Air Quality Index Mapping Using Programmable Single Propeller UAV Towards Internet of Drone Things

1st Nyoman Karna
School of Electrical Engineering
Telkom University
Bandung, Indonesia
aditya@telkomuniversity.ac.id

2nd Muhammad Alfarafi Maulana Firdausa
School of Electrical Engineering
Telkom University
Bandung, Indonesia
alfarafimaulana@telkomuniversity.ac.id

3rd Soo Young Shin
Dept. of IT Convergence Engineering
Kumoh National Institute of Technology
Gumi, South Korea
wdragon@kumoh.ac.kr

***Abstract*—Unmanned Aerial Vehicles (UAVs) with the advances in technologies are becoming more common, UAV has become a platform to gather data that humans simply cannot reach. With the mobility of a drone, it can cover a lot of areas in a single take, greatly benefiting the data gathering process. However, conventional model drones like quadcopter configurations are big and costly for mass implementation such as in Internet of Drone Things. To handle these issues, this research proposed the use of a Single propeller drone design, drone with only 1 propeller, that can lower the cost of making the drone unit and ease the data gathering process. The single propeller drone gathers data for the air quality measurement device that uses DHT22 as the humidity and temperature sensor and MQ-135 as the air quality sensor. From the test result, carried out on Sukapura Football Field, Bandung, Indonesia, the single propeller was able to obtain the air quality, sent it to Google Firebase, and displayed it using smartphone. The test showed a slight difference result in the air quality data between different placements of the sensors on the single propeller drone. The test also showed the difference between stationary single propeller drone, which gave 103 ppm, with hovering drone, which gave 124 ppm. Furter test showed there were no differences between temperature and humidity result, with a maximum of 24°C and 99.6% humidity. Besides the differences in the data quality, the test result was near accurate.**

Keywords*—*unmanned aerial vehicle, single propeller drone design, air quality index, temperature, humidity, Google Firebase

I. Introduction

The impact of economic growth in Indonesia is parallel to the rise of CO2 emissions. Due to the economic rises, more Indonesian people prefer a personal motorized vehicle as their method of transportation. Engine exhaust consists of several gases and particulate emissions, which in turn consist of various chemical mixtures. Air pollution is a concern to public health, either from short-term or long-term exposure and can cause various illnesses [1]. The government has taken several efforts to raise awareness against air pollution. There is another research conducted in Sleman that tested the car exhaust emissions in that area and the result is that 13 out of 120 cars did not pass the emission test [2]. The research on air quality has also been carried out in Bandung where they use node sensors to collect the data. The result of the air quality research is that the carbon monoxide (CO) concentration is high during work hours which makes the air unhealthy to breathe. In 2012 and 2015 in Kalimantan, there was a significant improvement in air quality, this was due to efforts to improve air quality by closing illegal mining and deforestation, this paper suggests educating the public by adding to the curriculum with lessons on the dangers of air pollution.

The Air Quality Index (AQI) is used to measure the air quality, where lower value means better air quality. AQI is an effective method to tell how polluted or how healthy the air is. AQI is calculated based on the concentration of air pollutants, a high AQI detects highly concentrated pollutions appear in that area, a low AQI indicates that the area has suitable clean air. AQI data can be gained by sensors at governmental observation stations, producing an AQI map in the local area [3]. However, these sensors can only obtain a limited number of area samples in the observation area and often induce high costs. To reduce cost, a mobile platform is chosen to use along with the sensors. The previous researches also suggested that this AQI sensor unit can be attached to an Unmanned Aerial Vehicle (UAV) [4], [5] using quadcopter drone. The main problem of quadcopter drone is its big size and higher cost.

To solve these problems, this research proposed a small drone designed using only 1 or single propeller. This is similar to previous research from Moon et.al. [6] and Zhang et.al. [7], where they name the drone as Uni-copter and Monospinner. The single propeller design made it agile and compact, portable enough to gather AQI data measurement even in remote places, whereas the quadcopter drone could not capable of. While still maintaining the ability to gather data in large area coverage, this also reduces the production costs and is effective to use in a large-scale area of operations [8]. However, single propeller is hard to control, especially for the movement in longitudinal axis (roll) and vertical axis (yaw). A single propeller without an additional actuator can only be capable of movement in transverse axis (pitch).

