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AUTOMATED IOT BASED AIR QUALITY MANAGEMENT SYSTEM EMPLOYING SENSORS AND MACHINE LEARNING

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Abstract

The topic of automation has been widely discussed, and the modern society is gradually transitioning to smart home systems. One of the goals of this paper is to incorporate Industry 4.0 IoT. The other goal that must be met is to build an automation system to regulate air quality. The designed system is better suited for agricultural use because it regulates three critical air factors in the room: temperature, relative humidity, and CO_2 level. Inappropriate control of any of them would result in significant financial loss and would have a negative impact on productivity. Fuzzy Logic Controller was developed to control the indoor air quality automatically based on pre-determined desire outcome. Data collected are stored in MySQL in every 3 second and are imported via Message Queuing Telemetry Transport (MQTT) and NodeRed. The system is fully automated and therefore shorter workweeks for labour as the workers can access and monitor the indoor condition by using smart devices. The people counting technique was added as an extra feature since the human body generates heat into the environment, which cannot be neglected if long-term measurement and operation are to be achieved. Tests were conducted to verify the effectiveness and reliability of the system. One of the tests was about to evaluate the effect of fan operational duration to relative humidity and CO_2. Initial value for 10 s and 30 s were 75.36% and 75.06% respectively. The final data of 5 minutes was successfully achieved 52.76% (10 s) and 51.98% (30 s) after the adoption of the system. Showing a significant reduction.

Keywords: Air quality monitoring, CO_2, Fuzzy logic, MQTT, NodeRed.

1. Introduction

The industry 4.0 concept emerged in the year 2011 by the German government. It indicates using modern intelligence technology to involve automation, interconnectivity, machine learning, real-time data transmission, and Internet of Things (IoT) in industrial practices [1]. HVAC (heating, ventilation, and air conditioning) motoring system specifications are rapidly growing in some industries dealing with air quality as a result in the advancement of automation technologies. This system maintains indoor air quality with desired air temperature and humidity [2]. In agriculture, semiconductors manufacture and food industries, air quality is vital in ensuring its quality.

Furthermore, the manufacturing requirements for semiconductors, microcircuits, and microchips must be done under an exact condition in terms of temperature, humidity, and a dustless clean room. The main factor that affects the cleanroom is relative humidity. If the clean room's humidity is over the acceptable compromise, chemical reactions occur, such as metal corrosion, which can lead to product defects [3].

Environmental factors can affect both quality and quantity in the production line [4]. Because the room condition does not meet the standard, many products can turn out below-accepted standards and get rejected. This consequence causes the company suffered the loss. Moreover, this can happen when air properties cannot be adjusted automatically to prevent manufacturing defects when the room condition has been changed. Thus, regulating air properties is critical not just for human health but also for product degradation, which leads to financial losses in manufacturing.

Maintaining the indoor air quality within acceptable ranges is essential to ensure human thermal comfort. Besides, it can reduce energy consumption according to reasonable assumption which the power consumption is high when the air conditioning needs to be adjusted greatly due to the gap between indoor and outdoor temperature is large. The researched acceptable thermal comfort range is between 20–26 °C [5].

Additionally, it is crucial to keep the CO_2 concentration level below certain threshold which is lower than 1000ppm otherwise the air quality is considered poor, and drowsiness would slowly occur. The CO_2 concentrations can reach to 1800ppm in a room during tests where decision making is needed [6]. Thus, an adequate ventilation system which can be the exhaust fan is necessary not only to maintain the indoor air quality (IAQ) but also provide a comfortable and odourless environment.

Nugrahanti et al. [7] had done researched on the impact of humidity and thermal comfort on worker productivity. According to the experimental results, it shows that 50% of humidity in temperature of 25 °C is the best humidity sensation for productivity. However, at 50% of humidity ratio, the most comfortable temperature for workers is 22 °C and workers would feel unwell when the humidity ratio is 40% in 31 °C According to the findings of this study, the tropical workers choose to work under a colder environment than experienced.

Moreover, milk production also gets affected if high temperature and high humidity exist. These factors influence the daily milk yield due to the reduced quality of milk and milk composition. Therefore, milk quality and production are real challenges in controlling temperature and humidity [8].

