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Monitoring System for Hazardous Gas in Landfill Site Based on Internet of Things

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ABSTRACT

The landfill is a place where waste reaches the last stage in its management since it began to arise in the source, collection, transportation, processing, and disposal. Muara Fajar landfill is one of the landfills in Pekanbaru City whose garbage increase exceeds the capacity of waste storage land so that it can produce 800 tons of garbage per day in dry weather and 1000 tons per day in rainy weather. The problem caused by the management of the Muara Fajar landfill is air pollution due to the process of decomposing organic matter anaerobically which has the potential to cause unpleasant odors and health problems. With this problem, a system was built to monitor and detect hazardous gases in landfill, namely H_2S gas using MQ-136 sensors, CH_4 gas by MQ-4 sensors, and CO_2 and NH_3 gases using MQ-135 sensors. This system is implemented with the IoT protocol, MQTT Broker to receive and send monitoring data to the Website with notifications from the telegram web application. Based on testing the value of ppm in CO2 Gas with a danger status of 1000-4000 ppm, H_2S Gas is 10-400 ppm, NH_3 is included in the status of be careful which is 0.03 ppm, and CH_4 with normal status because the value of ppm levels is below 10000 ppm

1. INTRODUCTION

The waste we generate is usually thrown into the garbage and then taken to a Temporary Collection Site (TPS). TPS is a place where waste is temporarily stored before being transported to recycling, processing, and/or integrated waste management facilities. From the TPS, the waste is transported and carried by the Department of Environment using garbage trucks to the Final Processing Site (TPA). A landfill is a place where waste is processed and safely returned to the environment, ensuring the safety of humans and the environment. The waste managed according to Law Number 18 of 2008 consists of household waste (originating from daily activities within households, excluding feces and specific waste), similar waste to household waste (originating from commercial areas, industrial areas, special areas, social facilities, public facilities, and other facilities), and specific waste (waste containing hazardous and toxic substances, waste containing hazardous and toxic materials, waste resulting from disasters, debris from demolition, waste that cannot be processed technologically and/or waste that arises periodically) [1].

Waste management in Indonesia is divided into two categories. First is the management of household waste and similar waste to household waste, and second is the management of specific waste. The management of specific waste is the responsibility of the government, while the management of household waste and similar waste to household waste involves waste reduction and waste handling. Waste reduction includes waste generation limitation, waste recycling, and waste reuse. In this regard, the central government, local government, businesses, and the community each have their roles to play. Waste handling activities include sorting waste according to its type, quantity, and/or characteristics; collecting waste to residual treatment facilities; transporting waste from residual treatment facilities to the Final

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Processing Site (TPA); processing waste by changing its characteristics, composition, and quantity; and final processing by safely returning the waste and/or residual products of previous processing to the environment.[1]

Muara Fajar is one of the waste Final Disposal Sites (TPA) in Pekanbaru City where the amount of waste sometimes exceeds the capacity of the landfill. Based on the results of observations and initial interviews conducted with the operators of the Muara Fajar landfill, the waste generated is mainly household waste, which continues to increase every year. During the dry season, the quantity of waste can reach 750 tons per day, and during the rainy season, it can reach 1000 tons per day. However, there is no separation of organic and inorganic waste implemented. As a result, the waste is left to accumulate until it reaches the maximum capacity and is then covered with soil. According to the regulations of the sanitation department, the burning of waste is prohibited at the Muara Fajar landfill to prevent fires and air pollution caused by smoke.[11]

The gases to be studied in this research are NH3 and H2S as the sources of foul odor in waste, CH4 gas generated from the anaerobic decomposition of waste, and CO2 gas produced from the aerobic decomposition of waste. To monitor these hazardous gases at the Final Disposal Site, an Internet of Things (IoT)-based gas monitoring system will be developed using the MQTT Broker protocol for publishing and subscribing to the monitored gas data, which will be displayed on a website. The system will utilize sensors for detecting hazardous gases. Specifically, the MQ-136 sensor will detect H2S gas, the MQ-4 sensor will detect CH4 gas, and the MQ-135 sensor will detect NH3 and CO2 gases. This system aims to assist landfill management in preventing the impacts of hazardous gases on waste by providing real-time data and displaying it on the website. It is hoped that this system will provide valuable information about gas conditions and their status in the waste management efforts at the Muara Fajar landfill in Pekanbaru.[5][9]