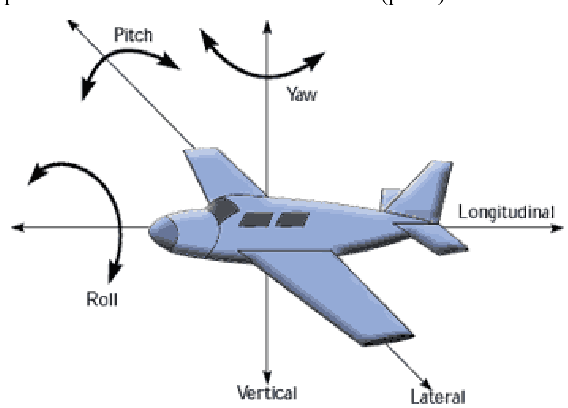

Fig. 1. Motion axis in flight control (picture taken from [9])

In drone applications that require low noise and low vibration, such as air quality measurement, the commonly used quadcopter drone's frame can not do this task optimally. The quadcopter produces so much noise that can interfere with the air quality index measurement and the amount of air flow generated by all the four motors will disrupt the sensor data acquisition. Moreover, the quadcopter drone may cause safety hazard when deployed in densely populated area and the production and maintenance cost is high.

There are many types of drone frames that can prevent or ease these conditions from happening and the single propeller drone, from authors' opinion, is the most suitable for this case of usage. In this research, authors proposed an air quality index mapping using a programable single propeller drone, to survey highly polluted areas and remote places. The data is going to be stored in the IoT Cloud Google Firebase using Arduino-based IoT. This research is a follow-up from previous research, which used the quadcopter drone and GPS for location information [4], [10].

II. Related Works on Internet of Drone Things

A. Internet of Things

The Internet of Things (IoT) is the act of gathering information value using automated sensor that is connected to the internet, this automation significantly reduces the work, time, and cost to gather data [11]. This was defined latter in ITU-T Recommendation Y.2060, where IoT is a global infrastructure collecting information through interconnected things using interoperable information and communication technologies [12]. IoT envisions every object connected to the internet this can be achieved via embedded systems, so those objects can communicate with each other to open tremendous possibilities for a large number of applications that can improve the quality of our daily lives.

B. Air Quality Index

Air pollution is both an environmental and a social problem, leading to a multitude of adverse effects on human health, ecosystems, and the climate [1]. Air pollution includes one of the biggest problems in Indonesia. Air quality in urban areas is the most crucial factor as it lowers the community's quality of life and causes disease. Air Quality Index (AQI) is an effective method to tell how polluted the air is or how healthy it is. AQI is calculated based on the concentration of air pollutants, where a high AQI means a highly concentrated air pollutant appears in that area, whereas a low AQI indicates that the area has a suitable clean air. With this, we can make a standard for healthy air and a suitable environment.

C. Computer-Aided Design

Computer-Aided Design, also known as CAD is a computers software that helps us design 2 or 3-dimensions products. With the help of computers hardware to process the design, CAD software can help us determine the size of the product with the help of computers calculations, which in return improve the quality of the design itself. CAD is usually used before the manufacturing of the product, to improve productivity and to speed up the designing process.

D. 3D Printing

3D printing, also known as additive manufacturing, is an additive technique in which layers of material are built up to build a 3D component from a computer-generated design using CAD software. 3D printing techniques were thought to be suited for the manufacturer of functional or aesthetically pleasing prototypes, and a more relevant name at the time was fast prototyping. One of the primary benefits of 3D printing is the capacity to generate highly complicated forms or geometries that would otherwise be difficult to be made by hand, such as hollow pieces or items with internal truss systems.

E. Thrust Vectoring

Thrust vectoring control is the ability of a flying device to manipulate the directions of its flying by making it change the propulsions of the engines so it can redirect the propulsions to its desired route to control the altitude, roll, pitch, and yaw. This method is designed for aircraft to have vertical take-off ability, but here we use this control to make this method the main way to move our drone, which is by using a propeller to redirect air generated from the motor.

F. Proportional-integral-derivative control

Proportional-integral-derivative (PID) control is used to control the movement of the robot, while in this case, our target is a drone. This control will directly affect the roll, pitch, and yaw of the drone. The proportional is controlling how well the drone will respond to an input movement. The integral is how much bounce back happens after the proportional movement is finished or if the drone is out of balance. The derivative is to correct the bounce-back that the integral made, this is to dampen the noise that the integral made .

