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Development of quadcopter for atmospheric data collection

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Abstract — The first stage of this research aims to develop a quadrotor system as unmanned aircraft vehicles (UAVs, or drones) for atmospheric data collection in a targeted area. The system consists of an APM 2.8 arducopter flight controller, Ublox NEO M8N GPS module with compass, Racerstar 920kV 2-4S Brushless Motor, Flysky Receiver FS-iA6B with FS-i6 Remote Control Transmitter, DJI F450 quadcopter frame kits, and a LiPo Battery 3300 mAh 35C. The system is set up and run through a Mission Planner. As for monitoring atmospheric conditions, the system consists of an Arduino Uno ATmega328P, BME280 sensors, and several modules (DS3231 Real-Time Clock (RTC), micro SD card, and 16×2 LCD). With a total weight of 1 kg, the drone can fly into space and maneuver to an altitude of more than 200 meters in an average of 10 minutes based on the line of sight (LOS). Atmospheric conditions such as air temperature, relative humidity, air pressure, altitude, and precipitable water vapor can be measured and logged properly from drones. By this development, the system can be applied in the future to detect or measure weather extremes, air pollution, or monitoring aerial topography automatically when equipped with gas sensors and cameras, respectively.

Keywords – Quadcopter, Arduino Uno, BME280, Atmospheric Monitoring

I. INTRODUCTION

Short-term and long-term meteorological data are necessities that are not only for weather forecasting and climate modeling but also for the mitigation of disasters and climate change adaption [1, 2]. However, the data for weather/climate monitoring currently available from space-based is a very broad scope. In addition, there is scarcity where not all freely accessible data have a completed time series nor does it provide the parameters we need to solve a particular problem in a particular location. Considering that each point of the earth's location can have different weather effects and early weather warning at a specific location is very important. Unfortunately, building a ground-based meteorological station for atmospheric monitoring every 10 km or 25 km radius is very expensive. The major constraint is the cost factor and the interest to the area.

In this study, a drone at low-cost solutions will be developed to mediate the above problems that can monitor the atmosphere at a certain height from the earth's surface or ground. The altitude in question is around the troposphere, where weather plays an important role in life on Earth [3, 4]. Factors that affect the weather of this troposphere include air pollution and the amount of water vapor [5, 6]. Therefore, recently, short-term space or atmospheric monitoring instrumentations have been built, known as UAVs (Unmanned Aerial Vehicles) or drones. Drones are aerial devices that can fly without a pilot or humans on board and are controlled remotely from the ground station [7]. Therefore, drones led a hot topic recently and potential to be developed in various fields, such as monitoring, surveillance, or learning media in schools or colleges.

In the context of atmospheric monitoring, many studies have developed UAVs. Zhang et al. [8] developed a six-rotor UAV platform (hexacopters) to collect meteorological elements of the atmospheric boundary layer such as temperature, relative humidity, pressure, elevation, and longitude. This development can make up for the deficiency of conventional measurements such as sounding balloons, anemometer towers, and remote sensing detection. Sørensen et al. [9] developed a UAV platform for aerial sensor applications with a low cost using the Pixhawk as a flight controller and capable of measuring water temperature in lakes. Varentsov et al. [10] used a DJI Phantom 4 Pro quadcopter, equipped with temperature, humidity, pressure, and infra-red surface temperature sensors for meteorological measurements in the atmospheric boundary layer. They concluded that a quadcopter could be successfully used for vertical temperature and humidity profile measurements during the winter research campaign in Northern Russia. While Rohi et al. [11] have used quadcopter Environmental Drones (E-drones) to measure the concentration of air pollution at certain altitudes, detect, and remove pollutants by implementing appropriate abatement options. From several related studies mentioned above, the contribution of this recent work is to develop a drone for atmospheric data collection which contains the above parameters and a new parameter, namely precipitable water vapor (PWV).

Although the measurement of meteorological parameters via drones can help improve the accuracy of local weather forecasts, unfortunately, drones cannot fly in all weather conditions. Weather conditions such as wind speed and precipitation greatly affect the drone's reliability for time-sensitive operations [12]. Therefore, it takes good planning to determine the type of drone used for monitoring or surveillance. Two types of aerial drones have commonly been used, i.e., multirotor airborne and fixed-wing [13]. The advantage of multirotor is the ability to take off and land vertically, and for surveillance, it does not require much space. The lack of multirotors is limited range and battery life. On the other hand, fixed-wing drones excel in terms of range and durability, and the drawback is that they require a proper launcher or runway to take off [14].

