



Embedded System

Condition Monitoring System and Automatic Air Cleaning in the Toilet of Firebase-Based Andalas University Lecture Building

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A B S T R A C T

Maintaining the cleanliness and comfort of toilets in lecture buildings is very important for the quality of the campus environment. This study develops a Firebase-based Automatic Air Condition Monitoring and Cleaning System in the restrooms of Andalas University lecture halls. The main problem identified is the lack of direct monitoring, which leads to the appearance of unpleasant odors and potential health problems. A survey showed that 64.8% of respondents sometimes felt unpleasant odors, while 59.3% indicated a lack of adequate air circulation. To solve this problem, the designed system is able to detect and monitor toilet conditions in real-time through gas measurements such as ammonia, hydrogen sulfide, and carbon monoxide using MQ-135, MQ-136, and MQ-7 sensors, the results of which can be monitored through a website. The system not only monitors, but also controls air quality by turning on the exhaust fan when the gas level exceeds a certain. Tests show that the system is accurate in detecting gas, with sensor precision above 90% and an average data transmission time of 1.74 seconds. However, the humidity measurement showed an error rate of 32.36%. The system effectively improves the hygiene monitoring of restrooms, thereby improving comfort and health on campus

INTRODUCTION

Campus toilets that are generally used by many academicians must be considered regarding aspects of cleanliness and comfort. Poorly maintained toilets can be caused by low hygiene and lack of control and monitoring of cleaning facilities. Low toilet hygiene can create discomfort for users and potentially cause health problems and cause unpleasant odors [1].

Defecation and urination activities that are not flushed produce Ammonia (NH₃) and Hydrogen Sulfide (H₂S) gases and the bad habits of some people such as smoking in the toilet make the air in it smelly, dirty, and even toxic which produces Carbon Monoxide (CO) gas [1][2]. The problem of lack of cleanliness facilities at Andalas University is caused by not monitoring all

lecture buildings directly by the joint building coordinator, so it takes a long time to take action. Based on a survey using a questionnaire, 64.8% of respondents answered that sometimes there was an odor, 29.6% of respondents answered that it smelled, and 5.6% of respondents answered that it did not smell. 59.3% of respondents answered that there was not enough air circulation and 40.7% of respondents answered that there was sufficient ventilation.

Meanwhile, according to the Indonesian Public Toilet Standards book, the main priority of public toilets is an adequate ventilation system to overcome the humidity in the toilet room so that mold or mildew does not grow easily, and to be able to extract odors quickly in the toilet room [3]. In addition, according to the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning the Implementation Regulations of

Government Regulation Number 66 of 2014 concerning environmental health related to latrines / toilets "Having a sufficient number of latrines / toilets, clean, available running water, soap, trash, tissue / dryer, and good ventilation" [5].

To overcome these problems, a tool is designed with the ability to be able to detect the condition of the toilet, can provide real-time information on toilet conditions and notification of toilet conditions, can provide action if the toilet conditions are not in accordance with the standard. Based on these needs, this system aims to be able to detect and monitor the condition of toilets in the lecture building of Andalas University in real-time, as well as a system that can control the condition of the toilet.

METHOD

Hardware Design

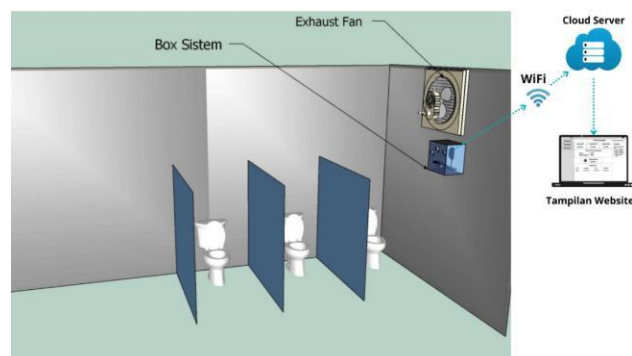


Figure 1. General System Design

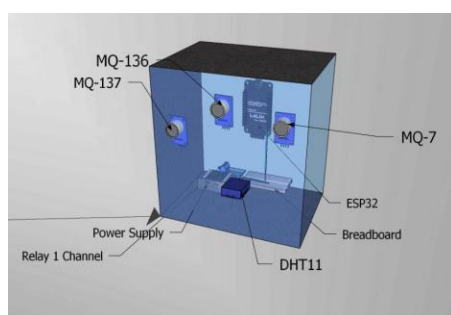


Figure 2. Tool Design

Figure 1. shows that the system will be placed in a toilet that has a size of $\pm 5 \times 3 \times 3$ m and the system is placed on the wall close to the place of defecation. The system box is connected to the internet network to send data from the system to Firebase (Firestore) and Firebase will send the data received so that it can be displayed on the website.

