Indoor Air Quality Monitoring System With Fuzzy Logic Control Based On IOT

Fadli Pradityo, Nico Surantha

Abstract: Air pollution is the biggest challenge of health in the world. Air pollution in a room, as inside home, is 2-5 times greater than outdoors. In this study, we developed an indoor air quality monitoring system to detect and dispose bad air out of the room. Proposed system applied internet of things concept to do monitoring of air quality for gases of carbon dioxide (CO_2) and PM10 gases. The sensors of CO_2 and PM10 are connected to Arduino UNO to process analog to digital signal.This system has a mamdani fuzzy logic rule to efficiently set the working interval of exhaust fan. To process fuzzy logic rules, it used Raspberry Pi 3 in this proposed system.Based on result, Proposed System can maintain PM10 and CO_2 AQI for safety level in longer periods compared to the system that used sugeno fuzzy logic system. For AQI PM10 values, if using the proposed system in 30 minutes, the interval of safe AQI values obtained in 30 minutes is for 1501 seconds. Whereas the safe AQI value interval obtained with fuzzy sugeno system only 1018 seconds. And for the value of AQI CO_2, if using the system in 30 minutes, the interval of safe AQI value obtained in 30 minutes is for 816 seconds. Whereas the safe AQI value interval obtained with fuzzy sugeno system only 686 seconds.

Index Terms: Internet of Things, Fuzzy Logic, Raspberry Pi 3, Arduino Uno, Indoor Air Quality, AQI, Exhaust Fan

1. Introduction

Polluted air in indoor environment can be contaminated by harmful chemicals and others 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 office, homes, school, etc. [2]. CO_2 is one of highest elements in indoor environment due to respiration and activities of human inside the room. High level of CO_2 can make variety of irritants and decrease cognitive performance [3]. Another material in the air that can effect for human health is PM10. There is standard for indoor air quality gases concentration in 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/m^3. For carbon dioxide ppm maximum in indoor room that still make comfort for human odor in room, ASHRAE has standard 1000 PPM maximum in the room [4]. Air quality has index that represent the quality of air. That has value from 0 to 500 called AQI. Indoor air quality monitoring needs to be implemented to control air quality in room. Indoor air quality monitoring can ensures that indoor environment in room is safe for stay or do activities[5]. With the current technology, Indoor air quality monitoring can also integrated with Internet .Internet of things concept can be implement on system indoor air quality monitoring. Internet of Things is technology that can make something smarter than before [6].

- *Fadli Pradityo, Computer Science Department, Binus Graduate Program- Master of Computer Science, Bina Nusantara University, Jl. Kebon Jeruk Raya No 27, Jakarta 11480, Indonesia, E-mail: fadli.pradityo@binus.ac.id*
- *Nico Surantha, Computer Science Department, Binus Graduate Program-Master of Computer Science, Bina Nusantara University, Jl. Kebon Jeruk Raya No 27, Jakarta 11480, Indonesia, E-mail: nico.surantha@binus.ac.id*

Internet of Things system will monitor the indoor quality of air in real-time [9]. With IoT, problems related to one of the limitations of storage on embedded system devices can be solved. Embedded systems do not need to use large 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 [10]. Raspberry pi can also be used as a tool for Internet of things 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 internet [11]. In this paper, author's proposed system is indoor air quality monitoring that could monitor concentration of CO_2 and PM10 density. The data of sensors push by raspberry pi 3 to cloud server and present the data in dashboard. To reduce the concentration of that materials inside room and bring it to secure level for humans, this system used ventilation fan [7][8]. This system has fuzzy logic to control fan speed depend on gases concentration. It makes power usage of ventilation fan efficient when the concentration level of gases changes.