UAVs can be classified based on their weight, altitude and range, wings and rotors, and applications [15]. The most common multirotor UAVs are tricopters, quadcopters, hexacopters, and octacopters. UAVs can be divided into personal, commercial, government and law enforcement, and military for the application. For commercial use, such as DJI with self-mounted cameras, and specialized UAVs for industrial purposes, such as mining, plantation surveillance, or cadastral mapping. Both commercial types can be modified on the battery to extend flight endurance, GPS/GNSS system to improve positioning accuracy, modification of payload (camera or LIDAR), number of rotors, unit of inertial measurement, and so on. Advances in battery technology now allow for a slight increase in the endurance of small-scale UAVs where they can fly for about 90 minutes using Lithium-Polymer (LiPo) batteries [16]. Roughly, most multirotor UAVs have an endurance of about 20-50 minutes [17] depending on the area's wind speed under observation, battery capacity, and payload. However, the Fixed Wing Hybrid VTOL (Vertical Take-Off Landing) can fly longer because of the stability of its wings to hover, take off, and land vertically.

Since meteorological datasets in space are important for atmospheric monitoring, this work will develop quadcopter drones. The quadcopter consists of four brushless servo motors and one propeller in each of its motors. The factor of choosing this multirotor is its stability in the air and ease to control. Quadcopters can perform several basic functions including pitch, roll, and yaw once a force F is applied. In this work, the system developed using the APM 2.8 flight controller. To monitor atmospheric parameters and store data, an automatic weather system (AWS) was developed using the BME280 sensor and is controlled via Arduino Uno. The sensor is attached to the body of the drone as a payload. In other words, the drone can fly and maneuver at a certain altitude and measurement data is also successfully collected. Thus, the focus of this paper is to contribute on how to develop a quadcopter using APM 2.8 technically. Many researchers build drones and apply them with a specific purpose but rarely explain the technical steps of designing and building the system. This still leaves a number of questions, especially for novice drone designers.

II. RESEARCH METHOD

A drone is a kind of robot that is controlled via RC media on the ground. Figure 1 shows the block diagram of how the quadcopter control system works that later to monitor and collect atmospheric data.

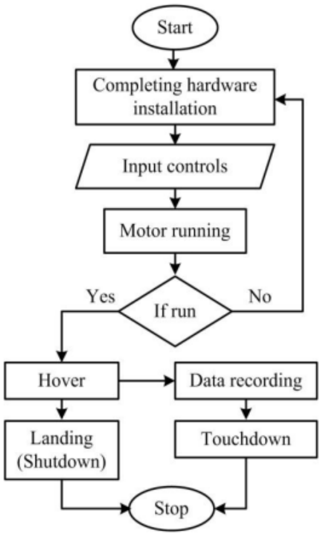


Fig. 1. Block diagram of how the quadcopter system works

A. *Quadcopter System Design and Implementation*

Figure 2 shows the entire system developed to collect atmospheric data based on drones using APM

2.8. As a basis for designing and implementing the system, the modules used to develop a quadcopter are briefly described as follows.

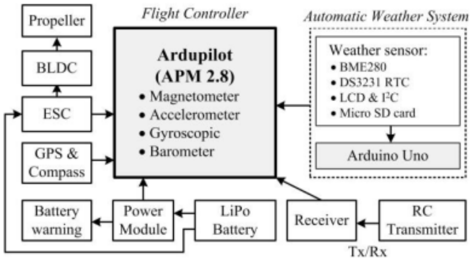


Fig. 2. Overall drone system developed for atmospheric data collection using APM 2.8