Generally, when the human body contributes to the room heat, the air temperature and relative humidity are affected. Comfort parameters must be maintained within acceptable range to prevent health consequences [9]. Therefore, people counting function is proposed to count total number of people entering a place to provide sufficient fresh air and at recommended air quality.

Several articles have proven that inappropriate control of indoor air quality can significantly affect industry production line and human health. Thus, an innovative IoT-based air quality management system is inspired to solve the problems.

2. Methodology

2.1. Block diagram of the system

Figure 1 shows the overall block diagram of the developed system, which shows all the hardware implementation in a clear manner. Data acquisition is the first approach to begin the automation process. Second, the collected data is transferred to MySQL via NodeRed by MQTT.

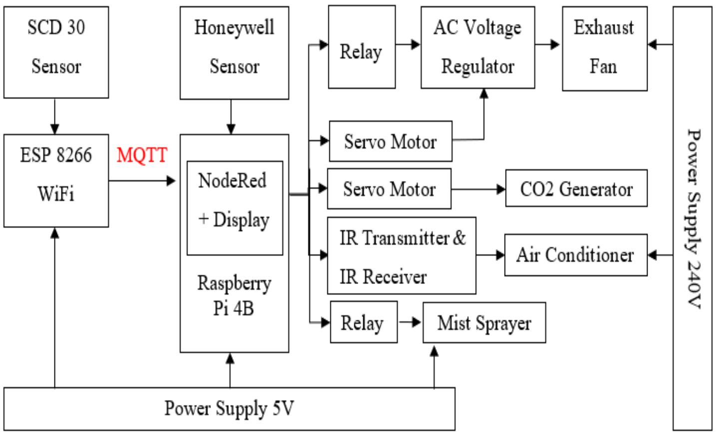

Fig. 1. Proposed block diagram of the overall automated air quality management system.

2.2. Data acquisition

The ESP8266 Wi-Fi collects data and uploads it synchronously to NodeRed. The data are updated as frequently as every three seconds in conjunction with the dust sensor. The dust sensor is linked to the raspberry pi to receive information on PM2.5 and PM10. Data is delivered via MQTT using the WiFi module on the ESP8266 microcontroller. MySQL is the final aiding tool in the data collecting process. It is used to store data collected every three seconds into the created table. The illustration is shown in Fig. 2.

2.3. Fuzzy logic control

Figure 3 shows the proposed structure consists of temperature, humidity, CO_2, and PM2.5 controlled with fuzzy logic control system. First, the fuzzy logic control system uses SCD 30 sensor and PM2.5 sensor to perform readings. If the air properties data obtained is in abnormal condition, the system activates fuzzy logic control. Actuators were implemented to monitor the air quality, there are exhaust fan, humidifier, CO_2 generator and air conditioner which are activated to neutralize the "desired" and "current" air properties.

The flow chart of the FLC operation is illustrated in Fig. 4. Attributed to the reason that two servo motors and two relays must be controlled, GPIO initiation is necessary to send signals to them when a given condition is triggered. Prior to accessing the FLC system, data was collected and stored in the MySQL database every three seconds. The inputs were checked to confirm that the readings of the input parameters were within the range specified in the FLC regulations. The inputs were then passed to the FuzzyAir FLC function. This approach necessitates decisions since the input data was retrieved one by one via MQTT, and every time a temperature reading was received, the remaining of the readings were zero. When relative humidity data was acquired, both temperature and CO_2 readings were zero. To solve this problem, existing data was checked and relocated to a defined array (temperature, humidity, CO_2). The output mode, represented by node A in the diagram, was used to control the air quality of the simulated room (Fig. 5).

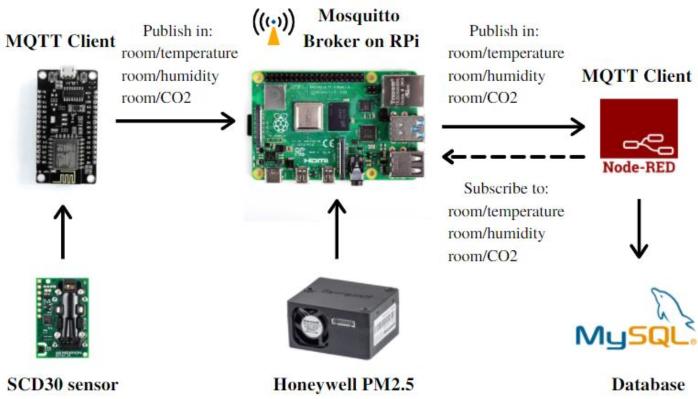

Fig. 2. Relationship between the sensors, hardware, MQTT and MySQL.

