Indoor Air Quality Monitoring and Controlling System based on IoT and Fuzzy Logic

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Abstract — **Air pollution is one of the biggest health challenges in the world. Indoor air pollution is 2-5 times larger than outdoors, but people still do not care about it. Currently, people open the window or use an exhaust fan to refresh the air condition inside the room. However, people sometimes are too busy to pay attention to the air quality inside the room. Therefore, automation is required to bring the air quality into the required level. This study discussed indoor air quality monitoring and controlling system that can monitor the air condition and control the air condition using an exhaust fan. This system used the IoT concept in conducting real-time monitoring of carbon dioxide and PM10. The proposed system has fuzzy controls that could adjust the working interval of exhaust fan automatically depends on the concentration of each pollutant. Experiment results show that the proposed system shows excellent performance in controlling indoor air quality in terms of pollutant concentrator, AQI, and processing time to remove the pollutants.**

Keywords—Internet of Things, Fuzzy logic, Indoor air quality

I. INTRODUCTION

Polluted air in an indoor environment can be contaminated by harmful chemicals and other materials [1]. Air pollution can lead to various diseases such as asthma, wet lung, even coronary heart. Pollution can be done outside or indoors. However, people spend around 90% of their activities indoor, such as at the office, homes, and school. [2].

CO2 is one of the highest elements in the indoor environment due to respiration and activities of a human inside the room. High level of CO2 can make a variety of irritants and decrease cognitive performance [3]. Another material in the air that can effect for human health is PM10. There is a standard for indoor air quality gases concentration in a room from ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers). For PM10, Based on US Environmental Protection Agencies (EPA), the standards for PM10 concentration in 24-hour is 150 ug/m3. For carbon dioxide ppm maximum in an indoor room that still make comfort for human odor in the room, ASHRAE has standard 1000 PPM maximum in the room [4]. Air quality has an index that represents the quality of air. That has a value from 0 to 500 called AQI.

Indoor air quality monitoring needs to be implemented to control air quality in the room. Indoor air quality monitoring can ensure that the indoor environment in the room is safe for a stay or do activities[5]. With the current technology, Indoor air quality monitoring can also be integrated with the Internet. Internet of things (IoT) concept can be implemented on system indoor air quality monitoring. IoTis a technology that can make something smarter than before [6]. IoT system will monitor the indoor quality of air in real-time [7]. With the IoT, problems related to one of the limitations of storage on embedded system devices can be solved. Embedded systems do not need to use ample storage because all data is stored on cloud servers. Cloud servers can guarantee data integrity, data validity, and data values as a place to store and share data [8]. Raspberry Pi can also be used as a tool for IoT based projects because of its small form and requires low power. Raspberry Pi 3 has built-in Wireless adapter to connect to Wi-Fi for accessing the internet [9].

In this paper, the indoor air quality monitoring system based on IoT that could monitor the concentration of CO2 and PM10 density and control the fan using fuzzy logic is proposed. The data of sensors push by raspberry pi 3 to cloud server and present the data in the dashboard. This system used an exhaust fan to reduce the concentration of that materials inside the room and bring it to a safe level for humans [10][11]. This system has fuzzy logic to control interval of exhaust fan depends on gases concentration. It makes power usage of exhaust fan efficient when the concentration level of gases changes.

II. RELATED WORKS

There are several journals regarding indoor air quality monitoring that has been studied previously. Mukesh and Sakula made a system of indoor air quality monitoring using CO2 sensor, CO sensor, and raspberry pi 3 with the output system is DC fan, but the feature of DC fan only has ON/OFF state[5]. On that Mukesh's system, the user can turn on the ventilation fan manually from application in smartphone, when the air quality tolerable limit exceeds. Their suggestion for future research is that the system can be enhanced with various sensors and also increase the reliability and accuracy of the system. Mukesh's system also does not have automation to power on the ventilation fan when the limit of gases exceeds.