a) Arducopter with APM 2.8

Ardupilot Mega (APM) is a second-generation autopilot system, where during 2009-2011 Ardupilot has changed up to 4 times where AMP 2.8 is the last type of Ardupilot (2013) officially issued by Michael Oborne with specifications that can be said to be complete enough to be an autopilot system (https://ardupilot.org). Figure 3 shows the APM 2.8 board system where it is used Atmel ATmega2560 and ATmega32U-2 processors were. As shown in the figure, APM 2.8 operates at 16 MHz clock speed and is capable of integrating the input receiver, Global Positioning System (GPS), telemetry port, Electronic Speed Controller (ESC) output, slots for connecting laptops, and other peripherals [18]. Inside the flight controller, it is consists of magneto sensors, accelerometer sensors, gyroscopic sensors, barometer sensors, and microcontrollers. While outside of the board showed eight input pins (four channels [Ch#1…Ch#4] is for the quadrotor input, and Ch#5 is used for flight mode). The output pins of Ardupilot are connected to the ESC and brushless DC electric motor (BLDC), and finally, each BLDC has mounted a propeller. BLDC is a servo motor to convert electrical energy into mechanical energy to drive the elevator, rudder, and aileron [19]. In addition, it has a stator and rotor as power-producing units to produce thrust by turning the propeller. This propeller produces lift for the aircraft so that the quadcopter can hover, take off, and land.

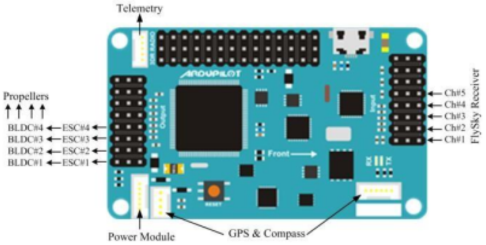
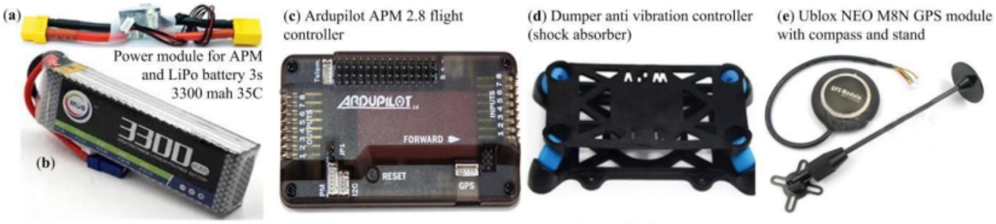


Fig. 3. APM 2.8 Board and its connection as a drone

Thus, APM 2.8 is a UAV autopilot system with open-source firmware and has a supporting device, namely Mission Planner (MP), which is run via MAVLINK. This MP allows users to turn any fixed, rotary-wing, or multirotor vehicle even cars and boats. This MP allows users to turn any fixed, rotary-wing, or multirotor vehicle, even cars and boats into a fully autonomous vehicle; capable of performing programmed GPS missions with waypoints. This flight section contains flight data and a flight planner. Flight data helps pilots to observe attitude (altitude, speed, coordinates, temperature, aircraft flying direction, etc.). This board revision internally has no onboard compass to avoid magnetic interference. However, APM 2.8 requires a GPS unit and external compass for full autonomy. Figure 3 shows detail materials or main components of the drone that was used in this project. The main reasons for choosing this component are affordability, stability, reliability, durability, and long-term use in collecting atmospheric data. For example, to run the drone for a long time with stable power requires a high-capacity LiPo battery in addition to a quality BLDC.

As shown in Figures 3 and 4, the 6-line Power Module (PM) (**a**) from the LiPo battery (**b**) is connected directly to the APM 2.8 power port (**c**) covered by a shock absorber (**d**) to enable flight controller, Ublox GPS and Compass module (**e**), receiver module (**f**), and ESC module (**g**). Another PM output is connected to the power board on the F450 frame (**i**) to activate the ESC as well as BLDC (**h**) to generate thrust and lift on the propellers (**j**). An ESC has 3 I/O cables where the two wires near the capacitor are for the ESC voltage and the middle wire (containing the signal, Vcc (+5V) and GND) connected to the APM 2.8 output. The other 3 ESC cable outputs are connected to the BLDC. The ESC is used to control the motor's rotational speed or to regulate the motor speed electronically. The basic function of ESC is an electronic circuit to regulate motor rotation according to flight needs or based on the location of the throttle stick. Thus, the BLDC, ESC, and propeller are propulsion systems designed to achieve the aircraft's highest thrust capability and efficiency [20].