III. System Design

A. Drone Design

Fig. 2 shows the design of a single propeller drone. This single propeller drone uses only one rotor to gain thrust, while some propellers keep it steady in the air. The design of the flaps works like plane flaps, the bottom flaps have the purpose of redirecting air that has been generated from the single rotor. With this design the flight controller can control the PID (proportional–integral–derivative) movement of the drone.

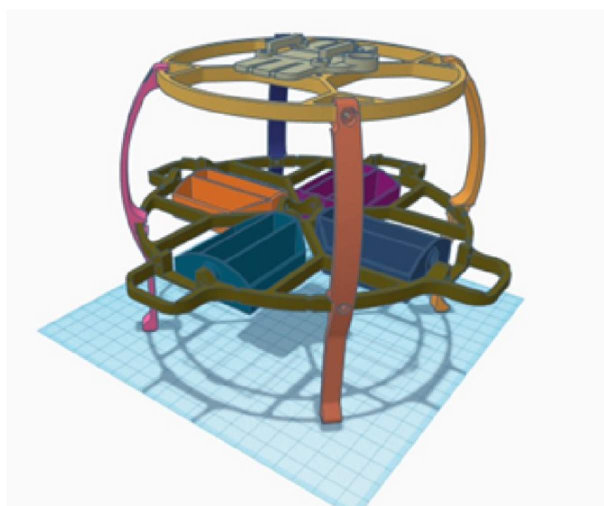

Fig. 2. Single propeller drone design

B. Flowchart of Stable Flight

Fig. 3 shows the flowchart that controls the behavior of drone stabilizations. After the lift-off, the stabilization starts to work, where each servo is designed to stabilize different scenarios. Servos 1 and 3 are responsible for roll stabilizations, servos 2 and 4 are responsible for roll stabilizations, and all of the servos are responsible for yaw stabilizations.

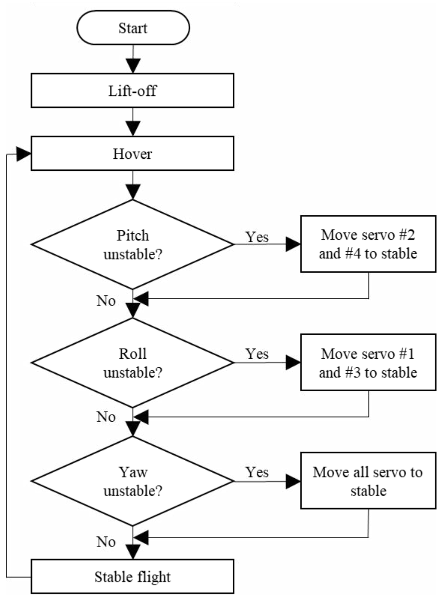

Fig. 3. Flowchart for flight stabilization

C. Flowchart of Measurement Unit

Fig. 4 shows the flowchart for Air Quality Index data measurement. The sensor capture the data every second after it is turned on, and give the average of the total data at the end of the test. Every cycle takes about 10 data snapshot and then it will calculate the average value at the end of the cycle and then upload it to the Google Firebase.

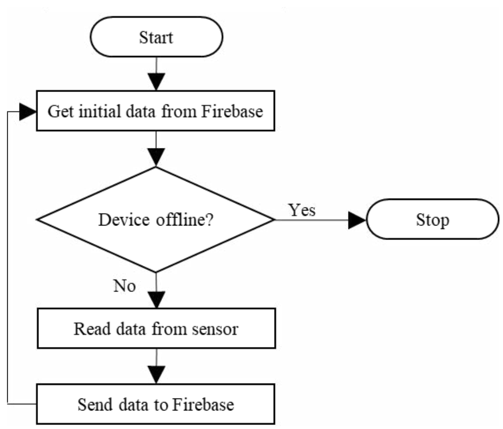

Fig. 4. Flowchart for Air Quality Index data measurement

D. Testing Scenario

To ensure the system works well according to the design and within its boundary, measurements should be taken at real condition or real field test. We tested 2 main parameters, drone and sensor performance. This way we can improve part or aspect that still as a drawback, ensuring the best quality of data reading and reliability.