Another studied indoor air quality monitoring, Kumar made a system of indoor quality monitoring that integrated with a server in the cloud. Data of the sensor showed as a graph in the dashboard cloud server. MQTT protocol is vital to establishing communication between raspberry pi and the cloud server. A medium that used to connect from system indoor air quality monitoring to the internet is using a Wi-Fi access point[9]. On Kumar's system used various parameter for monitoring, there are PM 2.5, carbon monoxide, carbon dioxide, temperature, humidity, and air pressure. However, the system that made by Kumar does not have the actuator to pull out bad air in the environment of sensors.

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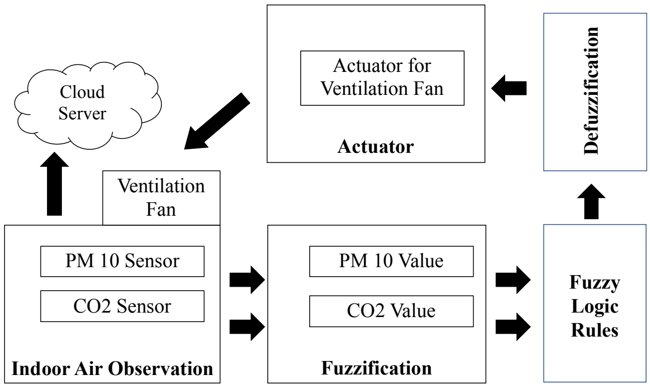

Fig. 1 General Architecture of the Proposed System

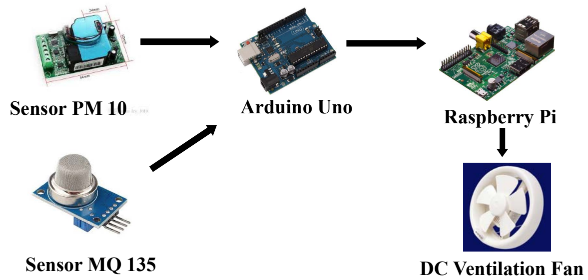

Fig. 2 Hardware Architecture of the System

Dr. Vivek proposed a ducting system using fuzzy logic control to distribute the air in the room. There are two inputs of fuzzy logic temperature and humidity. The output of fuzzy is to control the speed of a fan, pump, and duct in a fan. The system is using Mamdani fuzzy and has 30 rules. These system works appropriately to control the temperature and humidity of the room. However, Vivek's system does not have a monitoring dashboard to monitor real-time of environment. This system is using mat lab to compare the fuzzy in code with the simulation [12].

III. Proposed System Design

The proposed system architecture has four parts of the system. There are room environment, Fuzzy Logic process, Actuator system, and Cloud server. The room environment, including PM10, CO2 sensors, and exhaust fan. The proposed system indoor air quality monitoring has fuzzy logic control to set interval of exhaust fan automatically. There are fuzzy rules to create the possibility of many different situations of gases concentration. The result of defuzzification is a value of interval to tell how long exhaust fan will work. Data of sensors are sent to the AWS cloud server and provided as a dashboard for monitoring purpose. The dashboard is using kibana in AWS cloud. The dashboard consists of AQI PM10, AQI CO2, Real-time graph of PM10 value, and CO2 value in the room environment. User can access the dashboard from the browser of devices. Fig. 1 shows the general architecture of the proposed system.

A. *Hardware Design*

This system is using various hardware and sensors connected. The sensors used in this system are MQ-135 sensor for CO2 and Sharp GP2Y1010AU0F for PM10 density. In processing fuzzy logic, raspberry pi 3 is used in this system. Raspberry Pi is using raspbian 9 operating system. Raspberry Pi also has built-in Wi-Fi that can be used to connect to the AWS cloud server and send the data to the cloud server. Arduino UNO is also used for interfacing sensor and convert the analog value of the sensor with feature ADC (Analog to Digital Converter). All sensors are connected to Arduino UNO and will send the data to raspberry pi via serial cable.