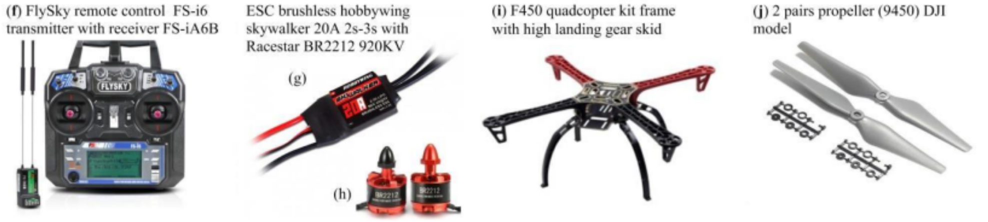
After gathering all the components, the complete drone design as described in Section III. Before implementing the design, the key of a drone works if all four motors will spin at once when controlled from Remote Control (RC). Quadcopter performance is affected by the rotor, natural conditions, and power efficiency. Therefore, the following briefly describes each component's function in forming a quadcopter controller. A Flysky FS-i6 RC (f) as a radio control system controls devices remotely consisting of a transmitter on the ground station and a receiver installed on the drone. Radio control can control the airplane connected to the ground station using RF data telemetry. The ground station will receive data about the condition of the aircraft in flight and then use it to monitor new flight data. The flight data is then used as a reference for resetting the parameters processed by the flight controller if necessary. The data generated from the sensor is then translated by the microcontroller (c) as a reference to set the output to the ESC (g). The radio control transmitter (f) is held by the pilot where the radio waves emitted by the transmitter (FS-i6) are received by the receiver on the drone (FS-iA6B) and then translated into commands to the flight controller. The last part is the GPS (e), a system for determining the position on the earth's surface with the method of synchronization of satellite signals which generally contain the control segment, the space segment, and the user segment.



(c) Ardupilot APM 2.8 flight controller

(d) Dumper anti vibration controller (shock absorber)

(e) Ublox NEO M8N GPS module with compass and stand


(f) FlySky remote control FS-i6 transmitter with receiver FS-iA6B

ESC brushless hobbywing skywalker 20A 2s-3s with Racestar BR2212 920KV

(i) F450 quadcopter kit frame with high landing gear skid

(j) 2 pairs propeller (9450) DJI model

Fig. 4. Materials used for a drone with F450 frame and APM 2.8 flight controllers

b) Setup the APM 2.8

Before the drone can function as an autopilot and can be used to carry out measurements or monitoring, the Mission Planner (MP) software must be installed. MP is a ground station used to control or configure drones or aircraft, where the latest installer in a zip file can be accessed via the ArduPilot link [21].

Based on the guide link above, the installation procedure in an orderly manner can be carried out in brief as follows:

1. Click the SETUP Menu ==> Install Firmware.
2. In this case, select Copter 4.1.1 OFFICAL (the firmware version is usually updated)
3. If failed to install firmware because the hardware version used is outdated (the board was retired), follow the instructions on your laptop monitor to download the recommended firmware.
4. If the installation still fails, restart the laptop and download the custom firmware available via the sublink, stable-3.2.1/apm2-quad [21]. Download the ArduCopter.hex file since we are designing a quadcopter in this work.
5. When the installation is successful, they will provide a COM PORT; for example COM7 says COM7-1 Quadrotor ==> 115200 (see the icon in the upper right corner). In addition, the Mission Planner that has been successfully installed will display a settings menu, as shown in Figure 5.
6. When the installation process is complete, connect the AMP2.8 board via USB cable to your laptop by selecting the port given above and clicking: Install Firmware Legacy.
7. Select Mandatory Hardware:
   - Frame type: Quadcopter
   - Compass ==> Live configuration
   - Accelerometer Calibration (follow the steps on screen)
   - Radio Calibration (without propeller)
   - Flight Mode
   - Other calibrations can be done manually without connecting via USB.