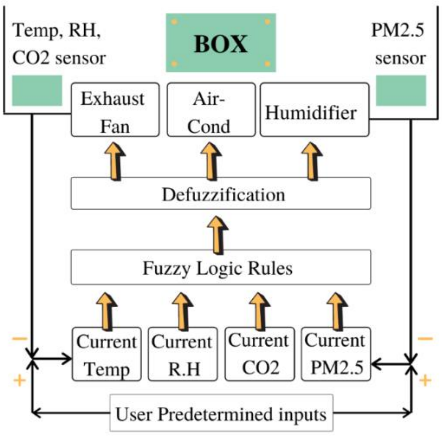

Fig. 3. Proposed block diagram of air quality control by fuzzy logic.

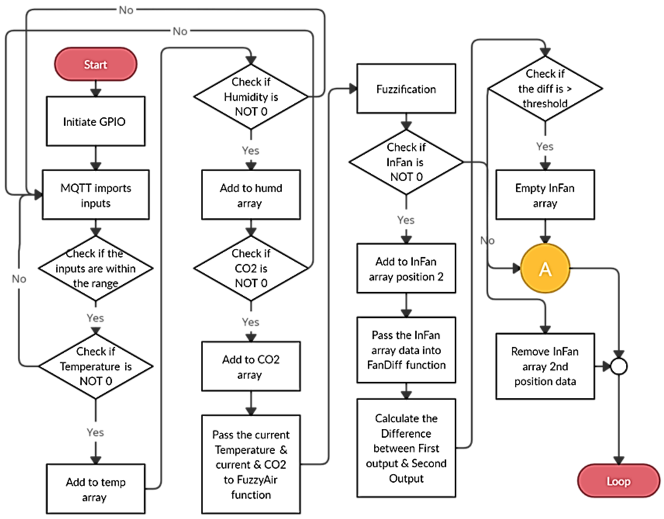

Fig. 4. Flowchart of the FLC system.

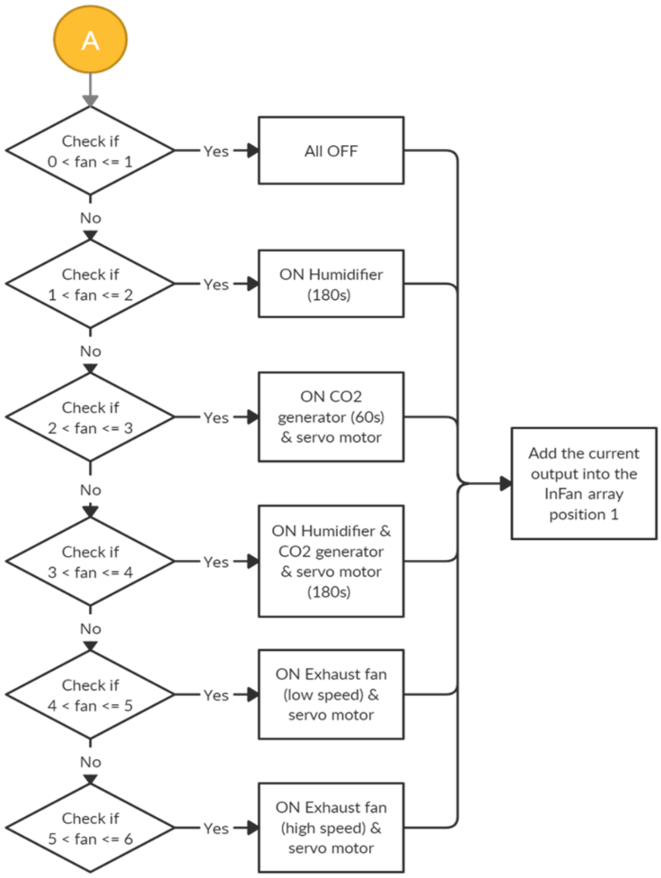

Fig. 5. Flowchart of the modes selection.