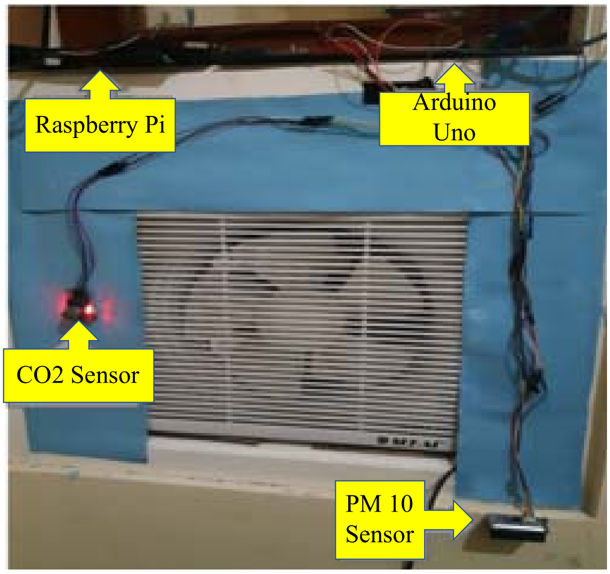

Fig. 3 System Implementation

This system is using exhaust fan as an actuator to pull out the air from the room — the exhaust fan mounts on the wall. The specifications of exhaust fan have dimension 10 inches with power usage 35 Watt. Moreover, it has 423 Cubic Feet Minutes (CFM) airflow. The exhaust fan will be working based on the interval that is produced by fuzzy logic. Fig. 2 shows hardware architecture and relation between each hardware. Figure 3 shows the implementation of all system installed in the room.

B. *IoT Cloud Platform and Dashboard*

Cloud server design includes designing all components in the AWS cloud server. The modules used in the AWS cloud server are AWS IoT, Elastic Search, and Kibana. Cloud server receives data, store, and present data in the form of dashboards to users. In the dashboard, the AQI values of CO2, PM10, and real-time values will be displayed for each sensor. The protocol used in sending data from raspberry pi to AWS IoT is the MQTT (Message Queuing Telemetry Transport) protocol. MQTT protocol uses the publish-subscribe method in sending and receiving data, which means the sender does not need to wait for the recipient to send confirmation of receipt of data. Raspberry Pi will publish data to brokers in the cloud server every 12 seconds. In the cloud server, there is an AWS IoT Rule service that will subscribe to the topics sent by raspberry. AWS IoT rule will also query the incoming message and send it to service elastic search.

Elasticsearch services store data published by AWS IoT into the database and filter data. Elasticsearch search will filter and query the topic of data contained in the AWS IoT. After configuration, service elasticsearch will generate a URL to open the dashboard. The URL can be accessed on

Fig. 4 Indoor Air Quality Monitoring Dashboard

Table 1 CO2 and PM10 Pre-evaluation Result

Parameters	High To Low (seconds)	High To Medium (seconds)	Medium To Low (seconds)
CO2	155	38	117
PM10	17	5	5

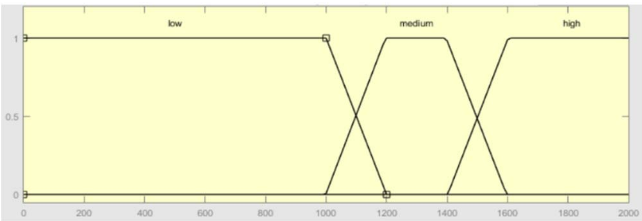

Fig. 5 Membership Function of CO2

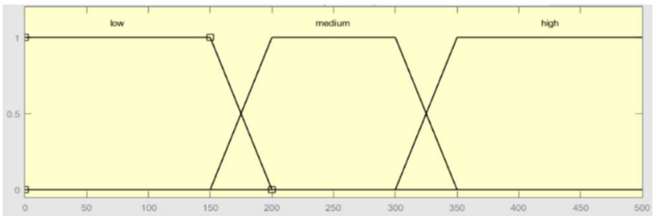

Fig. 6 Membership Function of PM10

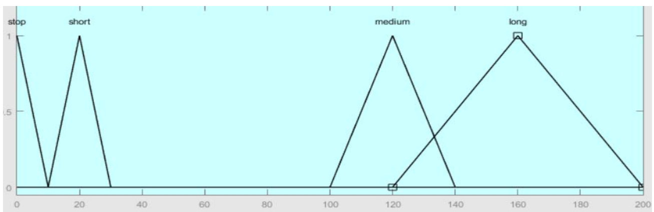

Fig. 7 Membership of the Output

mobile devices such as smartphones and laptops. The stored data can be displayed on the kibana dashboard. In the kibana module configurations can be done, such as selecting the chart type, color chart, and placement settings from the dashboard. Kibana in real-time displays data received by elasticsearch. In addition to displaying data in realtime, Kibana also can see the history of data that has been entered so that it makes it easy to search for the data needed.