2. Related Works

There are several journals regarding indoor air quality monitoring that has been studied previously. Mukesh and Sakula made system of indoor air quality monitoring using CO_2 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, user can turn on the ventilation fan manually from application in smartphone, when the air quality tolerable limit exceeds. Their suggestion for the future research is the system can be enhanced with various sensors and also increase the reliability and accuracy of system. Mukesh's system also doesn't have automation to power on the ventilation fan when limit of gases exceeds. Another studied about indoor air quality monitoring, Kumar made system of indoor quality monitoring that integrated with server in cloud. Data of sensor showed as graph in dashboard cloud server. MQTT protocol is important to establishing communication between raspberry pi and the cloud server. Medium that used to connect from system indoor air quality monitoring to internet is using 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. But the system that made by Kumar doesn't have the actuator to pull out bad air in environment of sensors. Dr. Vivek proposed ducting system using fuzzy logic control to distribute air in the room. There are two inputs of fuzzy logic temperature and humidity. The output of fuzzy is to control the speed of fan, pump, and duct in fan. The system is using mamdani fuzzy and has 9 rules. These system works properly to control the temperature and humidity of room. But Vivek's system doesn't have monitoring dashboard to monitor real-time of environment. This system is using mat lab to compare the fuzzy in code with the simulation [14]. Supina Batubara in the journal "Comparative Analysis of Fuzzy Mamdani And Sugeno Methods for Determining the Quality of Cast Concrete", comparing between fuzzy mamdani and fuzzy sugeno methods in accelerating the quality of concrete cast. In the mamdani method, defuzification uses centroid method where the crips value is obtained by taking the center of the fuzzy region. From the test results, the conclusions that can be taken are the mamdani and sugeno methods can be used to determine the quality of cast concrete, but the mamdani method is better because it is closer to the actual results compared to Sugeno[15].

3. Proposed System

Proposed system architecture has 4 parts of system. There are room environment, Fuzzy Logic process, Actuator system, and Cloud server. The room environment including PM10, CO2 sensors, Raspberry Pi3, Arduino, Relay switch and exhaust fan. Arduino will change the analog data of sensors to digital data. The proposed system indoor air quality monitoring has fuzzy logic control to setting interval of exhaust fan automatically. The input of fuzzy logic is from digital data that send from sensors. There are fuzzy rules to create possibility of many different situation of gases concentration. The result of defuzzification is value of interval to tell how long exhaust fan will work. After interval of time is reach, exhaust fan will off again and wait for the next input from output of fuzzy logic.

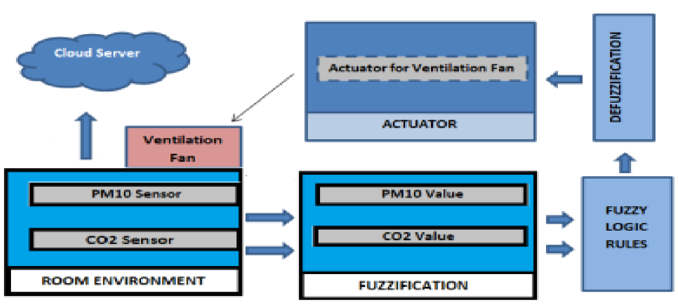

Fig 1. General Architecture of Proposed System

Data of sensors are sent to AWS IoT cloud server and provided as dashboard for monitoring purpose. The data sent by MQTT(Message Queuing Telemetry Transport) protocol. Raspberry pi 3 will publish string of data CO2 and PM10 to MQTT broker in AWS IoT server using internet.. 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 room environment.. User can access the dashboard from browser of devices. Below is the flowchart of proposed system.

