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Article

Particulate Matter Monitoring Using Inexpensive Sensors and Internet GIS: A Case Study in Nan, Thailand

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Abstract. Thailand has faced environmental issues that affect people all the time. Haze from the forest fires for instance is concerned as national problem that we confront every year. To determine the severity of smog conditions being a consequence of haze fire in some areas cannot be easily done. Unmanned Aerial Vehicle (UAV) then could be easily used as a tool for surveying in such difficult burning areas. Furthermore having the environmental sensing devices developed and mounted on the UAV would be a worthy approach for monitoring environmental status in hazardous areas.

This research was conducted to assemble the UAV and sensor device for measuring the environmental data including temperature, humidity and dust particle. The sensor was calibrated with reference devices. The field test was carried out in Nan province. Together with temperature, humidity and dust particle value, the location and time from GPS on UAV will be integrated correspondingly with environmental measuring data. Those entirely data will be imported to GIS and rendered in map form subsequently.

Keywords: Unmanned aerial vehicle (UAV), air pollution, micro weather device, forest fire, haze.

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1. Introduction

Several Southeast Asian countries have confronted serious impacts of haze pollution during the last two decades. In the northern part of Thailand, especially has taken around 67% of forest fire occurrences during October 2015 to July 2016 [1]. Either the fire events come from nature, burning of agricultural residues, or whatever its cause, the monitoring system is needed. This is because the concentrations of particulate matter would be a key decision to resolve the haze situation appropriately. The haze dilemma is not only a national crisis, it has been transboundary pollution in the Asian region [2].

To determine the severity of air pollution being a consequence of haze fire in some areas cannot be easily done. Unmanned Aerial Vehicle (UAV) then could be easily used as a tool for surveying in such difficult burning areas. Furthermore having the environmental sensing devices developed and mounted on the UAV would be a worthy approach for monitoring environmental status in hazardous areas.

This study therefore aims to apply inexpensive sensors as a monitoring instrument of particulate matter (PM).

This research was conducted to assemble the UAV and sensor device for measuring the environmental data including temperature, humidity and particulate matter (PM). The sensor was calibrated with reference devices. The field test was carried out in Nan province. Together with temperature, humidity and PM value, the location and time from GPS on UAV will be integrated correspondingly with environmental measuring data. Those entirely data will be visualized as 3D.

2. Methodology

2.1. Nan Province, Thailand

Nan is one of the nine Northern provinces in Thailand being disturbed by the haze situation. There are 2 monitoring stations at Nai Wiang, Mueang, Nan and Huai Kon, Chaloem Phra Kiat, Nan. Air quality parameters shown at both stations include PM10, Ozone (O_3), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and Air Quality Index (AQI).

2.2. Sensor Devices

Sensor devices for measuring the air quality data are including temperature, humidity and particulate matter (PM) which are connected with microcontroller board (Arduino Mega 2560) as shown in Fig. 1

Fig. 1. Air quality sensors set.

2.2.1. Temperature and humidity sensor

DHT22 is the sensor which is used for temperature and humidity measurement. Its characteristics can be seen as follows; 3.3-6.0 V (DC), can measure the humidity in the range of 0 – 100 %RH (Accuracy ±2%RH) and (-40) to 80°C for temperature measurement (Accuracy ± 0.5°C), dimension 14 × 18 × 5.5 mm.

2.2.2. Particle matter sensor

Plantower PMS 3003 is the particle matter sensor which use the laser scattering principle that the laser is scattering by particle matter in air and reflect to the diode that will generate the electric current. In case of the particulate matter pass into the chamber of sensor and be collided by the laser, the current will be generated by diode.

2.2.3. Microcontroller

Arduino Mega 2560 is the microcontroller which is used in the data transmission from the sensor DHT22 and PMS 3003 and record the data in the data storage (SD card) as shown in Fig. 2.