The membership functions for the input and output parameters are defined in Fig. 6. Ranges have been defined in accordance with the specifications. The conventional defuzzified findings method cannot be utilized to determine the functioning of each actuator since many actuators must be regulated. Thus, the defuzzified value in this system was used to determine the modes of operation required when the result falls within the defined range. This ensures that all actuators can work concurrently. The output plot in the figure above has no interception region, preventing misunderstanding in the operation of the actuators. Table 1 shows the rules of FLC. The temperature was set to 25 °C at the start of the codes, and the air conditioner is capable of maintaining that temperature in degrees Celsius. Appropriate actions are executed only when the input data meets the established criteria. Otherwise, the entire system will repeat itself.

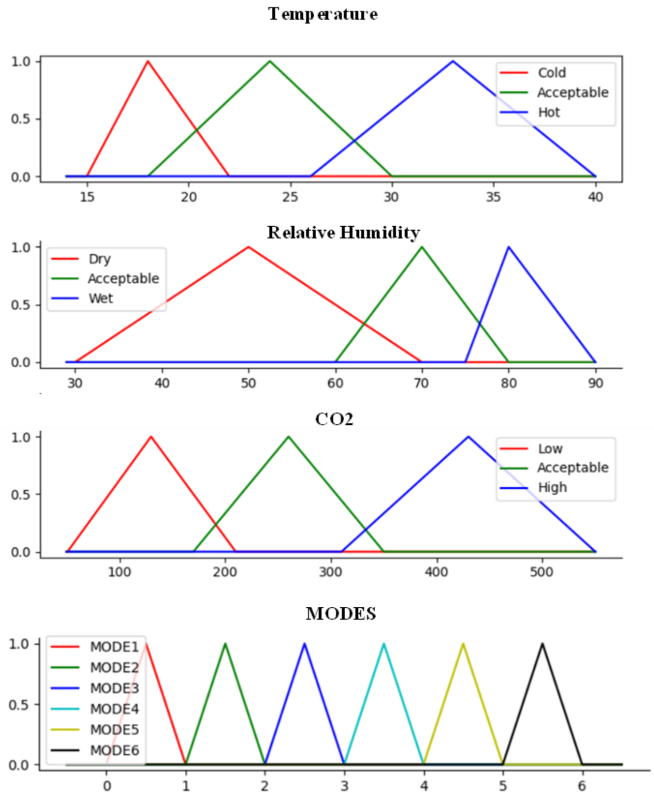

Fig. 6. Membership function of fuzzy logic control.

Table 1. Fuzzy rules statements.

Rule No.	Statements
1	If humidity low AND CO_2 low, THEN mode 4
2	If humidity medium OR high AND CO_2 low, THEN mode 3
3	If humidity low AND CO_2 medium OR high, THEN mode 2
4	If humidity medium AND CO_2 medium, THEN mode 1
5	If humidity medium AND CO_2 high, THEN mode 5
6	If humidity high AND CO_2 medium, THEN mode 5
7	If humidity high AND CO_2 high, THEN mode 6

Defuzzification method used in the fuzzy logic is Centroid of Area (COA) which is one of the popular methods to do defuzzification. The membership function distribution region used to depict the combined control action is separated into various sub-areas. The COA of each sub-area is identified, and the sum of all these sub-areas is used to calculate the defuzzified value for a discrete fuzzy set. The defuzzified value denoted as $X*$ using COA defined as:

$$X^* = \frac{\int x\mu_A(x)\,dx}{\int \mu_A(x)\,dx} \tag{1}$$

The above equation is only applicable when the membership function is continuous. Since the output membership function is not continuous, the simplest method is to determine the area included within the area.

The air parameters were regulated in an acceptable range with the FLC system employed in regulating the room air condition rather than the blue line idle condition. The result is shown in Fig 7. The yellow line represents the established acceptable range for air parameters. It's also clear that the outcomes were inconsistent. Because the entire system relies on an exhaust fan to minimize CO_2 and humidity, this is the case. In addition, a humidifier and a CO_2 generator were utilized to raise the internal relative humidity and CO_2 concentration. There is nothing more stable that can control the air condition than that external equipment to preserve the internal air quality. Nonetheless, it has been proven that FLC can regulate the temperature to a desired level.