Meanwhile, Figure 2. shows the shape of the device to be made and the components used in the system. The system is a box measuring $18.5 \times 11.5 \times 6.5$ cm made of plastic. In the system there are 4 sensors used, namely the MQ-136 sensor to detect Hydrogen Sulfide, MQ-7 to detect Carbon Monoxide, MQ-135 to detect Ammonia, and DHT11 to read the temperature and humidity in the toilet. Input from each sensor will be processed by ESP32 with output in the form of information on the level of each gas in the toilet as well as information on the exhaust fan in the ON/OFF state. The output of the system will be displayed on the website.

Process Design

Figure.3 is a general design that explains how the whole system will run. The system starts by initializing the components in the system such as sensors and relays, then continues with the process of monitoring toilet conditions and all data is sent to the database. All data in the database is sent and displayed on the website

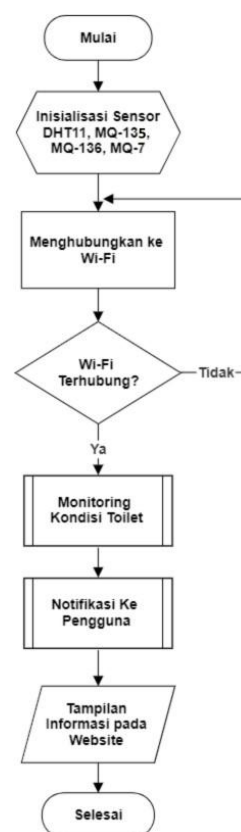


Figure 3. Flowchart of General System Design

While the monitoring flowchart can be seen in Figure 4., if CO is more than 2.5 ppm it will be checked again if NH₃ is more than 5 ppm then the air smells, the toilet is dirty, the exhaust fan will be active, otherwise the exhaust fan will be active, because the MQ sensor has a weakness that is disturbed if there are other gases. If CO is not more than 2.5 ppm then the next condition will be checked. If NH₃ is more than 2.7 ppm OR H₂S is more than 2.5 ppm AND CO is less than 1.3 then the exhaust fan will activate, the air smells, and the toilet is dirty. If NH₃ is more than 2.2 OR H₂S is more than 2 AND CO is less than 1.3 then the toilet is dirty. If the temperature is less than 20 or greater than 30 celcius then the relay is activated (ON) and the exhaust fan will activate, and the exhaust fan value will change to true. If the humidity is less than 39 or greater than 50 RH (Relative Humidity) then the relay is activated (ON) and the exhaust fan will activate, and the exhaust fan value will change to true. If all conditions are not met, the relay will be turned OFF and the exhaust fan will turn off.

Furthermore, all data is detected then proceed to the notification flowchart to the user in Figure 5, which begins with reading the condition of the toilet in firebase. If the toilet condition is dirty in the toilet status in the database, a notification will appear on the website indicating that the toilet condition is dirty, otherwise the toilet condition is clean and no notification appears