The literature review conducted by the author encompasses several studies that serve as the foundation for the current research. One of the previous studies examined was titled "Monitoring System for Waste Volume and Gas Using Real-Time Operating System (RTOS)". The system observed the volume of waste and the gases generated by NH3, CH4, H2S, and infrared E18-D80NK sensors, employing a Real-Time Operating System (RTOS). The research findings revealed that, in the case of decomposed waste, the MQ-135 sensor recorded an average ammonia gas level of 35.71 PPM, the MQ-4 sensor detected methane gas at 293.5 PPM, the TGS2602 sensor indicated a hydrogen sulfide gas level of 9.738 PPM, and the Infrared E18-DN80NK sensor detected the height of the waste, triggering an "above threshold" output when the waste exceeded the sensor's limit and a "below threshold" output when the waste did not surpass the sensor's limit. Therefore, the gas emitted by the waste primarily consisted of methane [6]. Another study titled "Development of Air Pollution Detection Device for Industrial Exhaust Gases (H2S and NH3) Based on Microcontroller" focused on creating a gas detection device for industrial exhaust gases, particularly hydrogen sulfide (H2S) and ammonia (NH3). The device was based on a microcontroller and utilized semiconductor sensors: MQ-136 to measure H2S gas content within a range of 1-100 ppm, and MQ-137 as the NH3 gas sensor with a measurement range of 5-500 ppm [4]. In the subsequent study titled "Gas Monitoring System in the Final Disposal Site Based on the Internet of Things," the researchers developed a gas monitoring system for the final disposal site. The system employed the Internet of Things (IoT) and utilized the Wi-Fi ESP8266 module to transmit the monitoring results of methane gas concentration (CH4) using the MQ-4 sensor, carbon dioxide (CO2) concentration using the MQ-135 sensor, as well as temperature and humidity data using the DHT11 sensor. The collected data was then sent to the ThingSpeak server [5]. Furthermore, another study titled "Design and Implementation of Urban Waste Monitoring and Management System Using the Internet of Things" involved the integration of various sensors, including a laser sensor to detect waste volume, a load cell sensor to measure weight, and an MQ135 sensor to detect ammonia gas (NH3). The measurements obtained from the sensors were converted by an Arduino UNO R3 board and then transmitted to a Node MCU board via serial communication. The received data was uploaded to a real-time Firebase database and ultimately displayed in an Android application that allowed monitoring of waste status anytime and anywhere with an internet connection. This system aimed to improve the efficiency of waste management in urban areas for waste management personnel [2].

Based on the aforementioned studies, it provides an overview of the current research, which focuses on the design and implementation of a hazardous gas monitoring system at the final disposal site based on the Internet of Things (IoT). The system will utilize an ESPduino-32 microcontroller and gas sensors such as MQ-135, MQ-136, and MQ-4 to detect hazardous gases. The system will also incorporate graphical displays to provide information on gas concentrations, enabling effective and safe waste management. Through this research, it is expected that waste management personnel and the surrounding community can monitor the gas conditions and status at the disposal site, whether they are hazardous or not. This information will allow personnel to take the necessary steps and measures to handle hazardous gas conditions effectively.

2. RESEARCH METHOD

In this research process, a descriptive method is employed, which involves referencing several relevant research sources as a baseline for the current study. This allows the researcher to understand the previous research conducted and identify areas that can be further developed in future research. Subsequently, an experimental method is utilized, which involves creating a device tailored to the field requirements based on observations and interviews conducted with the waste disposal site managers. The device developed by the researcher is then directly tested in the field. Lastly, a qualitative method is employed to analyze and present the collected data on the device, providing information to users regarding the gas conditions at the site. This serves as an initial step in determining whether the gas conditions at the disposal site are hazardous or not, enabling appropriate mitigation measures to be taken in anticipation of such conditions.

The hazardous gas monitoring system utilizes several electronic components, including sensors, microcontrollers, a web application, a database, and the Telegram API. The sensors used include the MQ-136, which measures the concentration of Hydrogen Sulfide gas, the MQ-135, which detects gases such as ammonia, benzene, alcohol, carbon dioxide, and other hazardous gases, and the MQ-4, which is used to detect toxic Methane gas. The system is equipped with an Arduino Uno-shaped Microcontroller Development Board with an ESP32 MCU, a 32-bit dual-core chip that supports WiFi and Bluetooth BLE 4.0 and serves as the core of the system. MQTT is the data exchange protocol used in this research.