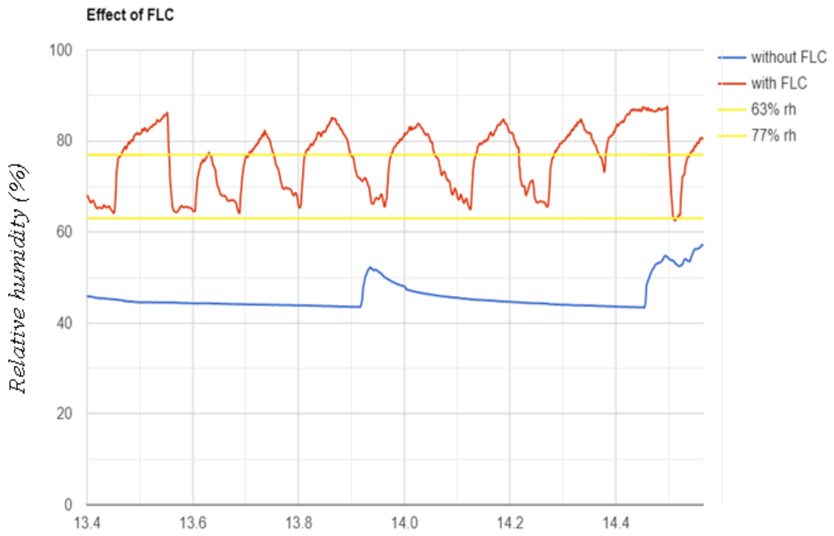

Fig. 7. Data collection in 1 hour on relative humidity.

2.4. GUI display and IOT

To make the system accessible via any smart device, a remote-Red node was used in NodeRed. The device is confirmed to display the GUI (As shown in Fig 8) by scanning the QR code provided by the flow. Without the remote-Red, the display panel can be accessed only by devices sharing the same WLAN/IP address.

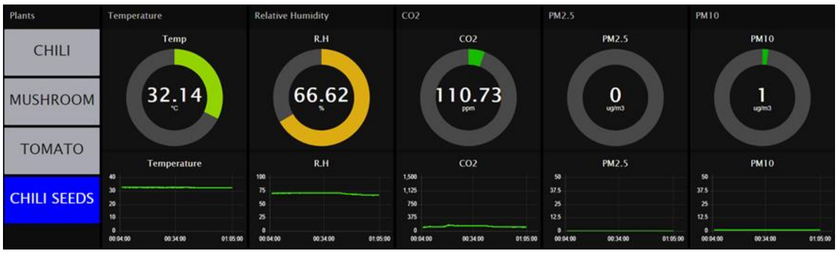

Fig. 8. GUI of the automated air quality management system.

2.5. Air-conditioner control

The Raspberry pi 4B is configured to control an air conditioner (A/C) using Linux Infrared Remote Control (LIRC). This package supports the decoding and transmission of infrared signals generated by a wide variety of popular remote controls. The microprocessor incorporates an IR transmitter and receiver for the purpose of transmitting signals and recording the A/C remote code, respectively. Infrared communication in Raspberry pi 4B is enabled to run the signal sending and recording actions. The protocols were retrieved by executing the procedures shown below by giving command in Raspberry Pi.

```
# The lircd service must be stopped to enter the infrared signal receiving mode
sudo service lircd stop
mode2 -d /dev/lirc1
```

```
# Send the power on command
irsend SEND  ONCE aircon POWER
```

The command shown above is used to control the air conditioner when a Raspberry pi 4B is used as the A/C controller. “aircon” is the controller’s name defined prior to beginning the process of recording the control code from an A/C controller. "POWER" is the defined button name associated with the corresponding recorded code.

2.6. People counting algorithm

Figure 9 shows the people counting process. “Person” class can be applied from MobileNet SSD trained model so that only “person” is detected and tracked but no other classes such as animals, vehicles, or plants. A middle line is drawn in the video frame to determine the direction of the tracking person head to. Live stream detecting or load recorded video are allowed in people counting. The frame size is required to resize to maximum width of 500 pixels to faster the process due to less data. The frame must be converted from BGR to RBG due to OpenCV only reads images in BGR form. Status of detection is displayed on the frame to show “waiting” or “detecting”. Bounding box captures detected people and filtration of non-person detection is done before accepting the bounding box. The detected people are tracked to check which direction the people are moving. Going down for entering and going up for leaving. The indication can be done by using the difference between y-coordinates of the current centroid and the mean of previous centroid. The idea is to count the people entering a place as +1 while leaving as -1.

