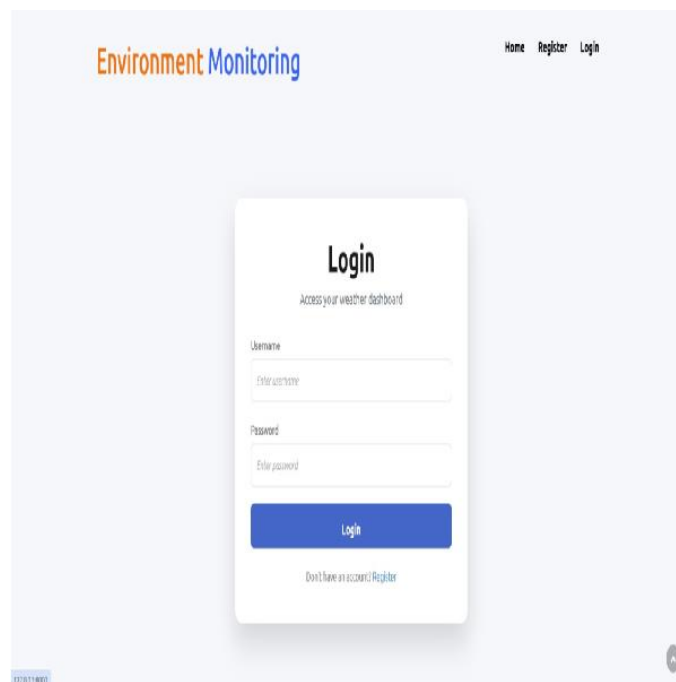
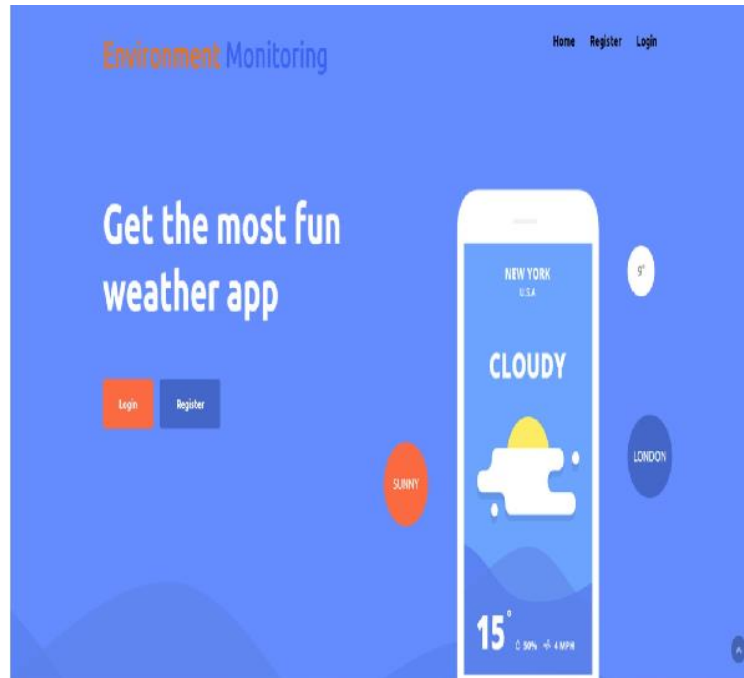
Functional Requirements

1. The system shall collect real-time environmental data such as air quality, temperature, humidity, and sunlight intensity using IoT sensors.
2. The system shall securely store the collected data using blockchain technology to ensure data integrity and prevent unauthorized modification.
3. The system shall process and analyze the collected data using machine learning algorithms to predict environmental conditions and trends.
4. The system shall provide a user-friendly dashboard to display real-time data, predictions, alerts, and historical reports.
5. The system shall generate alerts and notifications when environmental parameters exceed predefined threshold values.

Non-Functional Requirements

1. **Security:** The system must ensure secure data transmission and storage using encryption and blockchain-based mechanisms.
2. **Performance:** The system should process and update environmental data in real-time with minimal latency.
3. **Scalability:** The system must support the addition of new sensors, users, and monitoring locations without performance degradation.
4. **Reliability:** The system should provide continuous operation with minimal downtime and accurate data processing.
5. **Usability:** The interface should be simple, intuitive, and accessible across different devices such as desktops and mobile platforms.

IV. RESULTS



V. CONCLUSION

This paper presents a Smart Environmental Monitoring System that integrates IoT, blockchain, and machine learning for real-time environmental analysis. The system ensures accurate data collection through sensors, secure storage using blockchain, and intelligent prediction using machine learning models. It enables effective monitoring of environmental parameters and provides timely alerts for critical conditions. The proposed solution improves reliability, security, and decision-making compared to traditional methods. Overall, it offers a scalable and efficient approach for environmental monitoring, with potential future enhancements in advanced analytics and smart city integration

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