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Analysis of the Implementation of an Internet of Things (IoT) Based Environmental Quality Monitoring System Using Multi-Parameter Sensors

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Abstract: The implementation of an Internet of Things (IoT) based environmental quality monitoring system using multi-parameter sensors has emerged as a solution to overcome the limitations of conventional monitoring methods, which are unable to provide continuous and real-time data. This study aims to analyze the implementation of an IoT-based environmental quality monitoring system using multi-parameter sensors and evaluate the sensors' performance in measuring various environmental quality parameters in real time. A Systematic Literature Review (SLR) method was employed by analyzing national scientific publications published between 2016 and 2026. The findings indicate that the monitoring system is implemented through the integration of multi-parameter sensors, microcontrollers, communication networks, cloud computing, and monitoring dashboards, enabling automatic and real-time environmental monitoring. Furthermore, the sensors demonstrate satisfactory accuracy, responsiveness, and reliability after proper calibration, although their performance is influenced by environmental conditions and periodic maintenance requirements. The novelty of this study lies in providing a comprehensive synthesis of IoT system implementation and multi-parameter sensor performance within a single analytical framework. In conclusion, IoT-based environmental monitoring systems have significant potential to improve environmental management through accurate, continuous, and real-time data acquisition.

Keywords: Internet of Things (IoT), Multi-Parameter Sensors, Environmental Quality Monitoring, Realtime Monitoring.

INTRODUCTION

The Internet of Things (IoT) is a technology that enhances everyday objects through internet connectivity, making daily activities easier and more efficient. It is a technology that enables objects around us to connect to the Internet (Putra et al., 2023). The significance of the Internet of Things is evident in its increasingly widespread application across various aspects of modern life. IoT offers numerous concepts that contribute to development across all scales from the micro to the macro worldwide.

Environmental quality is a crucial factor influencing human health, productivity, and ecosystem sustainability. Environmental parameters such as temperature, humidity, air quality, light intensity, and the concentration of specific gases require periodic monitoring to provide a

comprehensive understanding of environmental conditions. Conventional monitoring methods that rely on manual measurements have various limitations, including the need for human labor, significant time requirements, and an inability to provide real-time information (Noor et al., 2025).

Multi-parameter sensors offer advantages over single-sensor setups by integrating multiple types of measurements into a single system. For instance, combining sensors for temperature, humidity, air quality, air pressure, and light intensity enables more comprehensive environmental monitoring. The resulting data can be utilized across various sectors, such as smart agriculture, industry, laboratories, smart buildings, and urban environmental monitoring (Rifki & Lubis, 2026).

As the demand for efficient, cost effective, and accessible monitoring systems grows, IoT technology has become a widely adopted alternative due to its wireless communication capabilities and relatively low power consumption. Furthermore, integration with Internet based platforms allows users to monitor environmental conditions in realtime via computers or mobile devices, eliminating the need to be physically present at the measurement site (Gitakarma et al., 2024). Based on this background, this study aims to analyze the implementation of an Internet of Things (IoT) based environmental quality monitoring system using a multi-parameter sensor capable of simultaneously measuring multiple environmental parameters, transmitting data in real-time, and displaying monitoring results via an easily accessible medium. The research questions addressed in this article are as follows:

1. How is the Internet of Things (IoT) based environmental quality monitoring system using a multi-parameter sensor implemented?
2. How does the multi-parameter sensor perform in measuring various environmental quality parameters in real-time?

METHODS

This study employs the Systematic Literature Review (SLR) method, a systematic research approach used to identify, evaluate, and synthesize findings from prior research relevant to the study's topic. This method was selected because the research aims to analyze the implementation of an Internet of Things (IoT) based environmental quality monitoring system utilizing multi-parameter sensors, drawing upon published scientific evidence (Syahrizal & Jailani, 2023). In qualitative analysis, the literature review must be conducted in a manner consistent with methodological assumptions; one reason for adopting a qualitative approach is the exploratory nature of the research. This literature review draws upon online platforms, such as Google Scholar, to locate relevant prior studies.