Figure 10 shows the flow chart of the object detection and tracking process. The centroid tracking is the object tracking algorithm. This object tracking algorithm relies on the Euclidean distance between the new object centroids and the existing object centroids. Firstly, a set of bounding boxes is passed to each detected object. The bounding box can be formed by using color thresholding + contour extraction, Haar cascades techniques or Single Shot Detector (SSDs). Once the object is detected, centroid must be computed for ID tracking purpose. Each detected object is assigned with unique ID so that while applying Euclidean distance, the non-registered ID can be registered as new ID (new object to track) This can be obtained by taking the smallest distance value between new and existing object to continuously tracking. When the object is lost or disappear in the frame of view, the system must remove the registered ID. This algorithm can be applied in this paper to count people entering or leaving a place so that the indoor air quality is adjusted automatically.

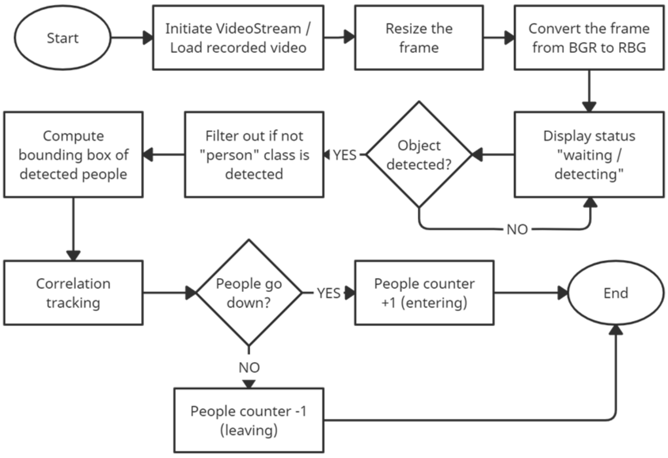

Fig. 9. Overall people counting algorithm flowchart.

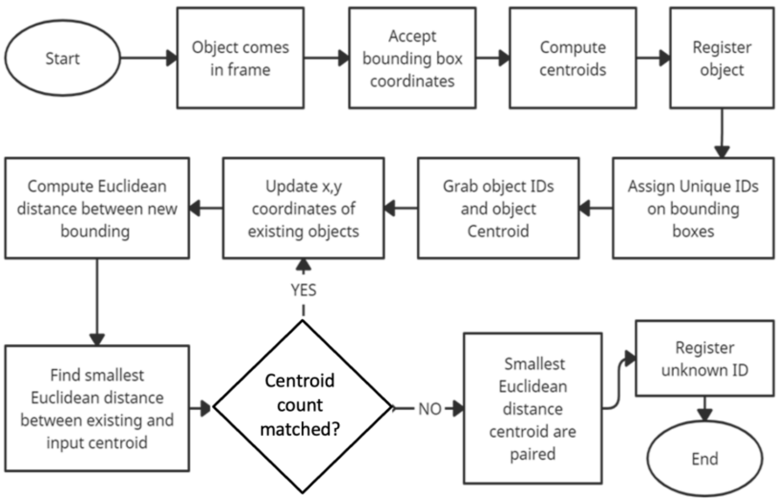

Fig. 10. Object detection and tracking flowchart.

2.7. Construction details (wiring diagram)

Figure 11 shows the wiring diagram of the whole system. 2 servo motors, 2 relays, 1 AC voltage regulator, IR receiver & transmitter, and a transistor are the components used. Sensors and actuators were connected to the Raspberry pi board to complete the entire operating process. The inclusion of transistor was used to improve the transmitting distance of an infrared emitting tube. The actual setup is shown in Fig 12.