The system architecture of the IoT-based landfill Gas Monitoring System that will be developed can be seen in Figure 1 below

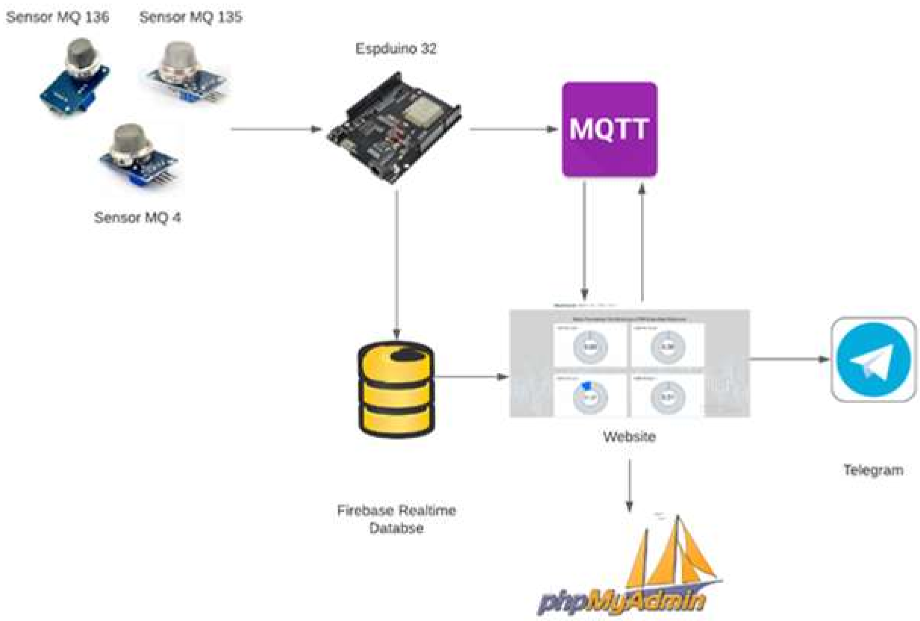

Figure 1. The architectural design of a gas monitoring system in a landfill

The system consists of MQ-135, MQ-136, and MQ-4 sensors, ESPduino 32, MQTT protocol, Telegram Website, phpMyAdmin Database, and Firebase Database. The System Architecture in Figure 1 shows the components and the design flow. The input of the system comes from the MQ-135, MQ-136, and MQ-4 sensors, which are connected to the ESPduino 32 communication module as a means of communication that provides WiFi access. Therefore, data from these sensors can be sent using the MQTT protocol through an MQTT Broker, where the ESPduino 32 acts as the Publisher that sends the data to the Subscribers. With WiFi internet access provided by ESPduino 32, notifications related to gas will be sent to Telegram in the form of a link that provides access to the gas status display on the website.

The MQTT Broker functions as a data transmission intermediary between the Publisher and Subscriber. After ESPduino 32 publishes sensor data, which includes topics from the gas sensors, through the broker, the broker will forward the data to the website, which acts as a data visualization and as a Subscriber that subscribes to the gas sensor topics. The Firebase Realtime Database is a real-time database that does not store historical sensor data but only displays real-time sensor data from ESPduino 32 on the website, which acts as a Subscriber. To store the historical sensor data, it is stored in the phpMyAdmin database. The flowchart in Figure 2 illustrates the process and mechanism of the device design.