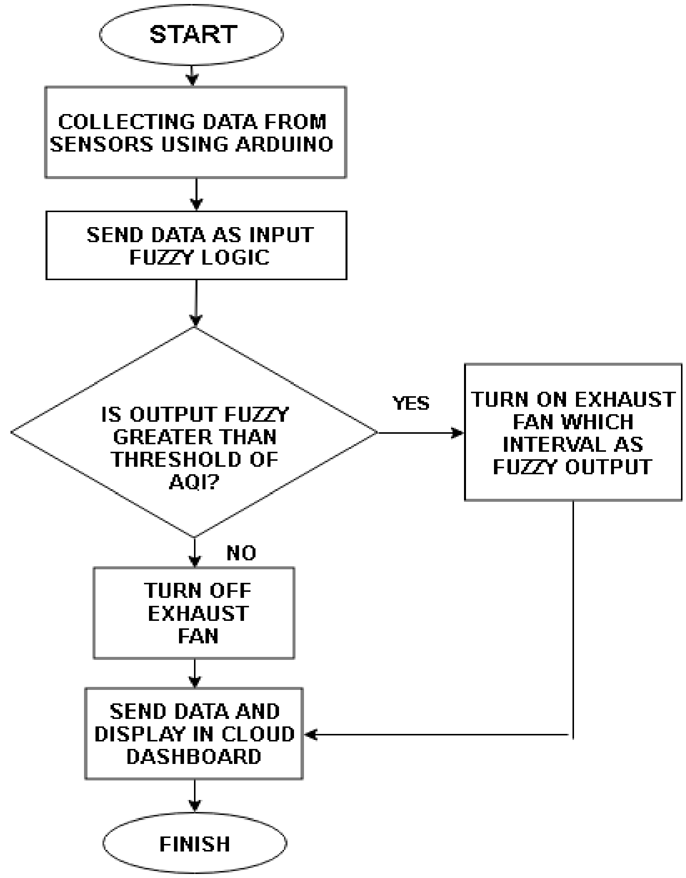

Fig 2. Flowchart of Proposed System

3.1 Hardware Design

This system is using various hardware and sensors that connected to each other. 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 3 is using raspbian 9 operating system. Raspberry pi also has built in Wi-Fi that can be used to connect to AWS cloud server and send the data to the cloud server. Raspberry Pi 3 running some python script and bash scripts that used to process fuzzy logic and send data to the cloud server. Arduino UNO is also used for interfacing sensor and convert analog value of 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. This system is using exhaust fan as actuator to pull out the air from room. The exhaust fan mounts on the wall. The specifications of exhaust fan has dimension 10 inch with power usage 35 Watt. And for air flow, it has 423 Cubic Feet Minutes (CFM). Exhaust fan will working based on the interval that produce by fuzzy logic.

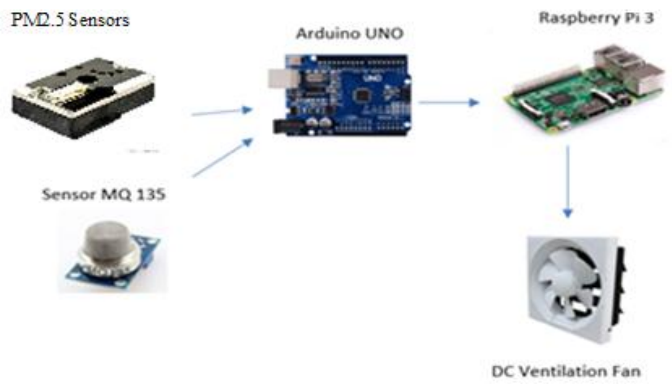

Fig 2. Hardware Architecture of System

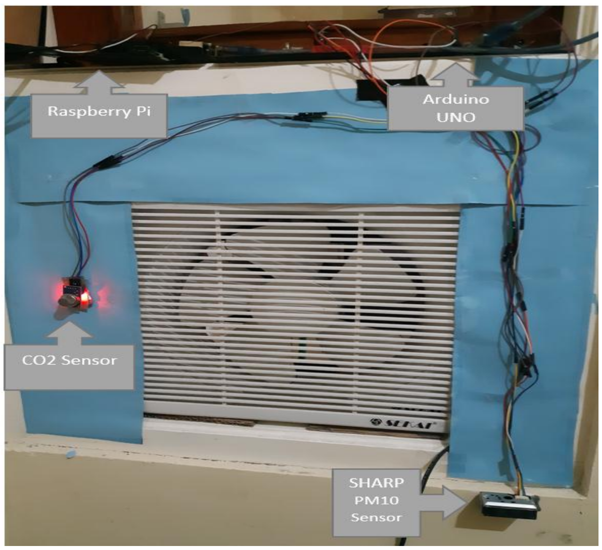

Fig 3. Implementation of System

3.2 Fuzzy Logic

Fuzzy logic is a cryptic logic that has a value of membership between 0 and 1. The main motivation in fuzzy logic theory is to map input space into output space using IF-THEN rules [12]. A complete fuzzy rule-based system consists of three main components: Fuzzification, Inference and Defuzzification[13]. This system proposed fuzzy logic to compute the interval of ventilation fan with Mamdani type fuzzy inference system. There are 2 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 interval of exhaust fan in second. To determine the rule and membership value of fuzzy output we have to know the specification and characteristics of sensors CO2 and PM10. MQ 135 as Carbon Dioxide sensor can reach maximum value of PPM is 2000. And Sensor Sharp GP2Y1010AU0F as PM10 that used in this journal has maximum read value is 500 ug/m^3. To find the output membership range of system, we need to figure out average value from exhaust fan ability to waste CO2 and PM10 substance from the high to low, high to medium, and medium to high level. According to the test of exhaust fan, the average time needed for exhaust fan to pull out High level of CO2 from the room, are 155 seconds. And for average time needed to pull out high level of PM10 are 17 Seconds.