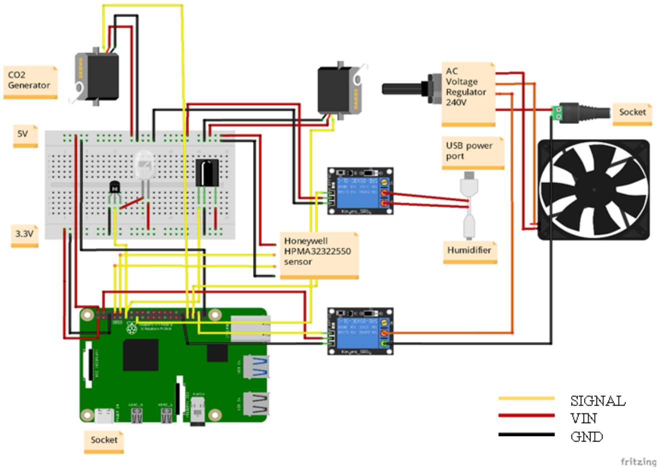

Fig. 11. Constructional details of microprocessor, sensor and actuators for the system.

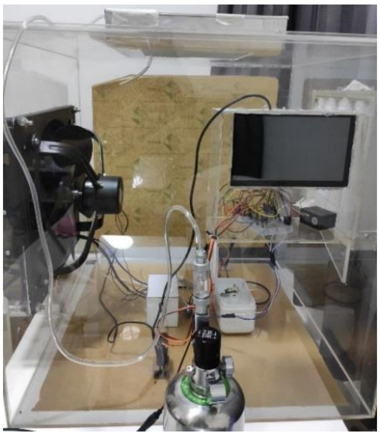

Fig. 12. Hardware setup (front view).

3. Testing of the System Developed

The data used for analysis and comparison was taken from downloaded MySQL recorded CSV data set. The process of bringing in fresh air from outside and eliminating polluted indoor air, which may contain virus particles, is known as ventilation. Fan was used to circulate air into and out of rooms in this mechanically ventilated prototype. Opening was made at the front part of the prototype with 2 pipes extended outside. This is to ensure air there is always some air flow when the exhaust fan is operating. In these tests, the exhaust fan can reduce the relative humidity and CO_2 concentration inside the prototype.

The effect of humidifier operating duration on maintaining the relative humidity was examined and compared. Generally, the temperature increases, the relative humidity in the air also increases and vice versa. Therefore, when the room temperature is turned to 25 °C, the amount of moisture in the air in low. The water vapor in the air is hard to maintain constant as other factors such as humans, walls, clothes, chairs, and table, etc.; can affect its concentration. In the FLC system, the control method is to set an operational period of 2/3 minutes.

It has been discovered that operating for 120 seconds provides better results than operating for 180 seconds (refers to Figs.13 and 14). The maximum relative humidity achieved was about 82% (120 s), while the maximum relative humidity reached was around 85% (180 s). Besides, the coverage area of relative humidity maintained in the desired range for operating 120 s is larger than that for operating 180 s. Hence, 120 s humidifier operating duration is chosen to be used in the system.

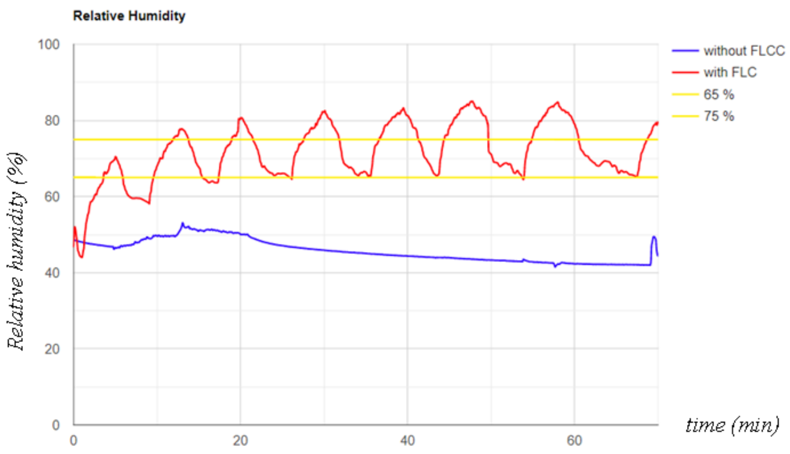

Fig. 13. Humidity changes with a humidifier operating for 180s in 1 hour.

