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Internet of Things (IoT)

IoT Based Industrial Waste Monitoring System Design with Data Visualization on A Web Application Using The Supervised Learning Method

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A B S T R A C T

Industrial waste management is a critical aspect of sustainable manufacturing, as improper handling can lead to severe environmental pollution and health hazards. Real-time monitoring of industrial waste parameters enables early detection of irregularities and supports informed decision-making for compliance with environmental regulations. This study presents the design of an IoT-based industrial waste monitoring system integrated with data visualization on a web application and enhanced by the supervised learning method for predictive analysis. The system utilizes IoT sensor nodes to measure key waste parameters such as pH level, temperature, turbidity, and chemical concentration. Sensor data is transmitted wirelessly to a cloud server, where it is stored, processed, and analyzed using supervised learning algorithms to classify waste quality and detect potential violations. The web application provides interactive dashboards, historical data tracking, and real-time alerts for stakeholders. Testing results demonstrate that the system achieves high accuracy in classifying waste conditions, offers user-friendly visual analytics, and enables proactive waste management. This research contributes to the development of intelligent environmental monitoring solutions, promoting efficiency, compliance, and sustainability in industrial operations.

INTRODUCTION

The rapid development of industry in Indonesia has had a positive impact on economic growth. However, on the other hand, this industrial growth has also created a new problem, namely the increasing volume of industrial waste produced. Poorly managed industrial waste can cause environmental pollution and endanger human health. The impacts of this pollution are far-reaching, ranging from damage to aquatic ecosystems, health problems for communities around industrial areas, to losses in the agricultural and fisheries sectors. Therefore, industrial waste management is a crucial aspect that needs to be considered to minimize negative impacts on the environment and society [15,16,17].

Data obtained from sensors can be sent in real time to a monitoring system, allowing for automated monitoring without relying on manual checks. With an IoT-based system, industries can improve waste management efficiency by optimizing resource use, reducing operational costs, and accelerating response to changes in waste quality. This automated monitoring allows companies to reduce reliance on manual labor, save on laboratory analysis costs, and prevent pollution by detecting changes in waste quality more quickly. Furthermore, this system helps ensure compliance with applicable environmental regulations by providing accurate and systematically documented data [18,19,20].

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Based on the description above, this study proposes a solution in the form of developing an IoT-based industrial waste monitoring system with data visualization in a web application. This system will integrate the use of IoT sensors to collect data, Supervised Learning methods to analyze data, and a web application as a medium to display information that is easy for users to understand. According to [21,22], a user-friendly web application that presents data in the form of informative graphical visualizations can facilitate users in understanding the condition of the monitored waste. With this system, it is hoped that the industry can be more effective in controlling waste and meeting established environmental standards.

Through this research, it is hoped that it can contribute to efforts to reduce the negative impact of industrial waste on the environment and society, as well as encourage the application of modern technology in waste management in Indonesia.

METHOD

System Merger

At this stage, all assembled hardware components will be integrated with the software system. The installed pH, temperature, and TDS sensors will be connected to the NodeMCU ESP32, which will serve as the control and data communication center. The trained Decision Tree algorithm will then be applied to the system to classify waste conditions based on the data received from the sensors.

Data collected from the sensors is sent directly to the server, where a Decision Tree model processes it and determines whether the waste is classified as Safe, Warning, or Hazardous. The classification results are then displayed on a web application in the form of interactive graphs and automatic notifications if any parameters exceed safe limits.

System Workflow Design

The IoT-based industrial waste monitoring system uses pH, temperature, and TDS sensors to measure waste parameters. The collected data is sent by the NodeMCU ESP32 to a cloud server, where it is stored and analyzed using a Decision Tree algorithm. The analysis results are then displayed in a web application in the form of graphs and reports. If waste parameters exceed safe limits, the system automatically sends a warning notification to the web application.