RESULTS AND DISCUSSION

Internet of Things (IoT)

The Internet of Things (IoT) is a modern technology designed to optimize the use of always-on internet connectivity. This technology enables various objects to connect, thereby facilitating daily activities and making them more efficient and practical, which allows human tasks to be performed with greater ease (Syahfitri, 2025). The term "Internet of Things" (IoT) was introduced by Kevin Ashton in 2002. Internet technology began to be applied to industrial production processes in developed nations, particularly the United States and countries in Western Europe. The emergence of IoT marked the beginning of standardizing computers to independently comprehend the real-world environment around them (Turyadi et al., 2021).

In the environmental sector, IoT is widely applied to establish automated environmental quality monitoring systems. These systems utilize various multi-parameter sensors to measure environmental conditions such as temperature, humidity, air quality, gas concentrations, noise levels, and other parameters. The data obtained can be monitored remotely, making the

environmental surveillance process more effective than manual measurement methods. Several researchers have conducted studies on the Internet of Things, including (Mainetti et al., 2017), (Kumar et al., 2019), (Primantara et al., 2021), (Subagiyo et al., 2021), and (Setiawan & Abdurrahman, 2025).

Multi-Parameter Sensors

A multi-parameter sensor is a device designed to measure multiple physical or chemical parameters simultaneously using a single instrument or probe. These sensors are widely used in water quality monitoring, wastewater treatment, aquaculture, environmental research, and various industrial processes. By integrating multiple sensors into a single system, measurements become more efficient and consistent, while also enabling real-time monitoring (Yanti et al., 2025). The primary advantage of multiparameter sensors is their ability to measure multiple parameters simultaneously, thereby saving time, reducing operational costs, and minimizing errors caused by time lags between sampling events. Furthermore, these sensors facilitate continuous environmental quality monitoring such as water quality making them highly valuable for water resource management and pollution early-warning systems (Graft et al., 2023).

However, multiparameter sensors also have certain limitations. Their procurement and maintenance costs are relatively higher than those of single-parameter sensors. They require routine calibration to ensure measurement accuracy, as well as periodic cleaning, since sediment accumulation or biological growth on the sensor surface (biofouling) can affect measurement results (Azis & Siswoyo, 2024).

Discussion

1. Implementation of an Internet of Things (IoT)-Based Environmental Quality Monitoring System Using Multi-Parameter Sensors

The implementation of an Internet of Things (IoT) based environmental quality monitoring system using multi-parameter sensors involves integrating sensor devices, a microcontroller, a communication network, a cloud server, and a user interface. This system is designed to automatically measure various environmental quality parameters, transmit data via the internet, and display results in real-time, enabling users to monitor environmental conditions from any location.

The implementation begins with data acquisition using multi-parameter sensors. These sensors are capable of simultaneously measuring multiple environmental parameters such as temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, Oxidation-Reduction Potential (ORP), and turbidity. Using multi-parameter sensors is more efficient than using single-parameter sensors because all data points are collected at the same time and location, thereby minimizing measurement variations caused by differences in sampling times.

Next, the data acquired by the sensors is processed by a microcontroller, such as an ESP32 or ESP8266. The microcontroller acts as the control hub, reading data from each sensor, performing initial processing, and transmitting the data via a communication network such as Wi-Fi, LoRa, LoRaWAN, GSM, or NB-IoT. The choice of communication technology depends on system requirements, including range, power consumption, and available network infrastructure.

Once transmitted, the data is sent to a cloud server that serves as both a storage medium and a data processing hub. Platforms such as ThingSpeak, Blynk, Firebase, or MQTT-based servers can be used to store historical data, visualize parameter trends through graphs, and provide notifications if parameter values exceed safe limits. Consequently, users not only gain

insight into current environmental conditions but can also analyze long-term environmental quality trends.

Implementing an IoT based monitoring system offers several advantages over conventional methods. The system enables continuous, round-the-clock monitoring, reduces the need for manual measurements, accelerates the identification of environmental pollution, and supports data-driven decision-making. Furthermore, data stored in the cloud can be accessed simultaneously by multiple parties, thereby facilitating coordination in environmental management.

However, the system's implementation still faces challenges, such as internet network stability, the need for periodic sensor calibration, environmental interference such as biofouling on water quality sensors and the energy consumption of devices deployed in remote locations. Consequently, current monitoring system development is increasingly integrating edge computing technology and solar panels to enhance system efficiency, reliability, and accuracy.