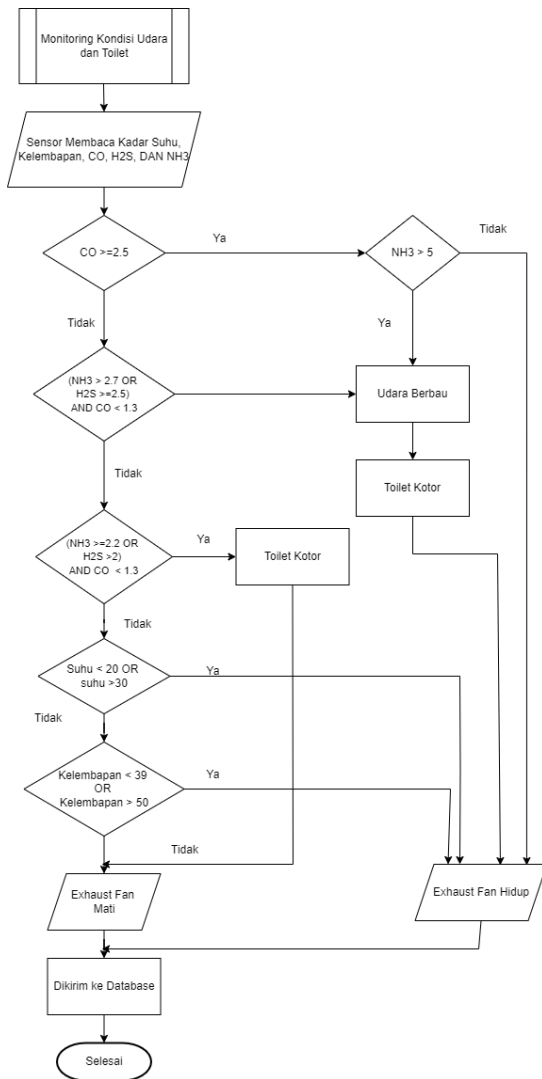


Figure 4. Flowchart: Monitoring

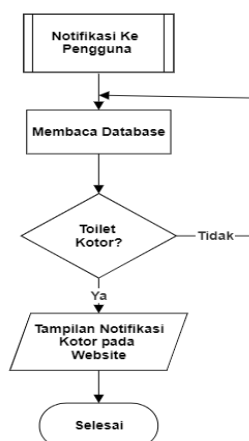


Figure 5. Flowchart: Notification

RESULTS AND DISCUSSION

Hardware Implementation

The hardware implementation was constructed using all the components shown in Figure 4.1, which include an ESP32, MQ-136 sensor, MQ-135 sensor, MQ-7 sensor, DHT11 sensor, relay, and power supply. Additionally, there is a power supply cable connected to the relay to automatically activate the fan. The hardware implementation was assembled in a box measuring 18.5 x 11.5 x 6.5 cm, which was placed under the exhaust fan to observe the influence of the exhaust fan when it is operational. The device was positioned 20 meters above the floor and in front of the restroom door for urinals or toilets.

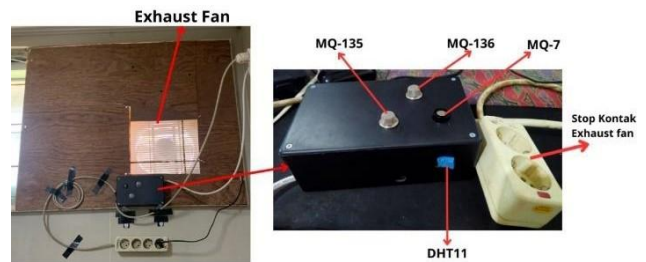


Figure 6. Outwardly visible hardware implementation

The internal structure of the hardware comprises several components, including a power supply, relay, and ESP32. The ESP32 is connected to all other components through a PCB, with the power supply providing a 5V 5A voltage source for all components, as shown in Figure 7.

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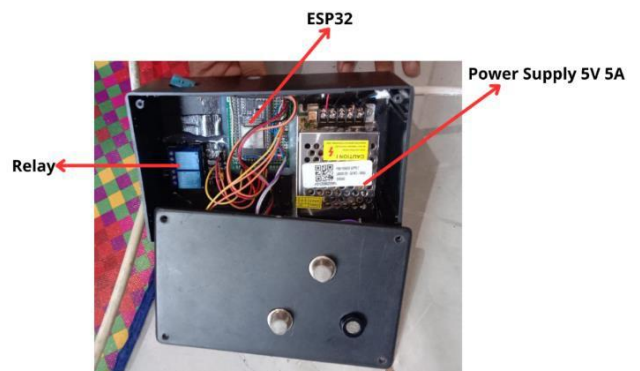


Figure 7. Hardware implementation looks from the inside

Software Implementation

The software implementation of the Monitoring Display on the website, as shown in Figure 8, includes several features, such as monitoring the condition of the toilet, air quality, gas levels in the toilet, background information, and exhaust fan status. The toilet condition will change to "dirty" if the data in Firestore indicates the toilet is dirty, or if ammonia levels exceed 2.2 ppm, hydrogen sulfide exceeds 2 ppm, and carbon monoxide is below 1.3 ppm.