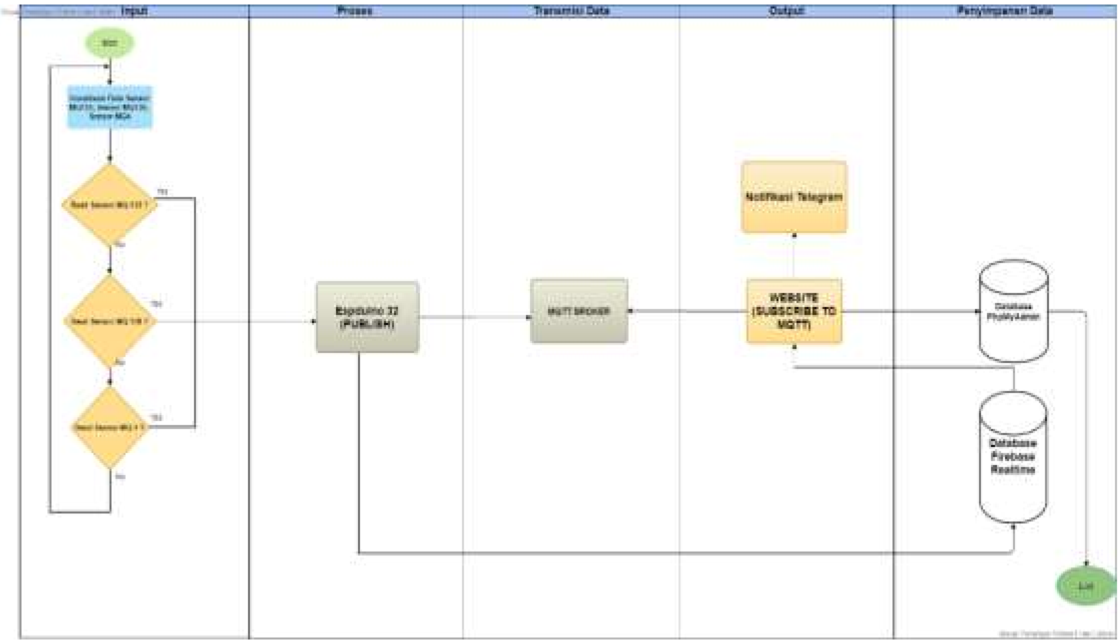

Figure 2. Flowchart of a swimlane monitoring system for hazardous gases in a landfill

The design prototype can be seen in the monitoring display of CH4, CO2, H2S, and NH3 gas concentrations in Figures 3 and 4. The status display model in Figure 4 will appear for each monitored gas, allowing the operator to see real-time updates and status information regarding the gas conditions at the landfill site. The displayed status will include "danger," "be careful," and "normal" for each gas condition.

The testing process is conducted in three stages: input testing, process testing, and output testing. In the input testing stage, the MQ-135 sensor is tested for detecting CO2 and NH3 gases, the MQ-136 sensor is tested for detecting H2S gas, and the MQ-4 sensor is tested for detecting CH4 gas. This testing phase aims to evaluate the performance and functionality of the sensors as well as the MQTT Broker protocol in accurately detecting gases over long distances. In the process testing stage, the designed conditions are adjusted to determine if they are appropriate. If the gas concentration exceeds the specified conditions, the testing will verify if the process functions according to the predetermined conditions. The conditions to be tested in the process testing include normal status when the gas concentration is within the specified range in parts per million (ppm), and dangerous status when it exceeds the specified range. The output testing is used to verify if the sensor data is successfully stored in the PhpMyAdmin database and if the gas sensor monitoring results in real-time from the Firebase database. When the gas concentration exceeds the specified conditions, the output will be in the form of a notification sent from Telegram to the website dashboard status. Overall, these testing stages ensure the accurate detection of gas concentrations, proper system functioning based on predetermined conditions, and successful storage and display of sensor data for monitoring purposes.

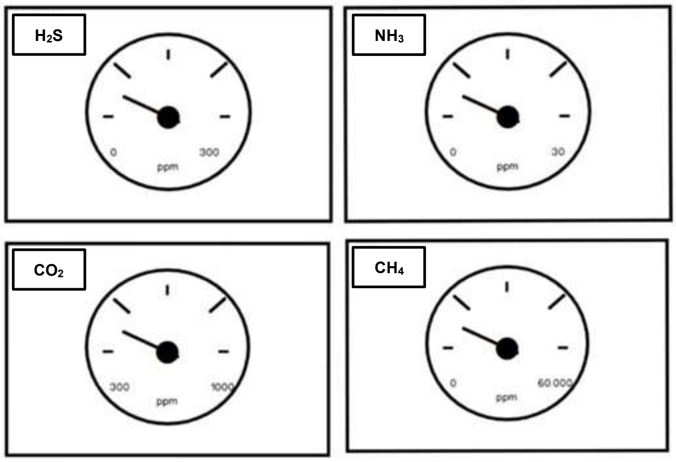

Figure 3. System dashboard prototype

Figure 4. Status display for each gas.

3. RESULT AND DISCUSSION

3.1. Hardware Implementation

Figure 5 shows the implementation of the hardware prototype design. The implementation includes various hardware components such as the MQ-135 sensor for detecting CO2 gas in the ambient air of the landfill site and NH3 gas for detecting air pollutants generated from the anaerobic decomposition of organic compounds, which results in odor in the waste. The MQ-136 sensor is used to detect H2S gas, which is a source of odor from the anaerobic decomposition of organic compounds in the waste. The MQ-4 sensor is employed to detect CH4 gas, which is a compound contributing to the odor in the waste. The microcontroller used for this implementation is the Espduino 32.