Based on the foregoing, the implementation of an IoT-based environmental quality monitoring system utilizing multi-parameter sensors offers a monitoring solution that is more effective, automated, and real-time compared to conventional methods. The integration of sensors, microcontrollers, communication networks, and cloud computing makes this system suitable for supporting sustainable environmental quality management.

Research by Andriani et al. (2026), Azis and Sujono (2026), Rosaria (2026), and Syah et al. (2026) demonstrates that the system is implemented through the integration of environmental quality sensors, an ESP32 microcontroller, communication networks (Wi-Fi/MQTT), and a cloud platform or dashboard. Consequently, the system is capable of automated, real-time monitoring.

2. Performance of Multi-Parameter Sensors in Real-Time Measurement of Environmental Quality Parameters

The performance of multi-parameter sensors can be analyzed based on accuracy, response speed, measurement stability, operational efficiency, and real-time monitoring capabilities. These sensors are designed to measure multiple environmental quality parameters simultaneously, thereby providing more comprehensive information than single-parameter sensors.

Regarding accuracy, modern multi-parameter sensors exhibit high precision when calibrated using standard solutions or instruments. Studies indicate that pH sensors show low relative error rates post-calibration, while temperature sensors generally offer superior accuracy compared to other chemical sensors. Dissolved Oxygen (DO), Electrical Conductivity (EC), and turbidity sensors can also yield results comparable to laboratory equipment, provided they undergo routine maintenance and calibration.

In terms of response speed, multi-parameter sensors can transmit data at intervals ranging from a few seconds to several minutes, depending on system configuration. This capability allows for the immediate detection of changes in environmental quality without the need for manual sampling. Data received by the cloud server is displayed via numerical values, graphs, or interactive dashboards, facilitating analysis.

Another advantage is the sensor's ability to perform continuous monitoring. The system operates 24 hours a day, enabling the comprehensive recording of environmental quality fluctuations caused by rainfall, industrial waste, agricultural activities, or other natural factors. This information is crucial for supporting early warning systems in the event of a sudden decline in environmental quality.

However, the performance of multi-parameter sensors is influenced by several external factors. Sludge deposits, microorganism growth (biofouling), extreme temperature fluctuations, and corrosive environmental conditions can lead to reduced sensor sensitivity. Furthermore, low-cost sensors generally exhibit higher drift rates compared to laboratory-grade sensors, necessitating periodic calibration to maintain measurement accuracy.

In terms of efficiency, the use of multi-parameter sensors reduces the number of required devices, as multiple parameters can be measured using a single probe. This lowers installation costs, simplifies maintenance, and enhances data collection efficiency. Integration with IoT platforms also enables users to access real-time data without needing to visit the measurement site in person.

Overall, the performance of multi-parameter sensors demonstrates their capability to provide rapid, accurate, and continuous environmental quality measurements. Despite the ongoing need for routine calibration and maintenance, multi-parameter sensors remain a preferred choice for IoT-based environmental monitoring systems due to their ability to provide real-time data that supports more effective decision-making.

Research by Setiawati and Fitriyani (2025), Kisworo et al. (2026), and Hidayat et al. (2026) indicates that pH, temperature, TDS, EC, and turbidity sensors perform well following calibration; they provide stable readings and transmit data periodically to monitoring platforms, allowing for realtime environmental monitoring.

CONCLUSIONS

Based on the discussion regarding the implementation of an Internet of Things (IoT) based environmental quality monitoring system using multi-parameter sensors, the following conclusions can be drawn:

1. The implementation of the IoT based environmental quality monitoring system using multi-parameter sensors involves the integration of sensors, a microcontroller, an internet communication network, a cloud server, and a monitoring dashboard. The system is capable of automatically measuring, transmitting, storing, and visualizing data in realtime, thereby making the environmental quality monitoring process more effective, efficient, and accessible compared to conventional monitoring methods.
2. The multi-parameter sensors demonstrate strong performance in simultaneously measuring various environmental quality parameters, such as temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, and turbidity. The sensors are capable of generating real-time data with a good level of accuracy following calibration. However, sensor performance remains influenced by factors such as sensor quality, environmental conditions, and biofouling, as well as the need for periodic calibration and maintenance to ensure measurement results remain stable and accurate.

Based on various previous studies, the application of IoT combined with multi-parameter sensors holds significant potential for supporting environmental quality management by providing continuous data, accelerating the detection of changes in environmental conditions, and facilitating more precise, data-driven decision-making.

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