- Drone performance

  This measurement will test the performance of the drone itself, starting from the frame performance and the flight configurations. The flight configurations contain a servo configurations test and PID output test. This test aims to find a stable configuration for the flight process.

- Sensor performance

  This test will test the performance of the sensor. From the placement of the sensor, the effect of the airflow on the sensor, and the measurement of the time.

IV. Test Result

A. Drone Frame Test

1) Crash Test

Table I shows the drone frame durability test. For this measurement, the single propeller drone from each material is tested when dropped from a certain height.

- In the nylon carbon, almost every part is durable, except for the propeller. This is because the build surface is rough, this easily chips the surface, and this affects all of the parts. All the part is thick enough to withstand this effect, except for the propeller.
- PETG plastic has a rigid and smooth surface characteristic. It provides advantages and disadvantages. The advantage of having a smooth surface is that it does not get chipped easily, but the disadvantage of having a rigid body is that it cannot withstand impact from falling.
- While it has a smooth surface, it is also brittle, and it does not have the rigid characteristic of PETG. This puts PLA in so many disadvantages

TABLE I. Drone Frame Durability Test

Drone Frame Material			
Specification	***Nylon Carbon***	***PETG***	***PLA***
Upper plate	Durable	Snap after failed landing	Easily snap
Bottom plate	Durable	Snap after failed landing	Easily snap
Leg	Durable	Durable	Easily snap
Propeller	Easily chip	Durable	Durable
Battery holder	Durable	Durable	Durable

2) Frame Performance:

Table II shows the drone frame performance test. For this measurement, the single propeller drone from each material is tested for its rigidness.

- Nylon carbon has good overall good performance, except in the propeller and legs. The propeller is so flexible, that the redirected air from the motor changes the shape of the propeller during the flight, and this result the inconsistent flight. The legs are also flexible, during flight, it introduces left and right wobble at the bottom plate.
- PETG has good overall performance because PETG is taking advantage of the rigidness characteristic. It can reduce the vibration, that the motor generated. The legs do not vibrate as much as nylon carbon.
- While PLA plastic has a similar performance to PETG plastic, because of its brittle nature every time it is

tested, it loses material over time, so it becomes a thinner profile, and the performance degrades over time.

TABLE II. DRONE PERFORMANCE TEST

Drone Frame Material			
Specification	***Nylon Carbon***	***PETG***	***PLA***
Upper plate	Good	Good	Good
Bottom plate	Good	Good	Bad
Leg	Bad	Good	Bad
Propeller	Bad	Good	Bad
Battery holder	Good	Good	Good

B. Flight Configurations Performance Test

1) Servo Configurations:

- Yaw moves along with thrust, the stabilization of this configuration is not working because the thrust value overpowers the PID value in the calculations. As a result, the configurations cannot be tested.
- The yaw is at a fixed angle and the propeller is fixed to the left at a 15-degree angle, thus resulting in the only stabilizations that the drone has being the pitch and roll. This configuration is effective at certain motor speeds as the higher speed required a higher angle of the propeller.
- In the last configurations, the yaw is controlled by the PID. This configuration proved to be the most effective method to fly a single propeller drone. The only thing that affects this method is the propeller angle of attack because if the propeller has a low angle of attack, it has to spin faster to generate lift, and if the angle of attack is high it required less effort to generate lift.

TABLE III. DRONE PID PERFORMANCE TEST

	Roll			Pitch			Yaw			Result
	P	***I***	***D***	***P***	***I***	***D***	***P***	***I***	***D***	
1	100	0	0	100	0	0	100	0	0	Stable[a]
2	0	100	0	0	100	0	0	100	0	Unstable
3	0	0	100	0	0	100	0	0	100	Unstable
4	100	100	0	100	100	0	100	100	0	Stable[b]
5	100	0	100	100	0	100	100	0	100	Stable[c]
6	100	0	100	100	0	0	100	0	0	Stable[d]
7	100	0	0	100	0	100	100	0	0	Stable[e]
8	100	0	0	100	0	0	100	0	100	Stable[f]
9	100	0	100	100	0	100	100	0	0	Stable[g]
10	100	0	50	100	0	50	100	0	0	Stable[h]
11	100	10	50	100	10	50	100	20	0	Stable[i]