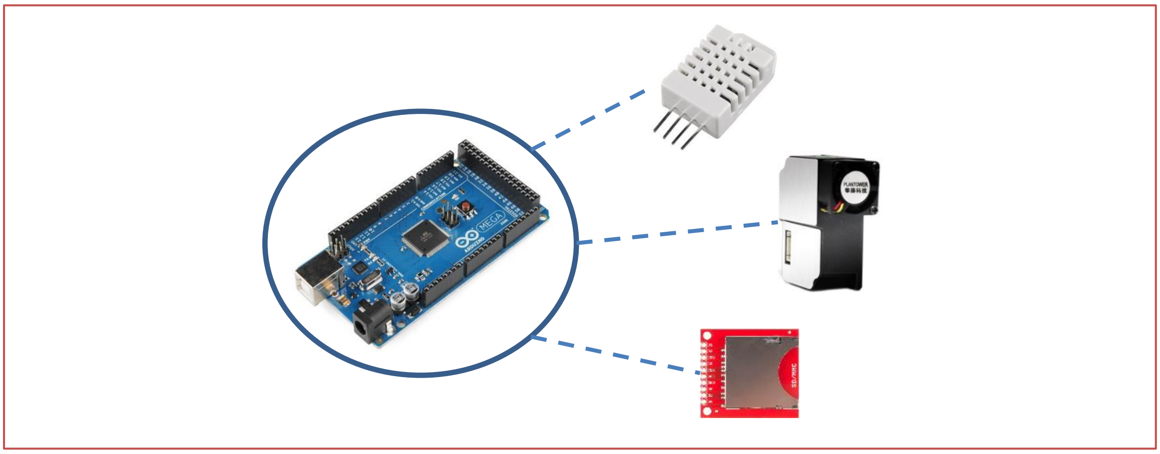

Fig. 2. The connection of Arduino Mega 2560 with DHT 22 and PMS 3003.

2.3. UAV

The UAV which is developed in this research is the hexarotor type that is more stable than the quadrotor type and can attach more devices. The hexarotor consist of a 6-axis type rigid cross frame, 30Amp-electronic speed controller (ESC), 380KV-motor (T-motor MT4008-18), 13x5 multi rotor propellers, Pixhawk automatic flight controller set, and FrSky Taranis X9D Plus 2.4GHz Digital Telemetry Radio Transmitter as shown in Fig. 3.

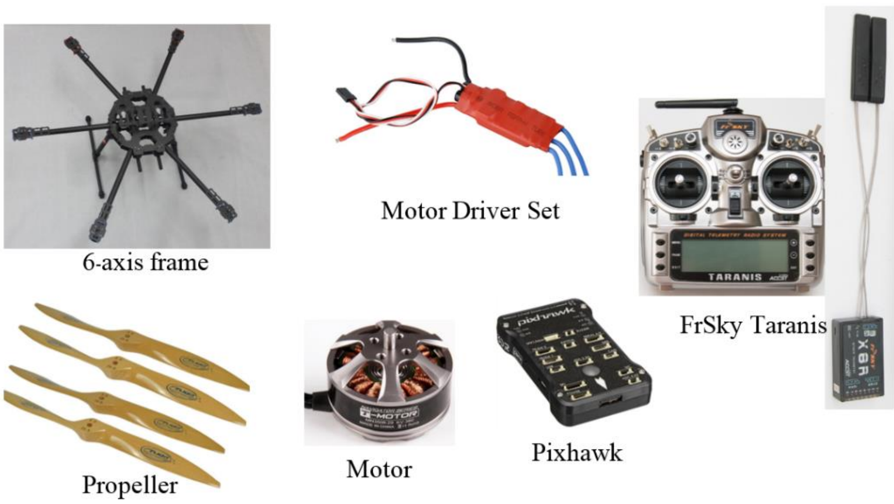

Fig. 3. Component set of Hexarotor.

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UAV-type plane will have automated flight feature which following our command by Pixhawk automatic flight controller set that connect with the radio transmitter and motors. Pixhawk automatic flight controller set will include 4 types of flight related sensors as follows: GPS for locating of UAV coordination, Barometer for the calculation the flight altitude, Inertial Measurement Unit (IMU) for calculating the inclination of UAV in 3 axis, and Compass for calculating the direction of UAV.