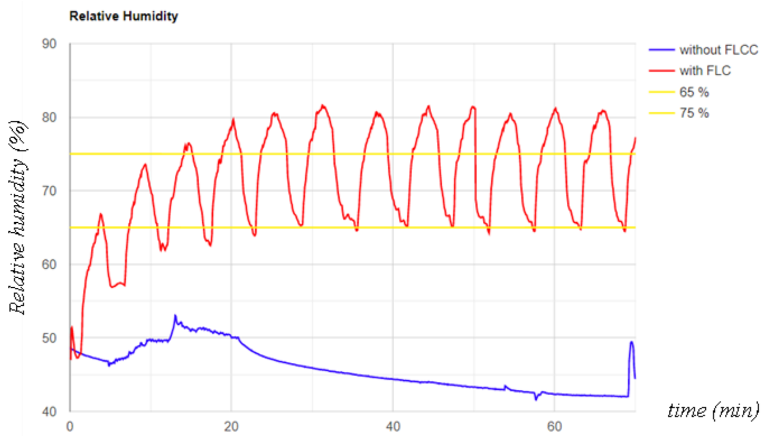

Fig. 14. Humidity changes with a humidifier operating for 120s in 1 hour.

4. Discrepancy

Then, temperature, relative humidity, and CO_2 levels in the air are all inherently unstable and change over time. Heat transfer on walls, windows, doors, roof, floor, equipment, and occupants, among other things, affects the internal temperature. These factors all led to the failure to maintain a constant temperature of 25 °C. Maintaining a specific temperature, relative humidity and CO_2 level is challenging, but fluctuating results can be achieved between ideal readings. Figure 15 illustrates that the theoretical result should be that the temperature stays constant at 25 °C, while the practical result displays a graph of ups and downs between 25 °C.

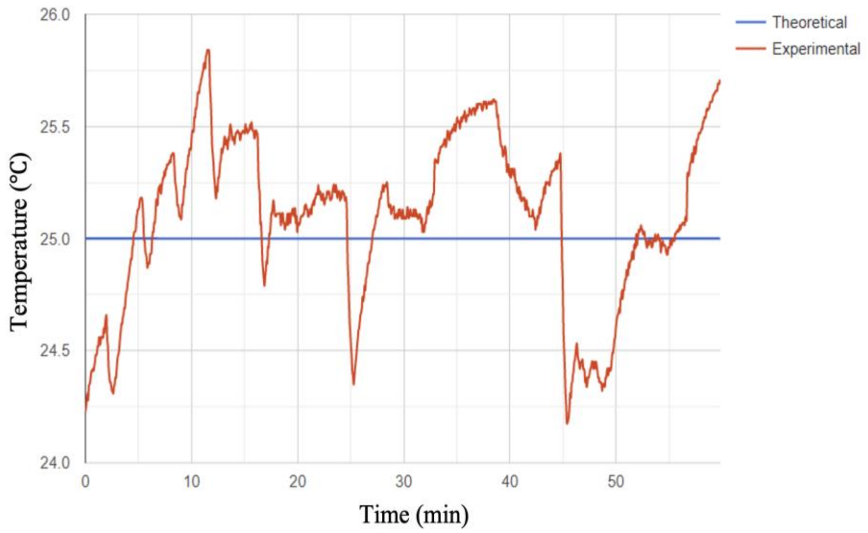

Fig. 15. Theoretical and experimental results of 25 °C.

5. Conclusion

The automated air quality management system based on IoT was achieved successfully. A fully automated & controllable IoT-based air quality system was developed using sensors and actuators. To automatically regulate the air characteristics, an FLC system with programmable rules was developed.

With the coded algorithm, the system can control the servo motors, exhaust fan, humidifier, and CO_2 generator automatically. This device regulates the indoor air quality based on the desired space condition. The system is accessible by all smart devices with NodeRed- Remote application installed.

The system can reduce and increase the air properties required in the prototype automatically to reach desired outcome. The system is limited by the space since this paper was planned to be initiated based on the size of actual agriculture industrial and office.

It is recommended that air-stream UV-C disinfection be installed in the HVAC system after COVID-19 crisis raised, which can be managed by the developed system in this paper to prevent the growth of harmful bacteria.

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