Fig. 5. Installed the Mission Planner for the ground station

8. Successful setup is also indicated by the spinning of the four motors simultaneously when ARMING is performed on the throttle stick of the RC Transmitter. Note that the binding process between the receiver and transmitter has been carried out before the RC communicates with the aircraft.
9. After completing the above steps, the drone is ready to be tested for flying.

B. Automatic Weather System with BME280 sensors

After the drone can fly stable, it can take atmospheric data through the drone. Two AWS containing atmospheric sensors and data loggers have been developed, one mounted on the drone body for payload and one on the ground for comparison. This sensor has been developed and tested as reported by Suparta et al. [2]. The main components used to build AWS are as follows:

1. Arduino Uno R3 SMD
   This controller uses the Atmega 328P as the main processor to control AWS. The affordable and the number of pins required by the sensor device are why choosing this type of Arduino.
2. BME280 sensors
   BME280 is the main core of the atmospheric sensor that can measure the temperature, humidity, air pressure, and altitude at a certain location. Its small size, sensitivity, and high accuracy, in addition to its affordable price are the main considerations to choose.
3. DS3231 RTC module
   This module is used to generate accurate logging time on the sensor.
4. 16×2 LCD with I^{2}C module
   This module is for displaying measurement data and knowing whether the system is working or not.
5. Micro SD card module
   This module stores measurement data that can be used for future analysis.

More details regarding the development and characteristics of this AWS can be found in the paper of Suparta et al. [2].

III. RESULTS

A. *Drone System Developed*

Figure 6 shows the drone developed with F450 quadcopter frame where all components were used in Figure 3. The figure shows that the APM 2.8 flight controller is protected by a plastic dome. The AWS with Arduino in a pink box is mounted on the bottom of the drone body. The pink box has multiple vents that allow the meteorological sensor to adapt to its environment. The 16×2 LCD is housed in the box behind the pilot.

Fig. 6. Assembled drone with an F450 frame and equipped with Arduino meteorological sensors as a payload

After the drone is tested without propellers where all the motors are turned simultaneously according to the movement of the throttle, and then the propeller is installed correctly. Finally, the drone can fly as shown in Figure 7. This drone is armed through the Flysky RC transmitter (FS-i6) mode 2 model. It can fly at an estimated altitude of over 200 m until it is out of sight. The drone was not equipped with telemetry and cameras in this initial design, so it was only controlled to fly around an area below 100 m above the ground level. If the drones fly above 100 m, it is feared that they will be lost in the wind and fall in a forbidden place. In the test and data collection, drones have hovered at the aircraft training field for ITDA students, south of Adisucipto International Airport. Note that Figure 7(a) shows the AWS for atmospheric measurement on the ground.

Fig. 7. Unedited photos for drones (a) before take-off and (b) successfully hovered and collected data

B. *Sensor Calibration*

Sensors or instruments used for measurements need to be calibrated to minimize uncertainty and ensure precision, consistency, and provided correct interpretation of measurement results. This calibration process from the results of AWS measurements is shown in Figure 8. As shown in each panel of the figure, T, H, P, ALT, and PWV is representing for temperature (in degree Celsius), relative humidity in %, air pressure (mbar), altitude (m), and precipitable water vapor (mm) respectively. The two sensors were placed at the same place and altitude, which is indoors in a residential area (GPS coordinates: 7°44’54” S, 110°26’16’’ E, and an elevation of 175 m above sea level (ASL)) to reduce external influences. From approximately 9 hours of measurements on September 18-19, 2021, the mean difference before offset between the sensor for drones (AWS1) was 1.08°C, 4.38 mb, and 37 m higher than the sensor for Ground Station (AWS2) for temperature, pressure, and altitude, respectively. Only the humidity of the two sensors had almost the same readings, with a mean difference below 1%. This calibration calibrates pressure and altitude with values obtained from Barometer & Altimeter Apps and weather reports from Adisucipto International Airport (JOG). At the same time, temperature and humidity are also compared with HTC-2 Thermometer Humidity. After the offset value is obtained in Table 1, the sensor is calibrated via an Arduino sketch. An example of a calibration offset in Arduino for the pressure of AWS1 is

P1 = bme280.readPressure()/100.0F + 18.373;

Note that the unit for pressure was converted from hPa to mbar (1 hPa = 1 mb). Note that the obtained differences in readings in the table may occur due to the high sensitivity of the sensor in addition to tired internal components from prolonged use such AWS2 sensor that have been used for more than one year. Overall, the two sensor readings consistently have the same variations and trends.