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Figure 5. Front, right and left side view of the gas detection device

In detail, the components of the Gas Detection Tool can be seen in Figure 6. An explanation of the component positions in Figure 6 above can be seen in Table 1.

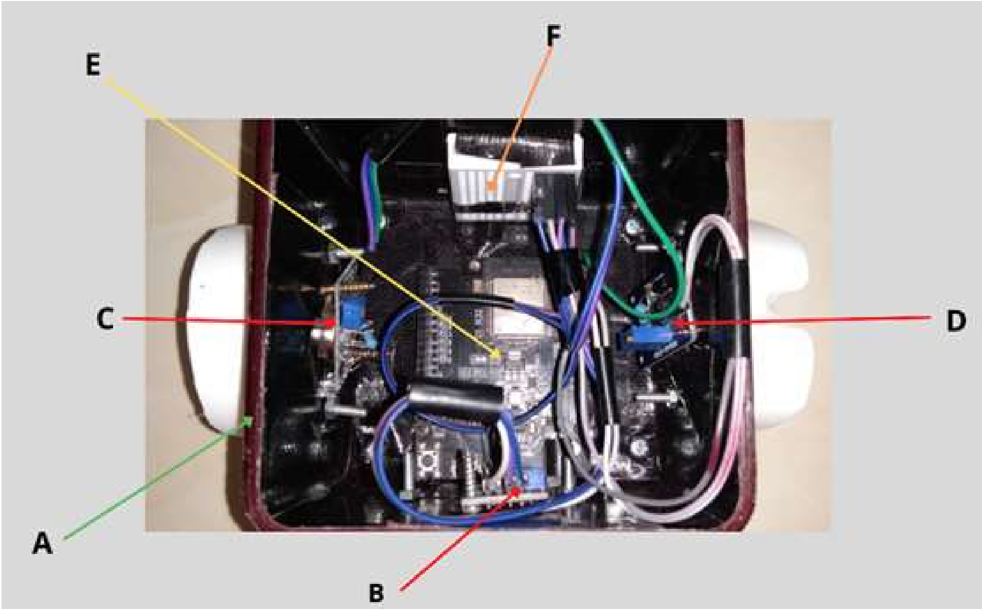

Figure 6. Position of the components on the gas detection device

Table 1. Details of the position of the gas detection device

Label	Component	Details
A	Box	The box is placed on the right side of the prototype which is used to place several components.
B	Sensor MQ-135	The MQ-135 sensor is placed at the front of the box. The MQ-135 sensor functions to detect CO2 and NH3 gases.
C	Sensor MQ-136	The MQ-135 sensor is placed at the front of the box. The MQ-136 sensor functions to detect H2S gas.
D	Sensor MQ-4	The MQ-135 sensor is placed at the front of the box. The MQ-136 sensor functions to detect CH4 gas
E	Mikrokontroler Espduino 32	Espduino 32 is placed in a box that functions as a microcontroller
F	Breadboard	Serves to make temporary electronic circuits for testing or prototyping purposes without having to solder.

3.2. Input Testing

In this testing phase, the success rate of the MQ-135, MQ-136, MQ-4 sensors, Espduino 32, and MQTT Broker is recorded. The testing process involves subjecting the sensors to specific conditions to determine if they can perform effectively according to their specifications and the type of gas they detect. Once the input testing process is successful, the next step is to conduct on-site testing at the landfill site, which serves as the research location.

Table 2. Input Testing

No	Name	details	result
1	Sensor MQ-135	Read CO_2 and NH_3 Gas	Berhasil
2	Sensor MQ-136	Read H_2S Gas	Berhasil
3	Sensor MQ-4	Read CH_4 Gas	Berhasil
4	Espduino 32	Publish Data	Berhasil

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5	MQTT Broker	Communicate data	Berhasil

In Table 2, it can be observed that the MQ-135, MQ-136, and MQ-4 sensors are able to read the gases present in the environment of Muara Fajar Pekanbaru landfill site. The MQ-135, MQ-136, and MQ-4 sensors function by measuring the gas values in the landfill site. Figure 7 illustrates the process of detecting and recording the sensor readings at the landfill site..