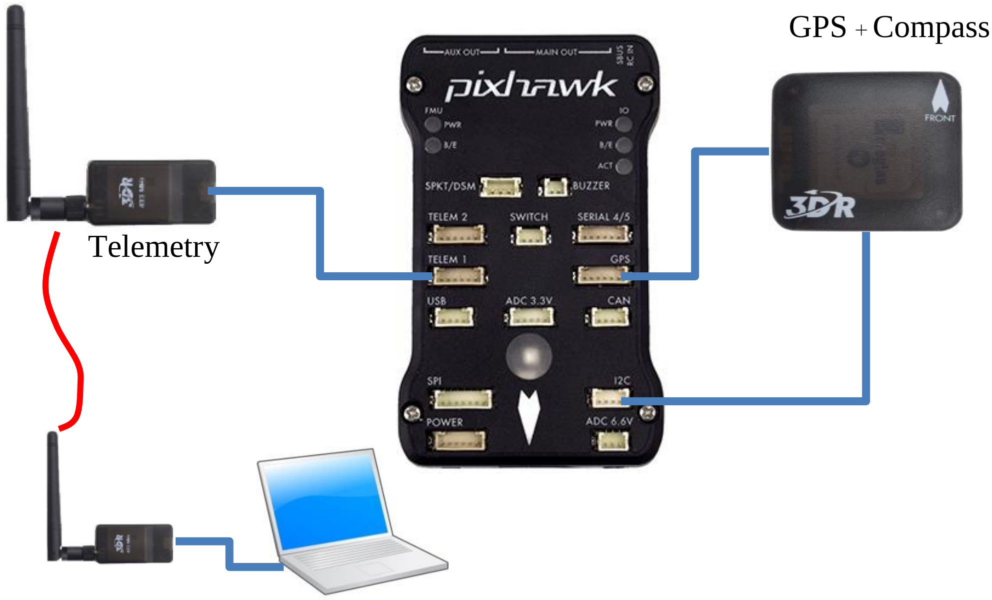

Fig. 4. Pixhawk automatic flight controller set.

The communication of earth station and UAV will communicate by 915 MHz telemetry system which are included in Pixhawk automatic flight controller set and the other one will attach with computer and the data transmission will be processed by computer software.

Flight control software which is installed in Pixhawk automatic flight controller set is ArduPilot that is the open source software. ArduPilot will include the firmware that can be selected to use with devices. In case of hexarotor UAV, we use the "ArduCopter" firmware to install the rotor-type UAV or vertical take-off landing system.

We can use the software "Mission Planner" to install the firmware to Pixhawk, set the flight planning and use for communication between earth station and UAV.

In the first time of firmware installation, we have to calibrate the related sensors i.e. Inertial Measurement Unit (IMU), compass, radio transmission, flight mode, and FailSafe as shown in Figs. 5, 6, 7, and 8 respectively.

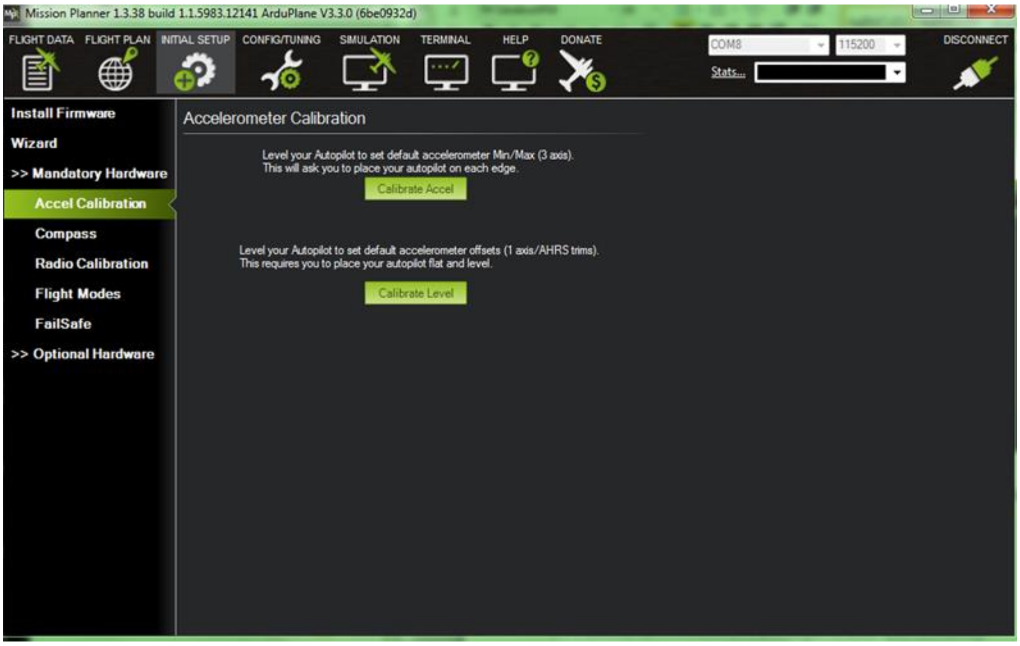

Fig. 5. IMU calibration.

Fig. 6. Compass calibration.

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Fig. 7. Radio calibration.

Fig. 8. Flight modes calibration.

Fig. 9. FailSafe configuration.