Table 1. CO2 & PM10 pre-evaluation result

Units	High To Low	High To Medium	Medium To Low
CO2	155 Seconds	38 Seconds	117 Seconds
PM10	17 Seconds	5 Seconds	5 Seconds

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

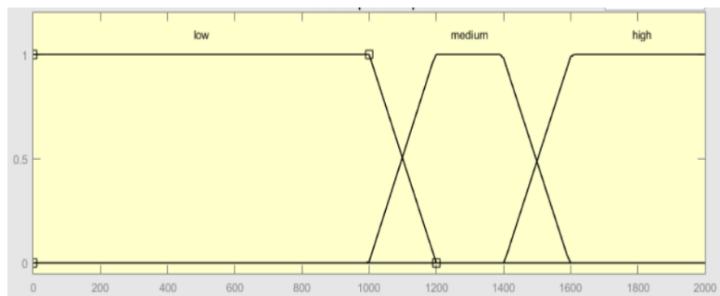

Fig 4. Membership of CO2

For PM10, it also defines three membership functions. The maximum value of this membership is 500 ug/m^3. Low condition has range 0 to 200 ug/m^3 with type trapmf. 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. Below is membership input of PM10.

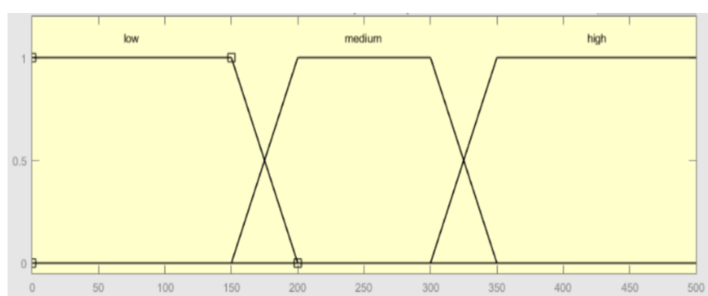

Fig 5. Membership of PM10

The interval of fuzzy output has 4 definitions. Fan-stop will generated if CO2-Low and PM10-Low. Fan-Short has interval range from 10 - 30 seconds with type trimf, Fan-Medium has interval 100-140 seconds with type trimf, and Fan-High has interval from 120 to 200 seconds with type trimf.The membership of output is define based on pre-evaluation result of CO2 and PM10.

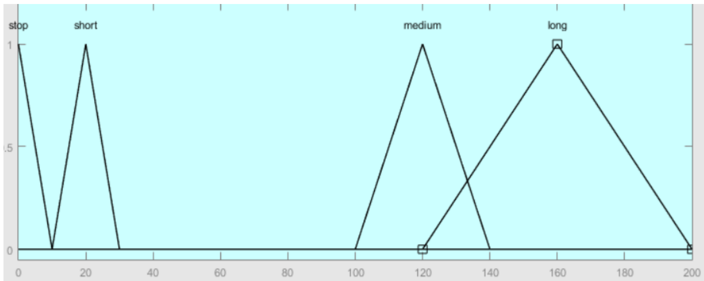

Fig 6. Membership Fuzzy Output

The proposed system has 9 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 waste high level PM10 only need a few moment of fan interval. For example if CO2 is in low condition and PM10 in High Condition, then Interval output of exhaust fan only need low interval. Following table are describing rules of fuzzy logic.

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

3.3 Cloud Server Design

Cloud server design aims to display the data of sensors and AQI value into a dashboard that can be seen directly by users. This system used Amazon Web Service as IoT cloud provider. The Block hardware system publish the data of sensors using internet to AWS IoT service with MQTT Protocol. AWS IoT service meet as broker in MQTT protocol communication. Furthermore, all data entered into the cloud server will be store in Elasticsearch database. Elasticsearch also do the indexing of data, so the data can be displayed on the dashboard that will be access by user. Dashboard of system using kibana plugin. Kibana display the AQI value of CO2 and PM10, and also PPM of CO2 and PM10 in graph and realtime mode.