Table 1. Calibration ofsset for AWS1 and AWS2

Parameter	AWS1	AWS2
Temperature	T = T + 0.2889	T = T + 1.1.5977
Pressure	P = P + 18.373	P = P + 22.753
Altitude	A = A – 6.6055	A = A – 43.78

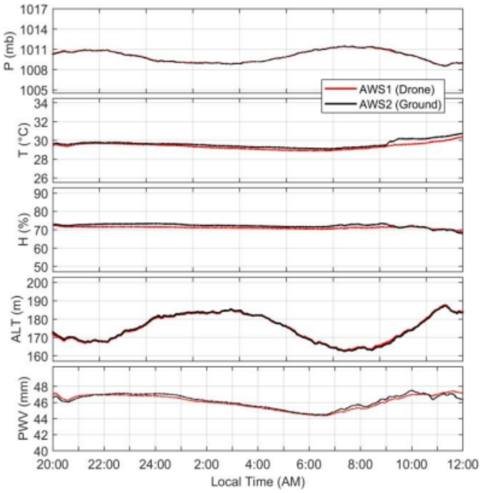


Fig. 8. The calibration of two sensors for the data collected indoors on September 18-19, 2021

C. Weather Measurement

Based on Figure 7, the data collection was carried out at GPS coordinates (ITDA: 7° 47' 48.51" S, 110° 25' 08.33" E and an elevation of 105 m a.s.l.). The first measurement results are presented in Figure 9. The second experiment on October 16, 2021, was carried out in the same place as the first test. Data is collected with an interval of one second. This experiment aims to compare the measurements obtained with previous experiments. This experiment is also to observe the drone's stability while hovering with maneuvers. Both experiments were carried out in the early morning due to the low wind effect. Figure 10 shows the results of the second weather data measurement. Similar to Figure 9, the blue up (↑) and blue down (↓) arrows on the altitude (ALT) panel indicate the take-off and landing times of the drone, respectively.

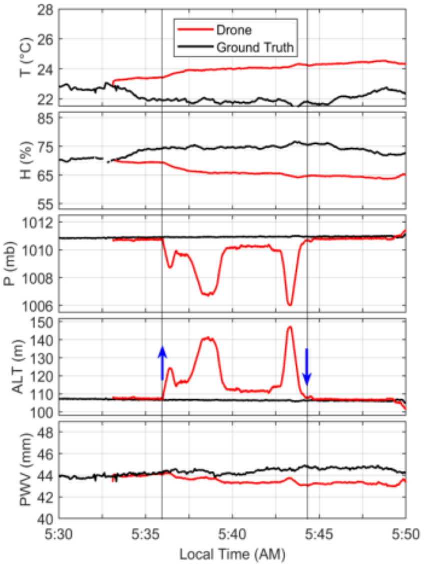


Fig. 9. Results of weather measurements from the drone and ground on September 24, 2021 in the early morning

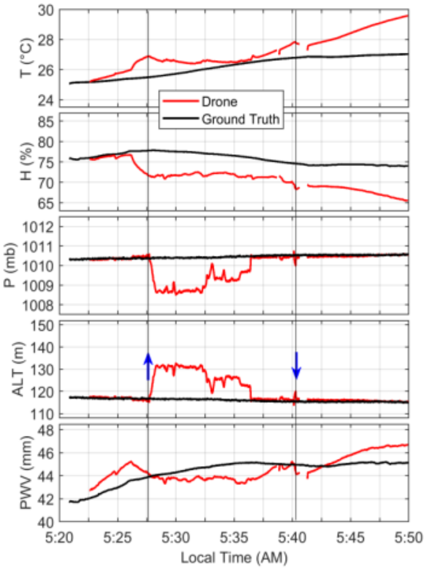


Fig. 10. The results of the second weather measurement from the drone and ground on October 16, 2021

IV. DISCUSSION

There are two results to be discussed in this paper. The first is the design result in the form a drone containing APM 2.8 as a controller. The second is atmospheric data obtained with AWSs on the drone and the ground, respectively. We start with the data obtained first and then discuss the drones that have been developed.