We combine the air quality monitoring sensors (i.e. temperature, humidity and particle matter) with Arduino Mega 2560 and Pixhawk as shown in Fig. 10.

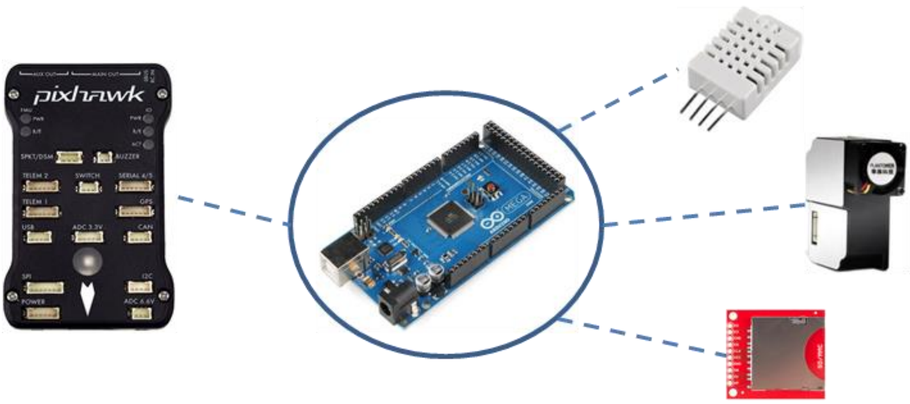

Fig. 10. The connection of sensors and Pixhawk.

3. Results and Discussion

3.1. Sensor Calibration

The secondary calibration of particulate matter (PM) sensors were tested with an instrument approved by Pollution Control Department [3]. Both sensors of PM10 (particulate matter less than 10 micron) and PM2.5 (particulate matter less than 2.5 micron) were set up and compared theirs results with a Tapered Element Oscillating Microbalance (TEOM) monitor. PM2.5 concentrations of sensor and TEOM were shown in Fig. 12.

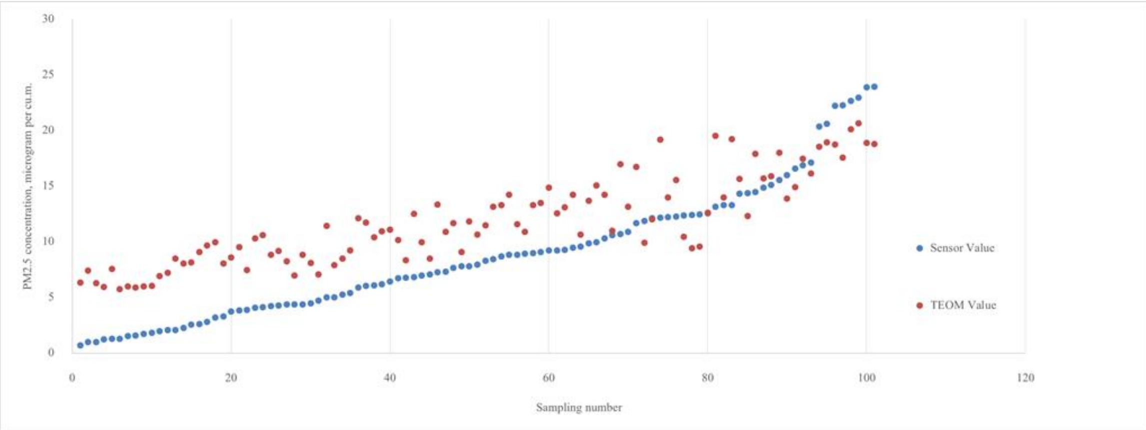

Fig. 12. Concentration of PM2.5 (μg/m^3) from sensor and TEOM.

As shown in Fig. 1, 84% of samples from sensor gave the values that lower than those from TEOM. Only 16% from sensor displayed the higher value than those of TEOM. To determine the difference between concentration of sensor and TEOM, t-test (two sample unequal variance) was used. The statistics result illustrated in Table 1, t stat was less than t critical then the hypothesis was accepted. The correlation between TEOM and sensor value also shown in Fig. 13.