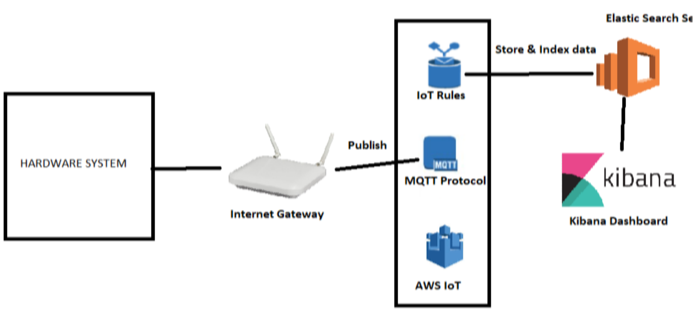

Fig 7. Cloud Server Design

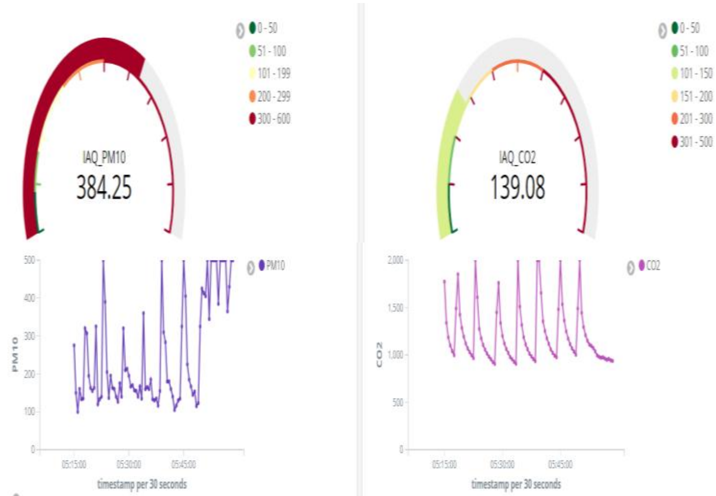

Fig 8. Dashboard of System

4. System Testing

The main purpose of system is to keep indoor air quality index (AQI) in safe level based on ASHRAE standard. If AQI level in room exceed safe level, system will work and exhaust fan will running for several times depend on crisp value of fuzzy result. After AQI level back to normal, 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 proposed system that made based on Mamdani Fuzzy compared with the system that running with Sugeno Fuzzy. To verify this system running well, we test it with give smoke to MQ-135 sensor until it reach maximum level that is 2000 ppm. In fuzzy setting, 2000 ppm is in high level of membership of CO2. And for PM10, we test it with give aerosol particle until it reached 500 ug/m^3. So all sensor are in High level membership of fuzzy. 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 get rid of air out of the room, the exhaust fan will rotate as air circulation. The system will check concentration of CO2 and PM10 every 14 seconds and produce fuzzy crisp result. Interval of working exhaust fan is based on crisp value of fuzzy result. The system will calculate fuzzy again after exhaust fan finished working as interval of previous fuzzy result. Below are the result of average time needed to dispose CO2 from high to low concentrations.

Table 3. Testing of Average Time between Proposed System and Sugeno System for CO2

Testing	Proposed System	Sugeno System
1	High To Low = 1:40 minutes	High To Low = 2:14 minutes
2	High To Low = 1:29 minutes	High To Low = 2:43 minutes
3	High To Low = 2:36 minutes	High To Low = 2:57 minutes
4	High To Low = 2:17 minutes	High To Low = 2:34 minutes
5	High To Low = 2:16 minutes	High To Low = 3:01 minutes
Average Time	2:03 minutes	2:41 minutes

Table 4. Result of CO2 Group Statistics when CO2 and PM10 High

Method	Total Data	Mean	Std. Deviation	Std. Error Mean
Proposed	131	1061.62	248.948	21.751
Sugeno	131	1156.36	276.885	24.192

From table 3, it can be seen that the average time to reduce concentration of CO2 from high to low of proposed system is shorter than system that using fuzzy sugeno. And from table 4, Total data of testing are 131 data, that same between proposed system and sugeno system. The mean value of proposed method is 1061,62, and the mean value for system with sugeno fuzzy is 1156,36. Thus, it can be concluded that there are significant differences between the two methods , but the proposed system is better to reduce CO2 concentration because it has a smaller mean value than system with sugeno fuzzy. For PM10 testing, Below is the table Result of PM10 average time needed to dispose CO2 from high to low concentrations and Group Statistics when CO2 and PM10 High.