Fig. 4 shows the dashboard of the monitoring system to present the data. In the dashboard, the data of PM10 and CO2 are shown. The upper part shows the indoor air quality (IAQ) level of the pollutants. It displays the real-time value of the pollutants and informs the user whether it is at a safe level or not according to the IAQ standard. While the lower part of the dashboard is the graphic of the real-time concentration value of pollutants every 30 seconds

C. *Fuzzy Logic for Controlling Exhaust Fan*

Fuzzy logic is a cryptic logic that has a value of membership between 0 and 1. The primary motivation in fuzzy logic theory is to map input space into output space using IF-THEN rules[13]. A complete fuzzy rule-based system consists of three main components: Fuzzification, Inference, and defuzzification[14].

This system proposed fuzzy logic to compute the interval of ventilation fan with Mamdani type fuzzy inference system. There are two inputs of fuzzy logic in this system and one output. Two inputs are Carbon Dioxide (CO2), and PM10. The output of fuzzy will generates the fuzzy result as an

Table 2 Fuzzy Rules of System

INTERVAL	CO2 - Low	CO2 - Medium	CO2 - High
PM10 - Low	Fan- Stop	Fan-Medium	Fan-High
PM10 - Medium	Fan-Short	Fan-Medium	Fan-High
PM10 - High	Fan-Short	Fan-Medium	Fan-High

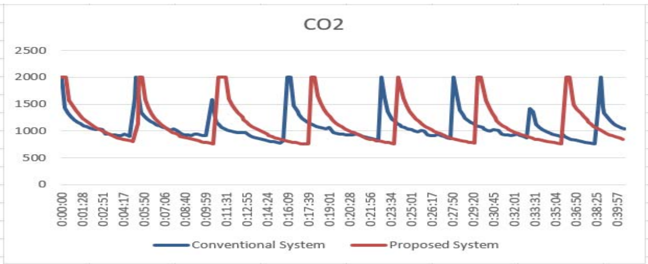

Fig. 8 CO2 Concentration Level Comparison in 1st Scenario

interval of exhaust fan in second. To determine the rule and membership value of the fuzzy output, we need to know the specification and characteristics of sensors CO2 and PM10. MQ 135 as Carbon Dioxide sensor can reach a maximum value of PPM is 2000. Also, Sensor Sharp GP2Y1010AU0F as PM10 that used in this journal has maximum read value is 500 ug/m3. To find the output membership range of the system, we need to figure out average value from exhaust fan ability to reduce CO2 and PM10 substance from the high to low, high to medium, and medium to a low level. According to the test of exhaust fan, the average time needed for the exhaust fan to pull out High level of CO2 from the room, is 155 seconds. Moreover, for the average time needed to pull out a high level of PM10 are 17 Seconds. Table 1 present the result of average CO2 and PM10 for each level.

After all sensors have been specified, the next step is setting the membership to input fuzzy from each sensor. On Fig. 5, there is 3 memberships function for CO2, which are low, medium, and high. Low membership of CO2 has a range from 0 - 1200 ppm with type trapmf. For Medium membership, it has a range 1000 - 1600 ppm with type trapmf. Also, For High membership it has a range from 1400 - 2000 ppm also in trapmf.

For PM10, it also defines three membership functions. The maximum value of this membership is 500 ug/m^3. The low condition has range 0 to 200 ug/m^3 with type trapmf. The medium condition has range 150 - 350 ug/m^3 with type trapmf and High Condition has range 300 - 500 ug/m^3 also with type trapmf — the details of PM10 membership present in Fig. 6.