a. Stable are in effect, still drifting and unstable

b. Stable with slight movement after lift applied

c. Stable with slight jitter effect after stable

d. Stable without jitter, slight drift

e. Stable with slight jitter, slight drift

f. Stable with slight jitter effect after yaw Stable

g. Stable with slight jitter, slight drift

h. Stable without jitter, slight drift

i. Stable without jitter, no drift

C. PID Output Test:

- From Table III at test number 1, 2, 3, 4, and 5, we can see the P or proportional is acting the role of the overall movement or the percentage of the movement. We can see in test numbers 2 and 3, we cannot determine the test result for I or integral and D or derivative unless we apply the P, like test numbers 4 and 5.
- From Table III at test number 4, we can see the I act as the counterbalancing force after the motor input was applied, this counterbalancing force can be seen as a slight movement to the servo that grows gradually within the signal position and the timing. So basically I can act as the trim for the drone.
- From Table III at test number 5, we can see the D act as the future reference after the stabilizations were done, there is a slight bit of movement with the servo, and the greater the D, the movement would become noticeable. If the D was too high, it will generate wobble because of the unnecessary movement or overshot by the servo.
- From Table III at test number 6, 7, and 8, we are still testing D, if D is applied to pitch and roll, the stabilization against pitch and roll is improved. When a D is applied to the yaw, the drone shakes if there is movement in the yaw and the servo tries to correct it. This happens because, after stabilization for the correction there is little movement, if applied correctly the drone will increase stability, but otherwise, the drone will make unnecessary wobble or overshoot.
- From Table III at test number 9, 10, and 11, we have the goal to stabilize the drone completely, the P can be set freely in the range of 80 until 100, then I have the functions of trimming the unnecessary movement Integral find 10 until 20 is the acceptable value, and the D has functions to correct movement after stabilizations, the value that I choose is 50, and left out the yaw.

D. Sensor Performance Result

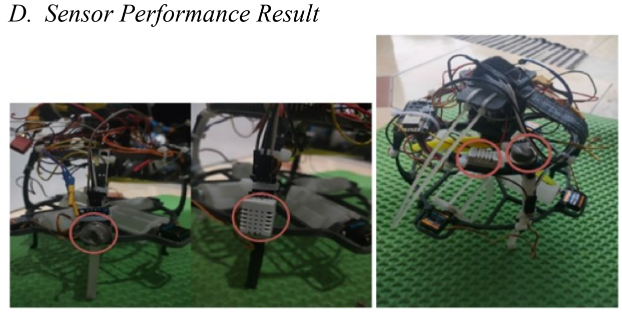

Fig. 5. Configuration 1 (right figure) and configuration 2 (left figure)

Fig. 5 shows the test for sensor measurement performance. Configuration 1 (right figure) is where the sensor is mounted inside the drone's frame and configuration 2 (left figure) is where the sensor is mounted on the outer part of the drone's frame. From both configurations, there is no significant differences between humidity and temperature measurement. However, the measurement results from both configurations show great differences in the Air Quality Index measurement by almost 20 ppm. The measurement test will use configuration 2 as the main way to read the data because configuration 1 is often caught by the propeller if not secured properly, and it has a much slower air velocity.

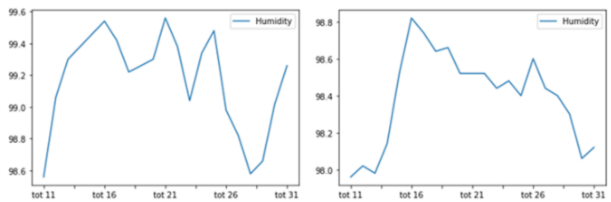

Fig. 6. Humidity sensor test result

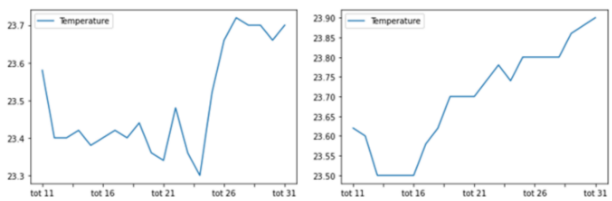

Fig. 7. Temperature sensor test result

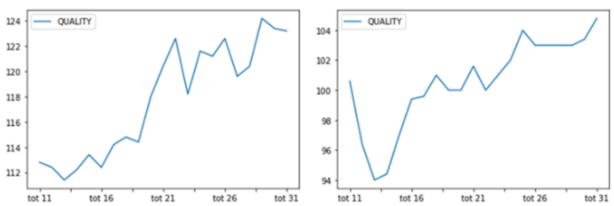

Fig. 8. Air Quality Index test result

E. Measurement Test Result

The measurement test was done at Sukapura football field at 8 am, 2 pm, and 6 pm. The Sukapura football field itself is near a public road. The development board nodeMCU is connected to the Internet through a personal hotspot (tether) from a smartphone.