Meanwhile, the air quality condition will change to "odorous" if ammonia levels exceed 2.7 ppm, hydrogen sulfide exceeds 2.5 ppm, or carbon monoxide exceeds 2.5 ppm.

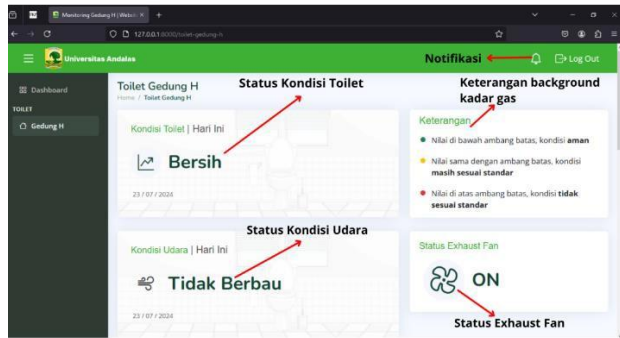


Figure 8. Website: Monitoring

The website's history display, as shown in Figure 10, includes data on time, NH₃, H₂S, CO levels, temperature, humidity, restroom condition, air quality, and exhaust fan status. This data is updated every 30 minutes based on changes in restroom conditions, enabling building coordinators to easily track when the restroom is clean or dirty.

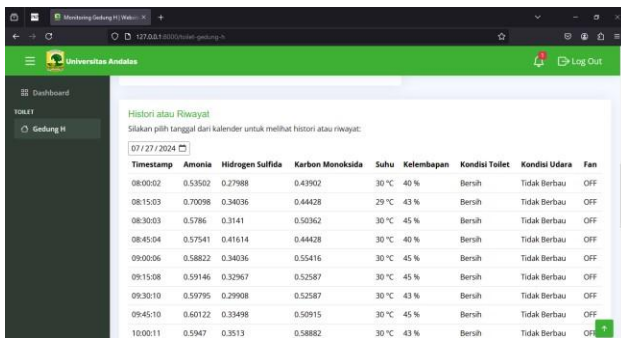


Figure 10. Website: History

Figure 11. shows the notification display when restroom data in Firestore is set to true or indicates that the restroom is dirty. The notification includes a message about the restroom's cleanliness and the time it was found dirty. If there are three unread notifications, the bell icon displays the number three. Once the notifications are read or the bell icon is accessed, the number disappears.

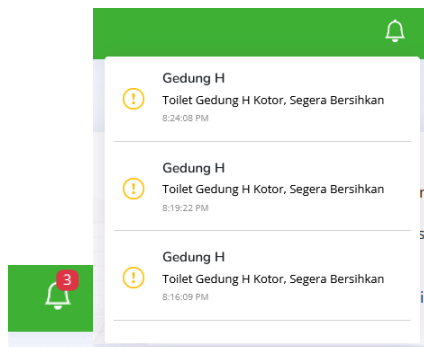


Figure 11. Website: Notification

Testing of MQ135

The testing was conducted for one minute, five times, in both clean air and ammonia-exposed air. Ammonia exposure was achieved using human urine in a container, with the same amount of urine used in each of the five trials. Each trial produced 60 data points, which were averaged and the precision calculated using equations 4.1 to 4.4[4].

$$\text{Mean} = \frac{\text{The sum of all data}}{\text{Lots of data}} \dots \dots \dots (1)$$

$$\text{Standard Deviation} = \sqrt{\frac{\sum (\text{Every data} - \text{Average})^2}{\text{Lots of data} - 1}} \dots \dots \dots (2)$$

$$\text{Coefficients of Variation} = \frac{\text{Standar Deviasi}}{\text{Average}} \times 100\% \dots \dots (3)$$

$$\text{Precision} = 100 - \text{Coefficients of Variation} \dots \dots \dots (4)$$

Based on the test steps that have been carried out and the calculations carried out with equations 1-4, the results obtained are as shown in Table 1 and Figure 12.