Table 1. t-Test on PM2.5 concentration.

t-Test: Two-Sample Assuming Unequal Variances (PM2.5)		
	Sensor	*TEOM*
Mean	8.847542261	11.84608911
Variance	34.27890732	15.58398268
Observations	101	101
Hypothesized Mean Difference	0	
df	200	
t Stat	-4.267591115	
t Critical one-tail	1.653607437	
t Critical two-tail	1.973612462	

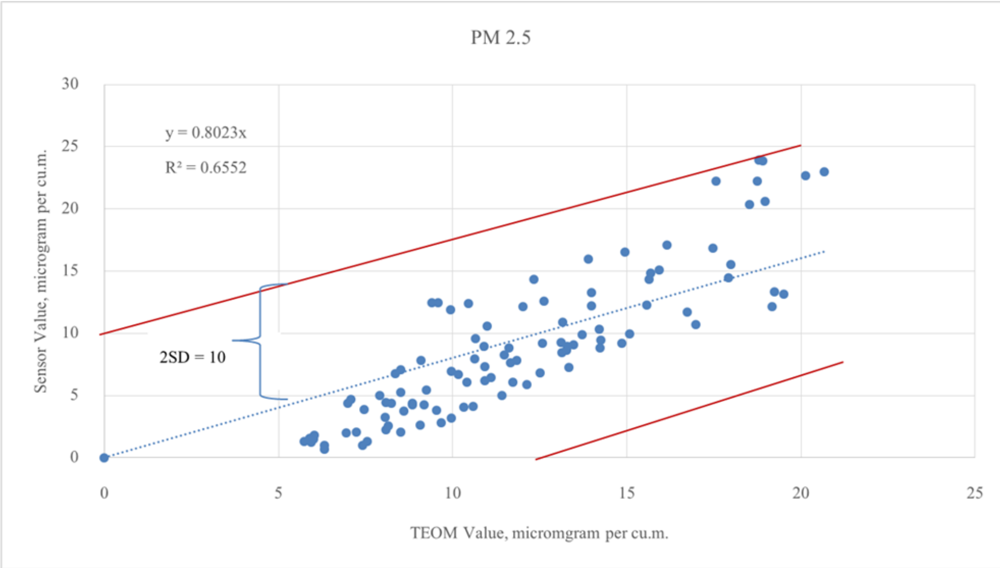

Fig. 13. Correlation between TEOM value and sensor value of PM2.5 (μg/m³).

In case of the PM10 calibration, the sensor report the lower concentration than the TEOM value as shown in Fig. 14. The t-test (two sample unequal variance) was used to determine the statistical difference of PM10. The t-stat is equal to -13.6 and t critical one-tail is equal to 1.65 that the computational value is less than the table as shown in Table 2. Therefore, the hypothesis which the average value of sensor and TEOM were not different was accepted. The correlation of PM10 from sensor and TEOM as shown in Fig. 15.