A. Atmospheric Data Collection

Referring to Figure 9, the drone took-off at 05:36:02AM and landed at 05:43:56AM. Furthermore, the drone flies and carries a payload in the form of meteorological sensors that can measure temperature (T), air pressure (P), relative humidity (H), altitude (ALT), and atmospheric water vapor (PWV). To compare the results of weather measurements made via drones, the same AWS is placed at the launch coordinates on the ground (see Figure 7(a)). The AWS on the ground was powered early at 04:36:15AM and shut down at 06:31:29AM. In other words, the drone for this experiment was only airborne for about 7 minutes 54 seconds. During in the air, the drone has made circular movements at a radius of 200 m and maneuvered up and down for 3 times (see ALT panel of Figure 9).

There is a significant difference in readings between the sensors on the drone and the ground during flight; when the drone's position increases, the pressure increases with the decrease in the air pressure value. The higher location point will get the temperature colder, and the humidity is inversely proportional to the temperature. While atmospheric moisture content as measured by PWV tends to follow the trend in humidity, its value decreases when the drone goes up into space.

The same result was also obtained in the second result (see Figure 10), where the drone was in the air for about 18 minutes. It is twice longer in the air than the first experiment. At the beginning of the hover, the drone was allowed to take measurements at a height of 133 m ASL for 5 minutes, and then maneuvered down and up for two times. During this maneuver, the drone's movement is well controlled and lands at its take-off point. After a smooth landing, it had been turned off for a while (as indicated by no data on the graph at 5:41AM). The power is turned on again to allow the drone to fly again but fails due to a lack of power as alerted by the battery alarm sound. Overall, experiments with different days will produce different readings due to different weather conditions, but they still have a similar trend.

B. Drone As A Measurement Vehicle

Many of the experiments carried out were not smooth, such as when the drone flies, it turns out that the data is not stored. In other cases, the drone suddenly falls and breaks its arm (see arm difference in Figure 6 and Figure 7(a)) and many other accidents. Therefore, the APM 2.8 board is protected with a plastic dome to minimize damage in the event of a sudden crash. In addition, the AWS sensor is housed in the box plastic, and the GPS antenna mast is attached to the drone arm (not screwed to one end of the power board because if the drone falls, the pole will come off the bolt, and the GPS receiver will be damaged). One of the serious problems when the drone suddenly crashes is due to the instability of the firmware on APM 2.8 during setup. Therefore, the manufacturer always updates the firmware from time to time, and we are forced to reinstall it. Another factor that destabilizes the drone is wind speed, and it is suggested to operate the drone considering wind conditions.

The use of drones to take measurements in the air as well as monitoring and surveillance provides new challenges and nuances to help provide solutions to events or cases that humans cannot directly access. The types of built drones are also adapted to the case to be studied and cost considerations. In this case, the use of quadcopter drones to collect atmospheric data is due to their stability of the movement, ease to build and operation, and the general drawback lies in battery life. It cannot be operated in all weather conditions.

V. CONCLUSION

The drone with a quadcopter platform to measure atmospheric parameters has been successfully developed with a DJI F450 frame. This quadcopter can fly stably by carrying a payload in the form of AWS. They can fly at an altitude of more than 200 m, and when in the sky, they can endurance for about 20 minutes on average in stable weather. Atmospheric data on the drone and the ground has also been successfully collected through a weather sensor using BME280 and controlled by Arduino Uno R3 SMD. The results of atmospheric measurements obtained in the short-term show that relative humidity is inversely proportional to temperature, and the water vapor content decreases as the altitude of the drone increases. In addition, the value of air pressure is also obtained inversely with altitude, which means that the higher the position of the object in the air, the more pressures.

From the quadcopter that has been successfully developed, the next measurement of atmospheric parameters such as PWV for weather forecasting, air pollution, and fire smoke to help mitigate the pollution index or surveillance activities. Data collection with drones can be programmed automatically by utilizing the waypoints facility in Mission Planner. For flying in the air for a long duration, using a high-capacity battery and light is recommended. On the other hand, this will present a new challenge for future work on developing a battery that can recharge itself during flight.

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