The interval of fuzzy output has four definitions. Fan-stop will be generated if CO2-Low and PM10-Low. Fan-Short has interval range from 10 - 30 seconds, Fan-Medium has interval 100-140 seconds, and Fan-High has interval from 120 to 200 seconds. All membership of fuzzy output present in Fig. 7 below.

The proposed system has nine fuzzy rules. The rules are based on IF-THEN statement with AND operator. Due to the duration of wasting PM10 is fewer than CO2 in the same level of membership, thus to reduce the high level PM10 only need a few moments of fan interval. For example, if CO2 is in low condition and PM10 in High Condition, then Interval output

Table 3 Processing Time Comparison in 1st Scenario

No Attempts	Proposed System (minutes)	Conventional System (minutes)
1	2.52	3:05
2	2.29	3:15
3	2.53	3:19
4	2.40	3:05
5	2.27	3:19
Average	2:40	3:13

of exhaust fan only need low interval. The table 2 decscribes rules of fuzzy logic

IV. Results and Discussion

The main purpose of the system is to keep the indoor air quality index (AQI) at a safe level based on the ASHRAE standard. If AQI level in a room exceeds safe level, the system will work, and an exhaust fan will run for several times depending on the crisp value of the fuzzy result. After AQI level back to normal, the exhaust fan will stop. It will save power usage rather than the fan is always running. The system testing is to see how effective the system that made compared with a conventional ways exhaust fan that is always working anytime, even the condition of the room is good. The testing room used is a room that has a size of 3x3x3 meters, with ventilation that is only in the exhaust fan installed on the wall of the room. The sensors of system, MQ-135, and PM10 sensors, are placed in the room around the exhaust fan. To verify this system is running well, we test it with giving smoke to MQ-135 sensor. For PM10, we test it with giving aerosol particle until it reached 500 ug/m^3. The test was carried out with three scenarios. The first scenario when only CO2 reached high concentrations. The second scenario when only PM10 reached high concentration. The third scenario when both of them in high concentrations.

A. Evaluation with 1st Scenario (High CO2, low PM10)

This test is carried out to see the system performance when the condition of the room is given smoke, which causes the level of CO2 in the room to increase. Giving smoke to increase CO2 levels is given at intervals of about 5 minutes in 30 minutes of testing. In this evaluation, we measure when the CO2 achieves the high level (due to smoke) until it reaches low value due to exhaust fan that is activated by the fuzzy rule. This test compared the proposed system and the conventional method, which means it does not use the system and exhaust fan. The purpose of this test is to see changes in indoor CO2 levels. Fig. 8. is the result of CO2 testing for conditions of high CO2 levels and low PM10.

From table 3, The results of the average testing time required above, then it appears that the average time needed to reduce CO2 concentration if using a fuzzy logic is faster than the conventional one. The average time needed to reduce CO2 levels to a safe level is 2:40 minutes, whereas if without using the system, it takes 3:13 minutes.

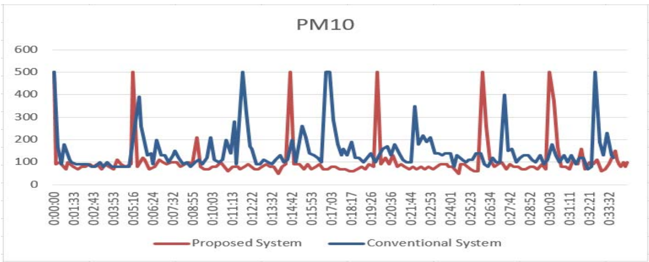

Fig. 9 PM10 Concentration Level Comparison in 2nd Scenario

Table 4 Processing Time Comparison in 2nd Scenario

No Attempts	Proposed System (seconds)	Conventional System (seconds)
1	14	26
2	14	40
3	14	55
4	14	53
5	26	2:09
6	28	40
Average	18.33	57.16

B. *Evaluation with 2nd Scenario (High PM10, Low CO2)*

This test is carried out to see the system performance when the condition of the room is given PM10 particles which cause the level of PM10 in the room to increase. Giving aerosol particle to increase PM10 levels is given at intervals of about 5 minutes in 35 minutes of testing. In this evaluation, we measure when the PM10 achieves the high level (due to aerosol) until it reaches low value due to exhaust fan that is activated by the fuzzy rule. This test compared the proposed system and the conventional method, which means it does not use the system and exhaust fan. The purpose of this test is to see changes in indoor PM10 levels. Figure 9 is the result of PM10 testing for conditions of high PM10 levels and low CO2.