Table 5. *Testing of Average Time between Proposed System and Sugeno System for PM10*

Testing	Proposed System	Sugeno System
1	High To Low = 40 Seconds	High To Low = 38 Seconds
2	High To Low = 40 Seconds	High To Low = 40 Seconds
3	High To Low = 26 Seconds	High To Low = 26 Seconds
4	High To Low = 14 Seconds	High To Low = 26 Seconds
5	High To Low = 14 Seconds	High To Low = 14 Seconds
Average Time	26 Seconds	28.8 Seconds

Table 6. Result of CO2 Group Statistics when CO2 and PM10 High

Method	Total Data	Mean	Std. Deviation	Std. Error Mean
Proposed	131	134.89	97.967	8.559
Sugeno	131	136.03	84.395	7.374

From table 5, it can be seen that the average time to reduce concentration of PM10 from high to low of proposed system is shorter than system that using fuzzy sugeno. From table 6, Total data of testing are 131 data, that same between proposed system and sugeno system. The mean value of proposed method is 134,89, and the mean value for system with sugeno fuzzy is 136,03. Thus, it can be concluded that there are significant differences between the two methods , but the proposed system is better to reduce PM10 concentration because it has a smaller mean value than system with sugeno fuzzy.

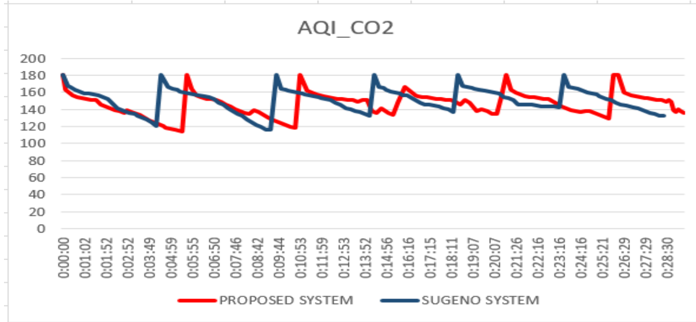

Fig 9. AQI Testing of CO2

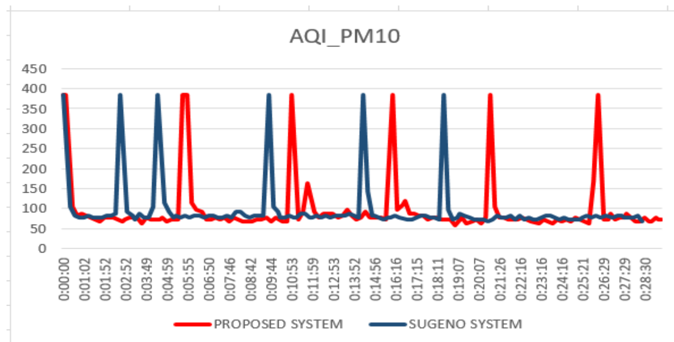

Fig 10. AQI Testing of PM10

According to fig. 9, we can see that through proposed system, the interval of safe CO2 AQI values that can be obtained in 30 minutes test are 816 Seconds. Whereas the safe AQI value interval that was obtained using fuzzy sugeno system is only 686 Seconds. From the comparison of CO2 AQI interval values, it can be concluded that proposed system can produce a safe AQI CO2 value longer than the sugeno system. From fig 10, the interval of safe PM10 AQI values obtained in 30 minutes test is 1501 seconds. Whereas the safe AQI value interval that was obtained using Fuzzy Sugeno system is only 1018 seconds. 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 sugeno system.

5. Conclusion

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 good quality of air. To reduce CO2 gas from a high level to a safe level, the system requires an average time of 2:26 minutes, while for PM10 gas it takes 18:33 seconds. In addition, The proposed system can reduce CO2 and PM10 faster than system with Sugeno fuzzy, because the output value of interval is greater than Sugeno fuzzy method so exhaust fan can active longer. Exhaust fan in the system is reducing PM10 faster than CO2, and so interval performance of exhaust fan to waste CO2 is longer than PM10. Moreover, the proposed system could also generate AQI value in secure level longer than without using system. Also it can save more energy rather than using sugeno system because proposed system could wasting CO2 and PM10 faster, so it will make exhaust fan work effectively .

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