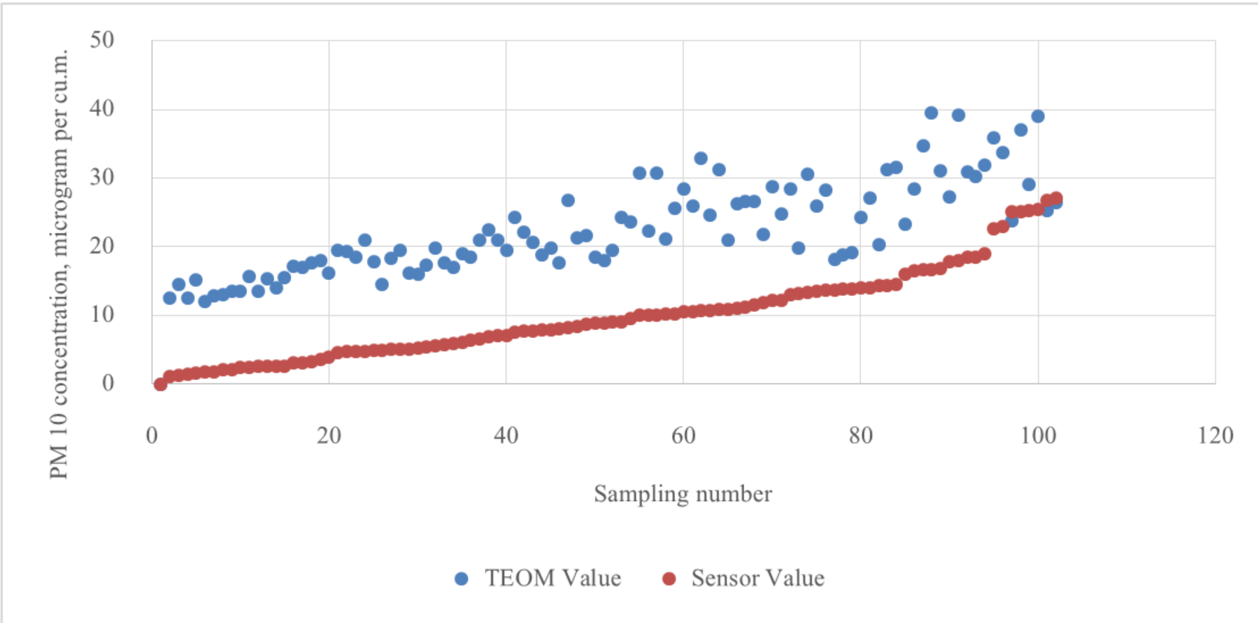

Fig. 14. Concentration of PM10 (μg/m³) from sensor and TEOM.

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Table 2. t-Test on PM10 concentration.

t-Test: Two-Sample Assuming Unequal Variances (PM10)		
	Sensor	*TEOM*
Mean	10.05281062	22.69759901
Variance	41.64841161	44.70464537
Observations	101	101
Hypothesized Mean Difference	0	
df	200	
t Stat	-13.6751908	
t Critical one-tail	1.652508101	
t Critical two-tail	1.971896224	

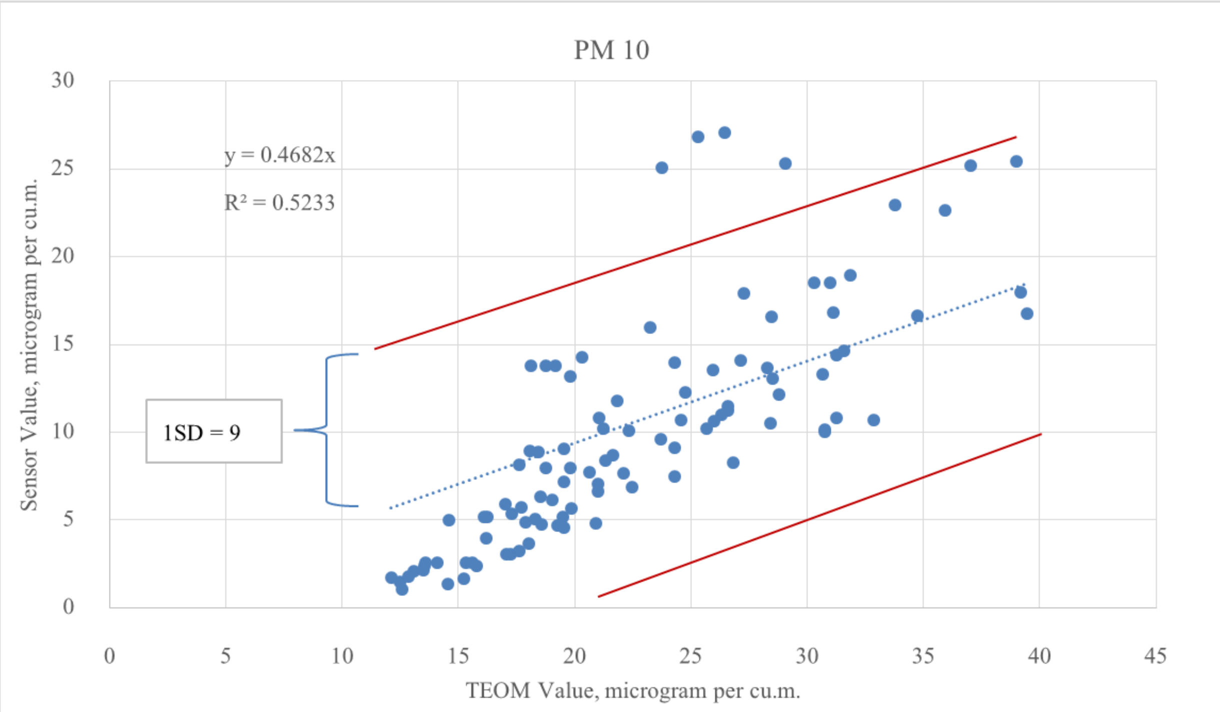

Fig. 15. Correlation between TEOM value and sensor value of PM10 (µg/m³).

Due to the result of the test of temperature, humidity, and particulate matter, we indicated that the reliability of temperature and humidity value which we got from the sensor are higher than the particulate matter. Hence, we did not use the calibration constant for the temperature and humidity measurement in our research. In case of particulate matter, even the reliability value is low (R^2 = 0.6 and 0.5), because of this research need the trend value of pollutant which the particulate matter data from sensor could be accepted due to the statistical comparison as mentioned above. However, the calibration constant still be necessary to use for the efficient measurement.