Hardware Design

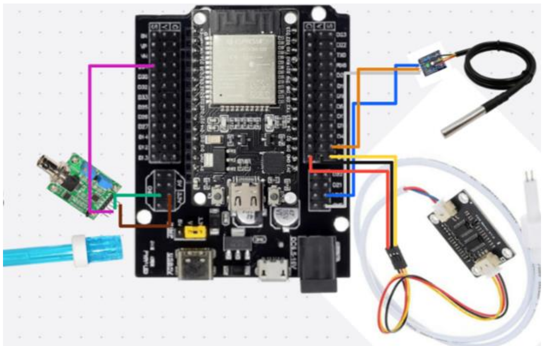

Figure 1. Hardware Schematic

The ESP32 is used as the main microcontroller that connects three types of sensors, namely the pH sensor, the TDS sensor, and the DS18B20 temperature sensor. The pH sensor is used to measure the acidity or alkalinity of water, while the TDS (Total Dissolved Solids) sensor is used to measure the level of dissolved solids in water. The DS18B20 temperature sensor functions to read water temperature digitally with high accuracy. The pH and TDS sensors are connected to the analog pins on the ESP32, which act as inputs to read the voltage from each sensor and convert it into digital data. Meanwhile, the DS18B20 temperature sensor is connected via digital communication using the OneWire protocol. The data obtained from these three sensors is then processed by the ESP32 and sent to a web application to be displayed and classified using the supervised learning method.

Decision Tree as a Classification Method

The Decision Tree method is an algorithm in Supervised Learning used to classify data based on labeled data. This algorithm works by creating a tree-like structure, where each branch represents a decision based on attribute (feature) values, and each leaf indicates the final result, a class or label.

In this study, a Decision Tree was used to classify wastewater quality based on three main parameters obtained from sensors:

1. Water temperature (in °C),
2. Water pH, and
3. Total Dissolved Solids (TDS) in ppm.

This algorithm will learn from training data consisting of a combination of temperature, pH, and TDS values that have been previously categorized as Safe, Polluted, or Hazardous. Once the model is trained, the system can be used to predict or classify new data from sensor readings.

Then, if there are new sensor readings such as: Temperature: 28°C, pH: 7.2, TDS: 280 ppm. The model will evaluate the results based on the decision tree rules and conclude that the water quality is considered safe. This way, the system can automatically and quickly inform users whether the monitored wastewater is safe, polluted, or hazardous.

RESULTS AND DISCUSSION

This system utilizes pH, temperature (DS18B20), and Total Dissolved Solids (TDS) sensors controlled by an ESP32 microcontroller. Sensor data is processed and classified using a Decision Tree algorithm, then displayed in real time via a local web application.

The primary focus of testing is the system's ability to read wastewater quality parameters and provide accurate classification results based on temperature, pH, and TDS values. Furthermore, the system is also tested for the stability of data transmission to the web application and the accuracy of its classification results based on a trained machine learning model.

Tool Assembly

This process discusses in detail the assembly steps of an industrial waste monitoring system that uses an ESP32 module as the main microcontroller. This system is equipped with three sensors: a DS18B20 temperature sensor, a pH sensor, and a TDS sensor. For power and data communication, the system uses a USB cable connection from the ESP32 to a computer. This discussion will cover the physical assembly of these components, setup, and initial testing to ensure the system is functioning properly.

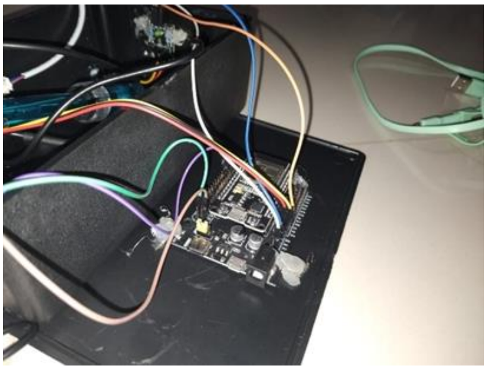

Figure 2. Pin Series

Figure 2. shows the wiring diagram for each sensor to the ESP32. The temperature sensor is connected to GPIO 2, the TDS sensor to GPIO 15, and the pH sensor to GPIO 34. All sensors receive power from the 3V3 and GND pins on the ESP32. Connections are made using jumper cables through the terminal blocks on each sensor.

Software Design

In this industrial waste monitoring system, software is designed to manage data collection from sensors via an ESP32 microcontroller and display water quality classification results interactively on a web application. The system consists of two main components: microcontroller programming using the Arduino IDE and Python Flask-based web application development.