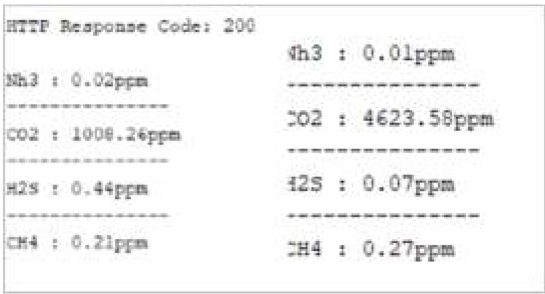

Figure 7. MQ-135, MQ-136, MQ-4 Sensor Values on the Arduino Serial Monitor

The results of this detection will be displayed on a Dashboard created for monitoring purposes by field officers and can serve as data or a source of information that can be processed daily by the officers and management of the landfill site. The testing process is conducted directly at the Muara Fajar landfill site, bringing all the necessary equipment and tools for the trial. This activity has obtained permission from the waste management authorities at the landfill site. Figure 8 shows the location where the researcher conducted the testing process.

Figure 8. Test site at the Muara Fajar landfill Pekanbaru

3.3. Process Testing

The conditions that will be tested in the process testing are as follows: when the gas level is within the specified range in parts per million (ppm), the status will be labeled as "Normal". If the gas level exceeds the normal range but is still within a certain threshold, the status will be labeled as "Be Careful". However, if the gas level exceeds both the normal range and the threshold, the status will be labeled as "Danger".

Figure 9 and Figure 10 show the notification status of the gas sensor detection results in terms of CO_2 concentration in ppm displayed on the web dashboard. In this case, the CO_2 status shows a value of 369.93 ppm, categorizing it as "Be Careful," indicating that the CO_2 level in the air in the landfill environment is not ideal for health. After a few seconds, the CO_2 concentration increases to 862.68 ppm.

Thus, the air quality in the landfill environment is categorized as "Dangerous" for the health of the community and workers at Muara Fajar landfill Pekanbaru. In Figure 9, there is also a notification status for H2S gas with a concentration of 10.20 ppm, categorized as "Be Careful," indicating that the odor from the waste falls under the "Be Careful" category for air and health concerns. After a few seconds, the H2S concentration increases to 479.61 ppm. Therefore, the air quality in the landfill environment is categorized as "Dangerous" for the health of the community and workers at Muara Fajar landfill Pekanbaru due to the odor emitted by the waste.

Figure 9. Condition and status of CO2 gas on the Dashboard

Figure 10. Condition and status of H2S gas on the Dashboard

In Figure 11, the notification status for NH3 gas shows a concentration of 0.03 ppm, categorized as "Be Careful," indicating that the odor from the waste falls under the "Be Careful" category for air and health concerns. As for the CH4 gas, based on the detection results, the concentration is less than 1000 ppm, categorizing it as "Normal." Regarding the "Normal" status, the detection results are not included as a notification status. Notifications are only triggered when the gas sensor readings exceed the "Be Careful" and "Danger" thresholds.

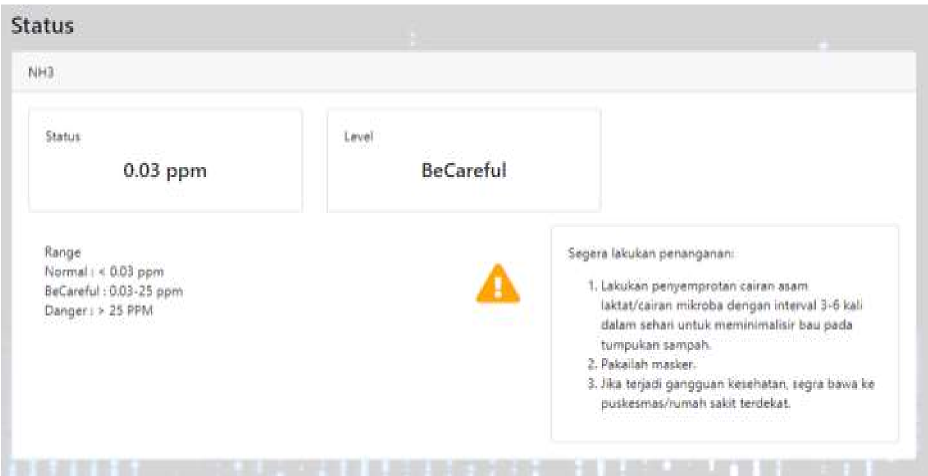

Figure 11. Condition and status of NH3 gas on the dashboard

3.4. Output Testing

The output testing is used to verify whether the sensor data has been successfully stored in the real-time Firebase database. Thus, when the gas levels exceed the specified conditions, the output will generate real-time status notifications on the web dashboard. The gas sensors' readings are displayed in real-time on the Firebase database. In this case, the CH4 gas shows a concentration of 0.03 ppm, CO2 gas has 148.75 ppm, H2S gas has 0.26 ppm, and NH3 gas has 0.00 ppm.