3.2. Results

The data collected from a drone is visualized using R. 3D representation was employed to show location (horizontal plane) as well as altitude of the flight path (vertical axis). Figure 16 shows side view of 3D showing temperature data. The value of temperature is displayed as colors.

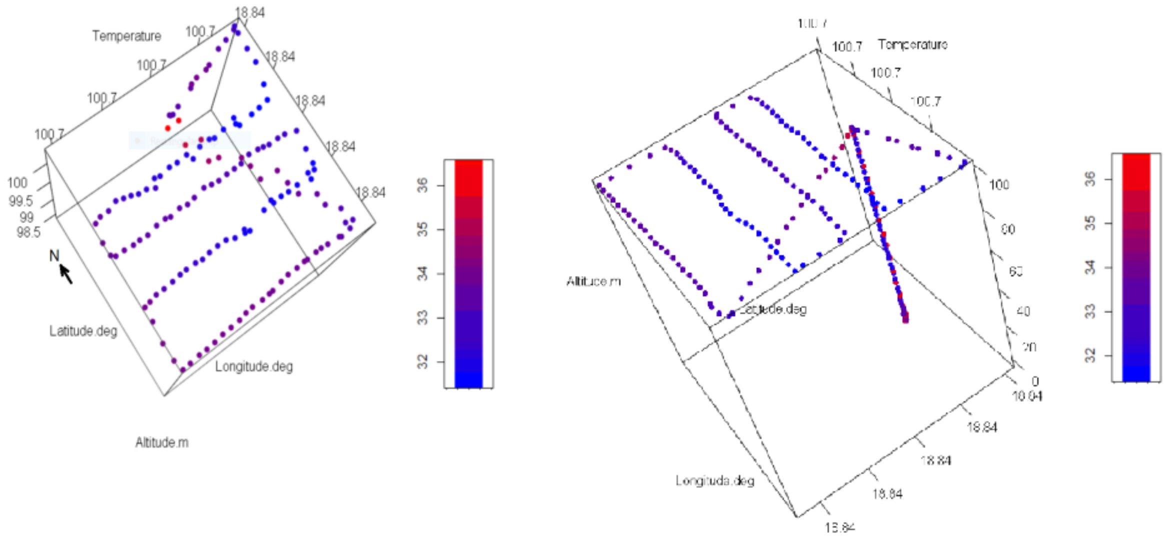

Fig. 16. Top view and side view of temperature data collected from drone.

The flight took off and flew back and forth at the same altitude to measure various parameters at different location. Figures 17-19 show the 3D display in the same angle view of humidity, temperature, and dust respectively. The result shows that the color became darker or lighter alternately, at the same altitude; especially temperature and dust— which means the value of all measures varied according to the direction of the flight.

The result for temperature and dust show the changes are inverse to each other (Figs. 18 and 19). The dust value was high while the temperature became low; when the drone went from West to East. To eliminate the effects of the wind, a windshield was needed to protect sensors from that effect.

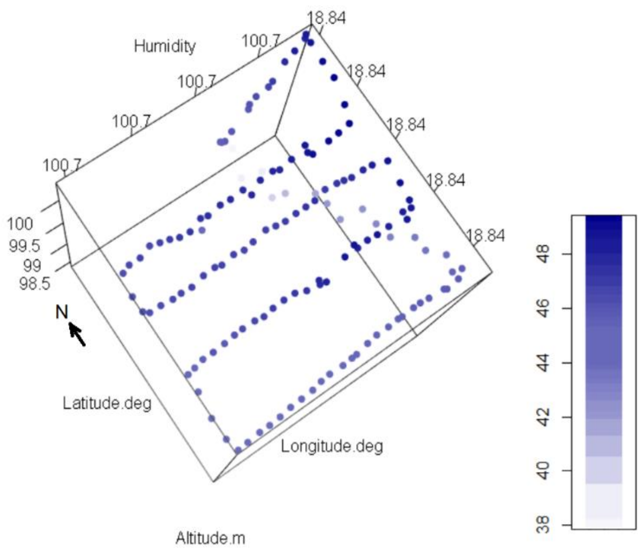

Fig. 17. Humidity result on 3D.