Table 1. MQ135 Testing Results

No	Average data	NH ₃ (ppm)	Clean Air (ppm)
1.	First Minute	137.21	0.58
2.	Second Minute	138.22	0.50
3.	Third Minute	142.65	0.57
4.	Fourth Minute	145.35	0.51
5.	Fifth Minute	150.87	0.49
Overall Average		142.86	0.53

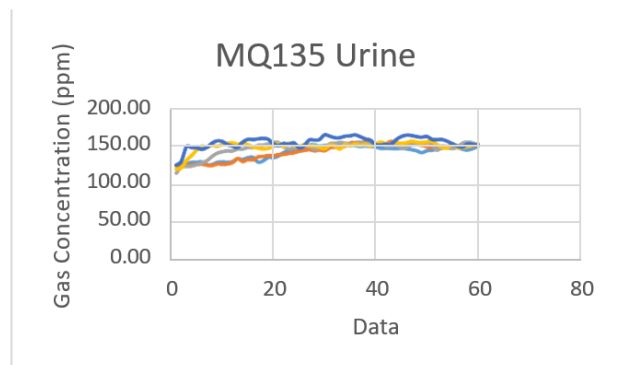


Figure 12. Ammonia Gas Exposure Testing Chart

Based on the test results, the average sensor reading in clean air is 0.53 ppm, the Coefficient of Variation is 7.55%, so the precision of the MQ135 Sensor when in clean air is 92.44%. Meanwhile, when exposed to ammonia gas, the average sensor reading in air exposed to ammonia gas is 142.86 ppm, with a Coefficient of Variation of 3.89% and the precision of the sensor when exposed to ammonia gas is 96.10%.

Testing of MQ136

This test was carried out for one minute five times in clean air and air exposed to hydrogen sulfide gas. In the air exposed to hydrogen sulfide gas is done using cat litter [47]. The test was carried out five times, so there were 60 data in each experiment

and the data for each experiment were averaged and the precision was calculated with equations 1-4. Based on the test steps that have been carried out and the calculations carried out with equations 1-4, the results obtained are as shown in Table 2 and Figure 13.

Table 2. MQ136 Testing Results

No	Average Data	H ₂ S (ppm)	Clean Air(ppm)
1.	First Minute	251.83	0.18
2.	Second Minute	251.76	0.15
3.	Third Minute	252.71	0.14
4.	Fourth Minute	250.27	0.19
5.	Fifth Minute	250.65	0.18
Overall Average		251.44	0.17

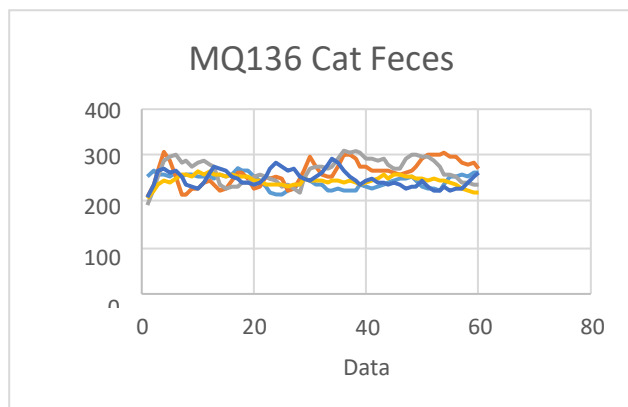


Figure 13. Hydrogen Sulfide Gas Exposure Testing Chart

Based on the test results, the average sensor reading in clean air is 0.17 ppm, the Coefficient of Variation is 14.12% and the precision of the MQ136 Sensor when in clean air is 85.87%. Meanwhile, when exposed to H₂S gas, the average sensor reading in air exposed to H₂S gas is 251.54 ppm, with a Coefficient of Variation of 8.86% and sensor precision of 91.13%.

Testing MQ7

This test is carried out for one minute five times in clean air and air exposed to carbon monoxide gas. Testing the MQ-7 in air exposed to carbon monoxide by inserting the sensor into a container that already contains carbon monoxide gas coming from the exhaust of a motorcycle by letting the container sit for 2 minutes on the motorcycle exhaust. The test was carried out five times, so that there were 60 data in each experiment and the data for each experiment were averaged and the precision was calculated with equations 1-4. Based on the test steps that have been carried out and the calculations carried out with equations 1-4, the results obtained are as shown in Table 3 and Figure 14.