- 8 am result

	Humidity (%)	Quality (PPM)	Temperature (Celcius)
test 11	98.56000	112.8	23.58
test 12	99.06000	112.4	23.40
test 13	99.30000	111.4	23.40
test 14	99.38000	112.2	23.42
test 15	99.46000	113.4	23.38
test 16	99.54000	112.4	23.40
test 17	99.42001	114.2	23.42
test 18	99.22001	114.8	23.40
test 19	99.25999	114.4	23.44
test 20	99.30000	118.0	23.36
test 21	99.56001	120.4	23.34
test 22	99.38000	122.6	23.48
test 23	99.04000	118.2	23.36
test 24	99.34000	121.6	23.30
test 25	99.48000	121.2	23.52

Fig. 9. Air quality at 8 am

Fig. 9 shows that at 8 am the air quality is good, due to the minimum activity of traffic. The average humidity is 99.28%, the Air Quality Index is 116 ppm, and the temperature is 23.41 ºC.

- 2 pm result

	Humidity (%)	Quality (PPM)	Temperature (Celcius)
test 11	94.25999	469.00000	27.92
test 12	94.24001	468.70000	27.90
test 13	94.25999	468.70000	27.90
test 14	94.30000	468.30000	27.87
test 15	94.47778	468.00000	27.80
test 16	94.64000	467.80000	27.78
test 17	94.71000	467.60001	27.77
test 18	94.55000	466.00000	27.74
test 19	94.83000	466.20000	27.70
test 20	94.67999	466.00000	27.72
test 21	94.41001	467.39999	27.70
test 22	94.53999	467.80000	27.70
test 23	94.70000	467.20000	27.69
test 24	94.74001	466.00000	27.60
test 25	94.80000	465.70000	27.70

Fig. 10. Air quality at 2 pm

The 2 pm data shows an increase in air quality data, this happens because there is an increase in vehicle traffic beside the road, and there are also people doing sport activity on the football field. The average for the 2 pm data is 94.54% for the humidity, 467.35 ppm for the air quality, and 27.76 ºC for the temperature.

- 6 pm Result

	Humidity (%)	Quality (PPM)	Temperature (Celcius)
test 10	92.08000	393.0	28.00000
test 11	92.16000	393.0	28.00000
test 12	92.16000	390.6	27.98000
test 13	91.82222	390.0	27.97778
test 14	98.04001	420.4	26.28000
test 15	98.04001	420.4	26.28000
test 16	98.04001	420.4	26.28000
test 17	97.80000	412.2	26.30000
test 18	97.63000	407.6	26.30000
test 19	97.60001	405.8	26.34000
test 20	97.12999	402.7	26.40000
test 21	97.00999	402.8	26.35000
test 22	97.00000	403.0	26.40000
test 23	96.83000	403.0	26.34000
test 24	96.78000	403.0	26.40000

Fig. 11. Air quality at 6 pm

At 6 pm, the sports activity is decreasing, people start to leave using a motorbike, and the traffic also decreases. The average for the 6 pm data is 96% for the humidity, 404.52 ppm for the air quality, and 26.77 ºC for the temperature.

V. CONCLUSION AND FUTURE WORKS

Although it is quite difficult to set the drone to be stable, this research shows that it can still be done with the PID output test and servo configurations test. This drone can be used to take air measurement data, and there is a minimal effect that affects the data-gathering process.

With the single propeller drone design, it can be used in many applications because the overall shape is small compared to conventional quadcopter drones, it can also be used in a populated area without having the fear of becoming a hazard. The overall cost is fairly inexpensive, so it can be mass-produced in high quantities, on a minimum budget.

Despite a single propeller drone has many advantages over a quadcopter drone, most of the firmware still does not support the single propeller design and it blocks access to features in that firmware.

To get the complete AQI measurement we also need to measure the particulate concentrations of 2.5 and 10. However, this particulate sensor is too heavy and wide to be mounted on a single propeller drone.