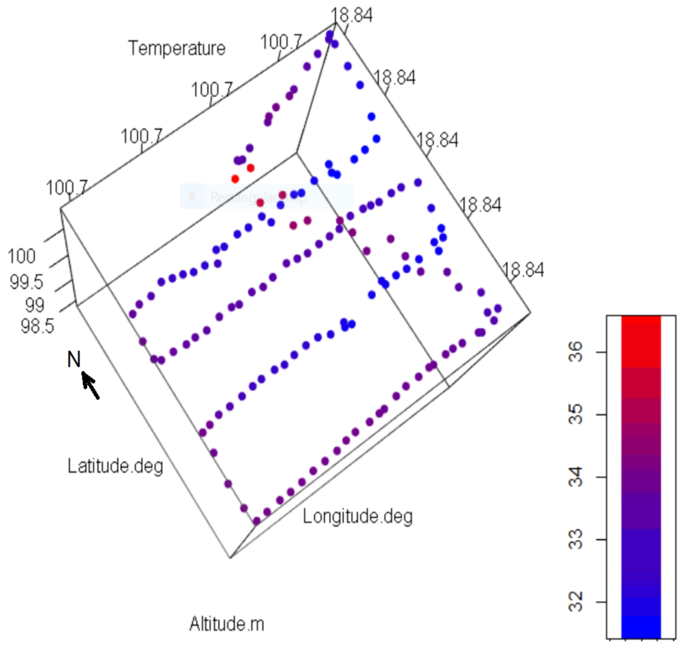

Fig. 18. Temperature result on 3D.

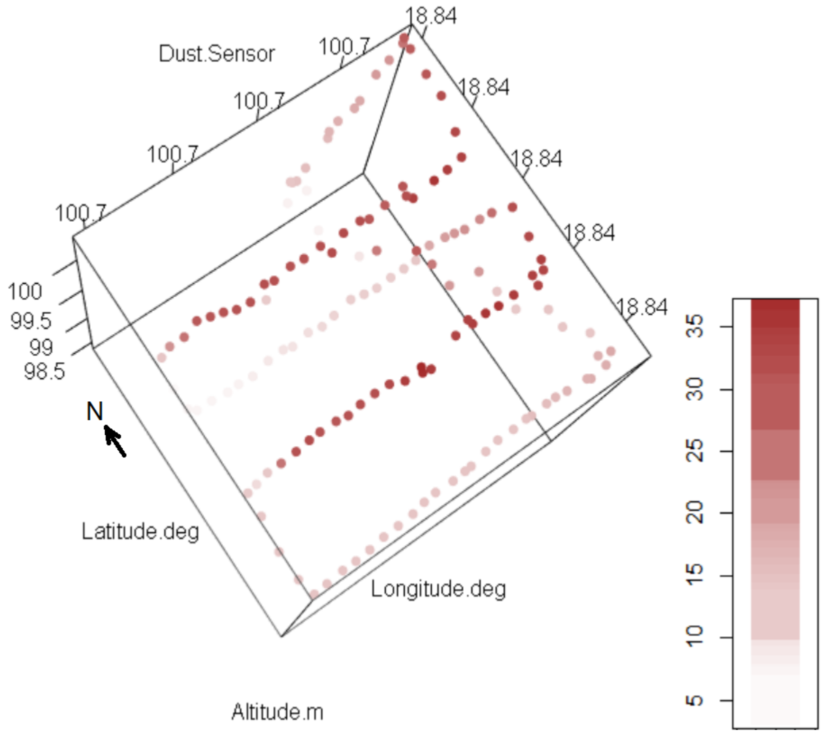

Fig. 19. Dust sensor result on 3D.

4. Conclusion

In this research, we set up PM sensors and compared the results with a Tapered Element Oscillating Microbalance (TEOM) monitor which is an instrument approved by PCD. In case of PM2.5, almost of sensor data are lower than TEOM. When we used t-test to determine the difference between concentration of sensor and TEOM, t stat was less than t critical thus the hypothesis was accepted. For the PM10 sensor calibration, the results from sensor was lower than the TEOM and t-test was also computed to determine the statistical difference of PM10. The t-stat was less than t critical one-tail. Hence, the hypothesis that the average sensor value and TEOM were not different was accepted. According to the result of temperature, humidity and PM test, the reliability of temperature and humidity data which are reported by sensor are higher than the particulate matter data. In case of reliability of PM data is low, the calibration constant should be used for accurate measurement. According to the data acquisition by using drone, the air quality data are visualized in 3D display that was employed to show location in horizontal plane and the altitude of the flight path on vertical axis. The value of air quality is displayed as colors.

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