Table 3. MQ7 Testing Results

No	Average Data	CO (ppm)	Clean Air(ppm)
1.	First Minute	20.21	0.46
2.	Second Minute	20.12	0.44
3.	Third Minute	21.04	0.43
4.	Fourth Minute	20.53	0.44
5.	Fifth Minute	20.90	0.44
Overall Average		20.56	0.44

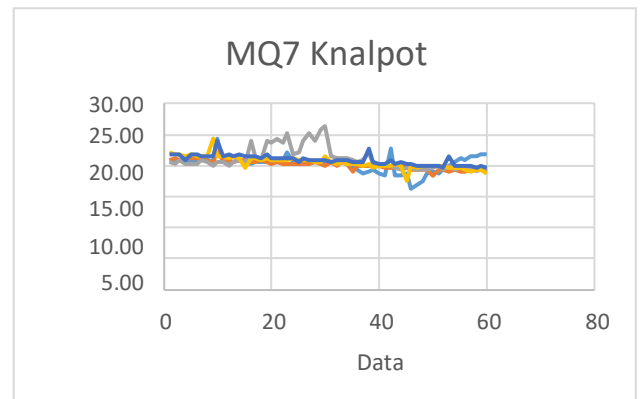


Figure 14. Carbon Monoxide Exposure Testing Chart

Based on the test results, the average sensor reading in clean air is 0.44 ppm, the Coefficient of Variation is 2.3% and the precision of the MQ7 Sensor when in clean air is 97.69%. Meanwhile, when exposed to carbon monoxide gas, the average sensor reading in air exposed to carbon monoxide gas is 20.56 ppm, the coefficient of variation is 6.19% and the sensor precision is 93.8%.

Testing of DHT11

Testing of the DHT11 sensor component was carried out with the help of HTC-01 as a temperature and humidity comparison which was carried out for 8 times by comparing the data on the website with the data on HTC-1, and calculating with equations 5-7.

$$\text{Average of difference} = \frac{\sum \text{Difference of Measurement}}{\text{Lots of data}} \dots \dots (5)$$

$$\% \text{error} = \frac{|\text{Sensor Value} - \text{HTC1 Value}|}{\text{HTC1 Value}} \times 100\% \dots \dots \dots (6)$$

$$\text{Average error} = \frac{\sum \% \text{error}}{\text{Lots of Errors}} \dots \dots \dots (7)$$

Based on the test steps taken, the DHT11 test results are shown in Table 4 for temperature and Table 5 for humidity. Based on testing and calculations with equations 5-7, it is found that the average difference in temperature is 0.55 °C and an average error of 1.75%. As for Humidity DHT11 has a fairly large average humidity difference of 25.13% and an average error of 32.36%.

Table 4. DHT11 Sensor Temperature Testing Results

DHT11 Testing Data (Temperature) / July 2, 2024				
Clock	DHT11(°C)	HTC 1(°C)	Difference	%error
14:50	31	32	1	0.03
15:02	31	30.9	0.1	0.003
15:12	31	31	0	0
15:21	31	31.6	0.6	0.01
15:30	32	31.9	0.1	0.003
15:41	31	31.9	0.9	0.02
15:51	32	32.1	0.1	0.003
16:00	29	30.6	1.6	0.05
Average of difference			0.55	1.75

Table 5. DHT11 Sensor Humidity Testing Results

DHT11 Testing Data (Humidity) / July 2, 2024				
Clock	DHT11(%)	HTC 1(%)	Difference	%error
14:50	57%	78%	17	21.79
15:02	52%	74%	22	29.72
15:12	44%	73%	29	39.72
15:21	48%	75%	27	36
15:30	46%	74%	28	37.83
15:41	50%	74%	24	32.43
15:51	47%	74%	27	36.48
16:00	47%	74%	27	36.48
Average of difference			25.12	32.36

Testing of Data Transmission

Data transmission testing is carried out for how long the average data transmission takes. Testing is done by calculating the comparison of the time of delivery on the serial monitor with the time the data is received by the database. Based on the test steps taken, the results of the Data Delivery test are shown in Table 6.

After testing by calculating the delivery time on the serial monitor until it is received by the database with 9 tests, the average delivery time is 1.74 seconds as shown in Table 6. The average delivery time of 1.74 seconds is a good enough time to be said to be real-time. This data transmission time can be influenced by the internet speed connected to the system. If the internet connection has a high speed, the data will be sent quickly, but when the connection has a low speed, the data sent will be long.