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System Circuit Testing

The system circuit was tested to ensure that all designed components, both hardware (ESP32 and sensors) and software (web application and classification model), could function according to the research objectives. The system tested was an IoT-based wastewater quality monitoring system that measures three main parameters: temperature, pH, and TDS, then classifies water quality based on these readings using the Supervised Learning method.

Figure 3. Waste Monitoring Web Application Display

The image shows that the temperature, pH, and TDS values are successfully displayed on the web page, and the classification results appear with the appropriate categories based on the thresholds specified in the table. This indicates that the website is functioning well in displaying sensor readings in real time and can process classification using a pre-trained decision tree model.

Furthermore, the web application interface can dynamically display data every few seconds without requiring a manual refresh. This demonstrates the smooth communication between the device, backend, and frontend.

Based on the test results, it can be concluded that the designed IoT-based industrial waste monitoring system has been successfully implemented. The system is not only capable of reading and transmitting data from sensors but also automatically processing it using a supervised learning algorithm and presenting the results in a clear, accurate, and user-friendly water quality classification via a web interface.

Test Results

The test results were conducted over five days, from June 8, 2025, to June 12, 2025. On the first day, June 8, 2025, the test was conducted from 9:00 a.m. to 10:00 a.m. WIB, with sensor data collected every five minutes. Data was collected automatically.

The results displayed by the system on June 8, 2025, from 09:00 WIB to 10:00 WIB are the results of temperature, pH, and TDS sensor readings sent via ESP32 and displayed on the waste monitoring web application. All read values are included in the Safe category based on water quality classification parameters. The web application displays these values in real-time in the form of text and status classification, which helps users understand the condition of the wastewater quickly and easily. On the second day, June 9, 2025, testing was carried out for a period of one hour, from 16.15 WIB to 17.15 WIB.

On June 9, 2025, from 4:15 PM to 5:15 PM WIB, the system again collected sensor data from the wastewater. The results displayed on the web showed that the temperature, pH, and TDS parameters remained within safe limits. The received data was automatically displayed on the web interface, providing users with immediate information without the need for manual analysis. The Supervised Learning classification function successfully provided accurate water quality status results. On the third day, June 10, 2025, testing was conducted for one hour, from 8:30 AM to 9:30 AM WIB.

Testing on June 10, 2025, from 8:30 AM to 9:30 AM WIB demonstrated the system's consistency in reading and displaying data. Despite being conducted at a different time than the previous day, sensor values remained stable and indicated a Safe category. The web system also provided consistent classification results and was able to handle repeated input data without errors or delays. On the fourth day, June 11, 2025, testing was conducted for one hour, from 4:45 PM to 5:45 PM WIB.

During testing on June 11, 2025, from 4:45 PM to 5:45 PM WIB, the system indicated that even though the TDS value reached above 60 ppm, the water quality status remained safe. This is because the safe TDS limit set in the system is ≤300 ppm. The web application successfully displayed all values quickly, and the classification was also displayed automatically based on a pre-trained decision tree model. On the fifth day, June 12, 2025, testing was conducted for one hour, from 7:50 AM to 8:50 AM WIB.

The final test was conducted on June 12, 2025, from 7:50 a.m. to 8:50 a.m. WIB. Temperature, pH, and TDS values were all within the safe range, and the system demonstrated that the web application was able to display sensor data and classifications stably without interruption. Thus, this monitoring system has proven to be usable consistently over several consecutive days of observation.

CONCLUSION

Based on the research and implementation of an IoT-based industrial waste monitoring system, it can be concluded that: An industrial waste monitoring system using a temperature sensor (DS18B20), a pH sensor, and a TDS sensor, controlled by an ESP32 microcontroller, has been successfully designed and built. The system is capable of periodically reading wastewater quality parameters (temperature, pH, and TDS) and sending the readings to a locally-based web application. The Decision Tree-type Supervised Learning method has been successfully applied to classify wastewater quality status into Safe, Polluted, or Hazardous categories based on the provided training data. The created web application can display sensor readings, waste quality classification, and a classification reference table in real time with a simple and easy-to-understand interface. Based on five days of testing at CV. Sepanjang Sejalan, measurement results indicate that the wastewater quality is classified as safe, indicating that the industrial wastewater treatment process meets quality standards.

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