From table 4, The results of the average testing time required above, then it appears that the average time needed to reduce PM10 concentration if using a proposed system is faster than the conventional one. The average time needed to reduce PM10 levels to a safe level is 18.33 Seconds, whereas with the conventional system, it takes 57.16 Seconds.

C. *Evaluation with 3rd Scenario (High PM10, High CO2)*

This test was conducted to see the system performance when the room conditions were given smoke, and PM10 particles simultaneously, which caused the levels of CO2 and PM10 in the room increased. Giving aerosol particles and smoke is given at intervals of about 5 minutes in 30 minutes of testing. In this evaluation, we measure when the CO2 and PM10 achieve a high level (due to smoke and aerosol) until it reaches low value due to exhaust fan that is activated by the fuzzy rule. This test compared the proposed system and the conventional method, which means it does not use the system and exhaust fan. The purpose of this test is to see the

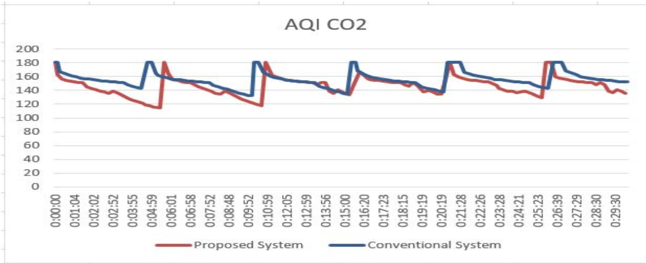

Fig. 10 CO2 AQI Level Comparison in 3rd Scenario

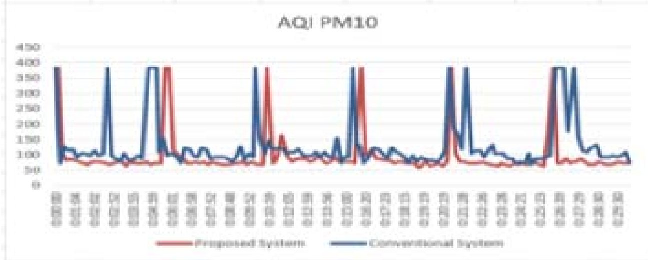

Fig. 11 PM10 AQI Level Comparison in 3rd Scenario

differences in CO2 AQI trends and PM10 AQI trends. Below are the results of testing of AQI CO2 and PM10 for conditions of high CO2 levels and high PM10.

According to Fig. 10, we can see that through the proposed system, the interval of safe CO2 AQI values that can be obtained in 30 minutes test are 16.3 Minutes. Whereas the safe AQI value interval that was obtained using the conventional system is only 8.13 Minutes. From the comparison of CO2 AQI interval values, it can be concluded that the proposed system can produce a safe AQI PM10 value longer than the conventional system. From Fig. 11, the interval of safe PM10 AQI values obtained in 30 minutes test is 26.4 Minutes. Whereas the safe AQI value interval that was obtained using a conventional system is only 14.3 Minutes. From the comparison of the PM10 AQI interval values, it can be concluded that the proposed system can produce a safe AQI PM10 value longer than the conventional system.

V. CONCLUSION

In this paper, we have proposed an indoor air quality monitoring based on IoT and Fuzzy Logic. Based on the performance of the proposed system after implementation and testing, it can be concluded that this proposed system can monitor the indoor air quality in real-time and effective to keep a good quality of air. Also, exhaust fan in the system is wasting PM10 faster than CO2, and so interval performance of exhaust fan to waste CO2 is longer than PM10. Moreover, this made system could also generate AQI value in safe level longer than the conventional system. Also, it can save more energy rather than exhaust fan always working like traditional ways because on this system exhaust fan only work when AQI level is not normal.

ACKNOWLEDGMENT

This publication is fully supported by Bina Nusantara University.

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