Table 6. Result Average Delivery time

No	NH ₃	Temperature (°C)	Delivery Time (second)
1	0.12	31	1.66
2	0.11	30	1.62
3	0.15	30	1.71
4	0.17	30	1.88

5	0.13	30	1.73
6	0.1	31	1.88
7	0.13	31	1.78
8	0.11	30	1.56
9	0.11	30	1.87
Average Delivery Time			1.74

Overall Testing

System testing is done by conditioning a dirty and smelly toilet with human urine. After conditioning the toilet to be dirty and smelly, it is seen how long it takes from conditioning the dirty toilet at the beginning until the toilet is detected as dirty in the system. After that, cleaning is carried out and it is seen how long it takes until the toilet is detected clean again.

Table 7. Overall Testing

Time	NH ₃	H ₂ S	CO	Temp	RH (%)	Toilet	Odor	Fan
14:46:12	0.74	0.19	0.59	30°C	42%	Clean	None	OFF
15:01:19	0.59	0.20	0.59	30°C	44%	Clean	None	OFF
15:16:17	0.88	0.20	0.67	30°C	45%	Clean	None	OFF
15:31:18	0.91	0.11	0.61	30°C	39%	Clean	None	OFF
15:40:05	2.30	0.30	1.29	30°C	40%	Dirty	None	OFF
15:40:09	2.18	0.27	1.25	30°C	40%	Clean	None	OFF
15:55:09	0.97	0.09	0.63	30°C	43%	Clean	None	OFF
16:10:11	1.15	0.13	0.62	30°C	43%	Clean	None	OFF
16:16:47	3.02	0.75	1.48	30°C	42%	Dirty	Smelly	ON
16:17:12	2.10	0.43	1.13	30°C	42%	Clean	None	OFF
16:18:05	2.53	0.98	1.18	30°C	42%	Dirty	None	OFF
16:19:11	1.78	0.45	1.24	30°C	42%	Clean	None	OFF
16:34:25	1.00	0.17	0.67	30°C	40%	Clean	None	OFF
16:49:23	1.07	0.16	0.68	30°C	39%	Clean	None	OFF

Based on the test results presented in Table 6, the system effectively activates the exhaust fan when certain conditions are met and can detect a dirty toilet from the gases produced by urine in the toilet. Additionally, the system has been able to detect dirty and foul-smelling toilets. The time taken for the system to detect a dirty toilet, in a toilet with dimensions of 5x3x3 meters, ranges from approximately 30 to 40 minutes, from around 3:00 PM to detection at 15:40 WIB. This is influenced by several factors, such as the time required for the gas to evaporate, the distance between the system and the toilet floor, and the relatively large size of the toilet. A dirty toilet due to gases from urine and feces will generally have a consistent dirty value until cleaned. This differs from a toilet detected as dirty due to other gases, where the value typically rises above 2 ppm only once or twice before dropping again due to the exhaust fan. The time needed for the toilet to be detected as clean again after cleaning is around 20 to 25 minutes, still affected by the remaining gases. After cleaning, the detected gas levels gradually decrease.

CONCLUSIONS

Based on the implementation and testing of the automated air monitoring and cleaning system in toilets, the system effectively monitors toilet conditions in real-time by detecting gases with an average data transmission time of 1.74 seconds, with results accessible via a website. The system detects dirty toilet conditions when ammonia levels exceed 2.2 ppm and hydrogen sulfide levels exceed 2 ppm during direct testing in a 5 x 3 x 3-meter toilet. The gas detection precision for each sensor when exposed to specific gases is as follows: MQ-135 (Ammonia) 96.10%, MQ-136 (Hydrogen Sulfide) 91.13%, and MQ-7 (Carbon Monoxide) 93.8%. The system also measures temperature accurately with an average error of 1.75%. Variations in gas sensor readings occur because human urine, cat feces, and motorcycle exhaust emit multiple gases, not just ammonia, hydrogen sulfide, and carbon monoxide, respectively, and due to the sensitivity of the sensors to specific gases. However, humidity measurements are less accurate, with an average error of 32.36%.

The system controls air quality using an exhaust fan that activates when certain thresholds are met: ammonia levels above 2.7 ppm, hydrogen sulfide levels above 2.5 ppm, or carbon monoxide levels above 2.5 ppm. Additionally, the system provides real-time notifications to the Building Coordinator via the website when the toilet is detected as dirty or when ammonia levels exceed 2.2 ppm and hydrogen sulfide levels exceed 2 ppm, with an average data transmission time of 1.74 seconds.

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