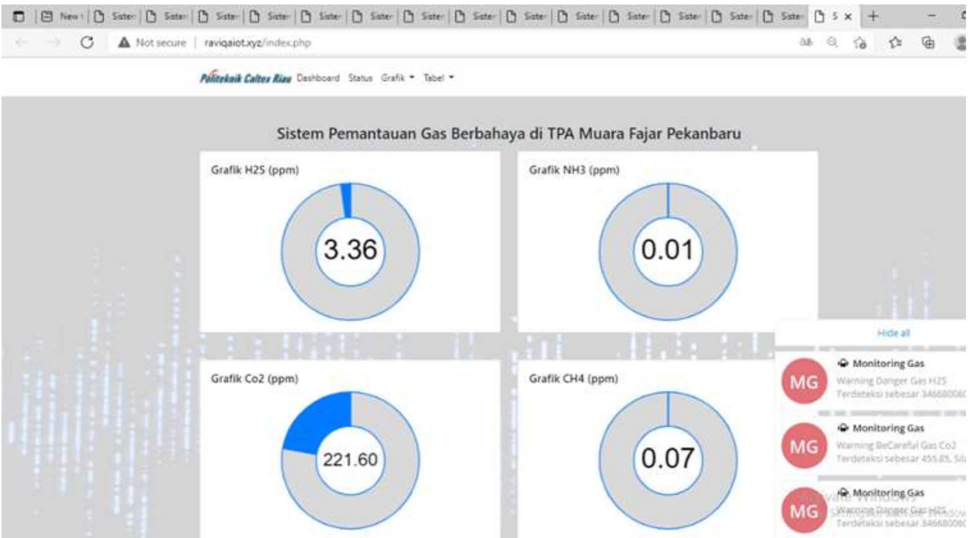

Figure 12. Display of Realtime Gas Monitoring on the Dashboard Chart

The detected gas sensor readings are also displayed on a real-time chart. The H2S gas has a concentration of 3.36 ppm, NH3 gas has 0.01 ppm, CO2 gas has 221.60 ppm, and CH4 gas has a concentration of 0.07 ppm.

4. CONCLUSION

After testing the hardware and software components, including the microcontroller components and web dashboard, it can be concluded that the prototype design is in accordance with the planned design. The prototype design is a Gas Monitoring System in the landfill using an Espduino 32-based website. The input testing results show that the MQ-135, MQ-136, and MQ-4 sensors are able to work and read the gas values present in the environment of Muara Fajar landfill Pekanbaru. The process testing results show that the CO2 gas has a concentration of 369.93 ppm, which falls under the "Be Careful" category, indicating that the CO2 air in the landfill environment is not good for health. After a few seconds, the CO2 gas concentration increased to 862.68 ppm, categorizing the air in the landfill environment as "Dangerous" for the health of the community and workers in Muara Fajar landfill Pekanbaru. The H2S gas testing results show a concentration of 10.20 ppm, categorized as "Be Careful." This indicates that the odor from the waste affects air pollution and health. After a few seconds, the H2S gas concentration increased to 479.61 ppm, further confirming that the air in the landfill environment is hazardous for the health of the community and workers due to the waste odor. The NH3 gas testing results show a concentration of 0.03 ppm, categorized as "Be Careful." This indicates that the odor from the waste affects air pollution and health. On the other hand, the CH4 gas testing results show a concentration below 1000 ppm, categorizing it as "Normal." In the output testing, the gas sensor readings were displayed in real-time on the Firebase database. The CH4 gas showed a concentration of 0.03 ppm, CO2 gas had 148.75 ppm, H2S gas had 0.26 ppm, and NH3 gas had 0.00 ppm. In conclusion, the research findings indicate that the environment of Muara Fajar landfill Pekanbaru is classified as having poor air quality and is not conducive to good health.

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