To achieve swarm capability we need to increase the number of drones and preliminary research has been done by Gholiyana et. al. [13] using simulation on the Artificial Bee Colony algorithm. However, to achieve swarm control in the real world, all the drones must be able to communicate with each other, while there are records for drone control over the internet using a Raspberry Pi that is connected to telemetry data using a Mavlink protocol.

Acknowledgment

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2023-RS-2023-00259061) supervised by the IITP (Institute for Information & Communications Technology Planning & Evaluation).

References

[1] M. P. Sierra-Vargas and L. M. Teran, “Air pollution: impact and prevention,” *Respirology*, vol. 17, no. 7, Oct. 2012, doi: 10.1111/j.1440-1843.2012.02213.x.

[2] Z. Arifin, Sutiman, and M. Solikin, “Assessment of the air quality monitoring system in Sleman district by vehicle emission measurement,” *J Phys Conf Ser*, vol. 1446, no. 1, p. 12036, Jan. 2020, doi: 10.1088/1742-6596/1446/1/012036.

[3] B. Zou, W. J. Gaines, Z. F. Benjamin, and Z. Yongnian, “Air pollution exposure assessment methods utilized in epidemiological studies,” *Journal of environmental monitoring*, vol. 11, no. 3, Mar. 2009, doi: 10.1039/b813889c.

[4] N. Karna, D. L. Lubna, and S. Y. Shin, “Air Quality Measurement Device Using Programmable Quadcopter Drone Towards Internet of Drone Things,” in *2021 International Conference on Information and Communication Technology Convergence (ICTC)*, 2021, pp. 753–758. doi: 10.1109/ICTC52510.2021.9621039.

[5] P. Y. Haas, C. Balistreri, P. Pontelandolfo, G. Triscone, H. Pekoz, and A. Pignatiello, “Development of an unmanned aerial vehicle UAV for air quality measurement in urban areas,” in *32nd AIAA Applied Aerodynamics Conference*, doi: 10.2514/6.2014-2272.

[6] J.-S. Moon, C. Kim, Y. Youm, and J. Bae, “UNI-Copter: A portable single-rotor-powered spherical unmanned aerial vehicle (UAV) with an easy-to-assemble and flexible structure,” *Journal of Mechanical Science and Technology*, vol. 32, no. 5, pp. 2289–2298, 2018, doi: 10.1007/s12206-018-0440-1.

[7] W. Zhang, M. W. Mueller, and R. D’Andrea, “Design, modeling and control of a flying vehicle with a single moving part that can be positioned anywhere in space,” *Mechatronics*, vol. 61, pp. 117–130, 2019, doi: https://doi.org/10.1016/j.mechatronics.2019.06.004.

[8] S. S. Anjum, R. M. Noor, I. Ahmedy, N. B. Khamis, and M. H. Anisi, “Development of Portable Air Quality Index (AQI) and Emergency Vehicles Preemption Prototype Based on Internet of Mobile Things (IoMT),” in *Proceedings of the 3rd International Conference on Information Science and Systems*, in ICISS ’20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 158–161. doi: 10.1145/3388176.3388194.

[9] “What is the exact meaning of ‘attitude’, does it include translational movement?,” *https://aviation.stackexchange.com/questions/35933/what-is-the-exact-meaning-of-attitude-does-it-include-translational-movement*, Mar. 01, 2017.

[10] A. M. Luthfi, N. Karna, and R. Mayasari, “Google Maps API Implementation On IOT Platform For Tracking an Object Using GPS,” in *2019 IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob)*, 2019, pp. 126–131. doi: 10.1109/APWiMob48441.2019.8964139.

[11] K. Ashton, “That ‘Internet of Things’ Thing,” 1999.

[12] INTERNATIONAL TELECOMMUNICATION UNION, “ITU-T Rec. Y.2060 (06/2012) Overview of the Internet of things,” 2012.

[13] G. Muntasha, N. Karna, and S. Y. Shin, “Performance Analysis on Artificial Bee Colony Algorithm for Path Planning and Collision Avoidance in Swarm Unmanned Aerial Vehicle,” in *2021 International Conference on Artificial Intelligence and Mechatronics Systems (AIMS)*, 2021, pp. 1–6. doi: 10.1109/AIMS52415.2021.9466085.