Development of Medical Drone for Blood Product Delivery: A Technical Assessment

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Abstract—Drone is the well-known technology in military and amateur application. Recently, the drone was used to deliver goods and parcels. There is an increasing need for urgent delivery of medical supplies in low resource setting due to traffic congestion and terrain obstacles. The delivery of blood in emergency cases such as postpartum hemorrhaging is challenging and can be delayed due to geographical condition in underserved area. Postpartum hemorrhaging needs an immediate blood transfusion with proper blood product to save the life of mother and baby. To address to this need, a drone that can deliver blood supply to the desired location may be a good option. Therefore, research has been conducted to identify the baseline of drone specifications for blood delivery. A Hexacopter with the ArduPilot firmware and a Lithium-Polymer battery of 16,000 mAh were used to study the applicability of blood products delivery using drone. Using several tests to assess drone limitations, experimental data was obtained and analyzed using distinctive methods. The results indicated that the thrust-to-weight ratio of the drone play a paramount role for the drone performance and flight time. The GPS guidance performance showed a reliable and stable flight with only a slight deviation of ±6 meters during the tests. Finally, a test flight was conducted to simulate the actual test location from Queen Elizabeth Hospital and Hospital Wanita dan Kanak-Kanak, Likas, Sabah. The developed drone reached a flight time of 25 minutes covering 8.38 km with 4.3 kg take-off weight.

Keywords—Medical Drone, Blood Products, Blood Transportation, Hexacopter, Payload

1 Introduction

The Drone is an unmanned aircraft which has been used in military applications. Recently, drones are used for various scientific applications, public safety, commercial industry and leisure [1]. Today, drones can be launched into the air and can be controlled remotely using various methods such as vertical takeoff and landing, conventional wheeled takeoff from a prepared runway and launched by a pneumatic launcher. Selection of the method to be used is depending on the terrain, weather conditions, local legislations, and predefined security measures.

Most drones still belong to civilian hobbyists whilst some of the healthcare and corporate are interested to explore drones for medical purposes. As for commercial goods delivery application is concerned, Amazon Inc. plans to fly drones to deliver parcels to its customer. The parcel delivery can be made within a 16 km radius of its warehouses and at a speed of up to 80.5 km/h with packages weighing up to 2.26 kg [2]. In medical supplies delivery, it is still limited to wheeled motor vehicles and manned aircraft. It can be expensive and slow, especially for those who need it on times for critical need such as blood in underserved areas [3]. Due to this limitation, researchers have explored the feasibility of its application in the healthcare industry. The applications of medical deliveries using drone include delivery of medicine, defibrillators, blood samples and vaccines [4-5].

Furthermore, an organization, "Doctors Without Border", used drones to transport dummy tuberculosis (TB) test samples from a remote village to a large city in Papua New Guinea using drones [6]. The National Aeronautics and Space Administration (NASA) used a drone to deliver medical supplies to a small clinic in rural Virginia using a drone [7]. It is the first drone delivery approved by the government in United Stated. In addition, drones have been used to transport blood products and medicinal products to critical access hospitals and remote areas of Rwanda, Africa [8]. Global positioning systems (GPS) and cellular networks were used to navigate drones. The hospital can order the blood and medicine using text messages and received the supplies within 30 minutes.

In the study of the quality of blood products after a drone flight, Amukele et al. [9] designed and conducted a study using red blood cell (RBC), platelet (PLT) and frozen plasma (FP24) units. By placing the blood product in a cooler, attach it to the drone and flown over the ground level of 100 m for a maximum of 26.5 minutes with a temperature logging. After flight, RBC units were centrifuged and visually checked for hemolysis. PLT units were checked for changes in mean PLT volumes, PH value, and PLT count. As for FP24 units, frozen air bubbles on the back were examined for any changes in size or shape. The study showed no evidence of RBC hemolysis, no significant changes in PLT count, PH value, MPVs and in the FP24 bubbles. The result showed that drone is a feasible option for transporting blood products in emergency situation [9].

A similar study conducted in Japan showed credible results regardless of the slight deviation in temperature. The results showed that the UAV flight did not affect blood samples. The parameter used to determine the effect of UAV flight on blood samples was not significantly different between the flight and non-flight samples [10]. In order to monitor the delivery box temperature during the delivery mission, a mobile application-based temperature monitoring system for medical needs delivery has been designed and developed [11]. A systematic review by Mohamed Afiq et al. [12] revealed that the application of drones as mode of transportation for medicinal products delivery is lacking in academic research especially for maternal healthcare services.

In East Africa, Zipline had collaborated with Rwanda government since October 2016 to deliver blood products and medicines using drones in remote region with poor road infrastructure and critical access hospitals. The drone transport system solved the problem by reducing hours of delivery time through rough and difficult terrain to minutes of flight time in airspace without any significant adversity. The drones, called

Zips, take-off with the blood product from distribution center in Muhanga, Rwanda, to 21 hospitals within 75 kilometers radius.

In emergency, a doctor may use WhatsApp Messenger to request blood, which will be packed in Zip that is fired using a catapult into the air. Using GPS navigation in coordination with Rwandan air traffic control, the drone heads to the location of the recipient. When Zip arrived its destination, Zip drops the blood pack in a padded container with its parachute. The doctor received a notification from WhatsApp to retrieve the cargo in a given location. After completing its mission, Zip returns home for an arresting-hook-assisted landing onto a soft mat. It is ready to fly again after changing a fully charged battery. The blood delivery using drone not only solves the problem of the logistic management of blood products but also managed a lifesaving situation very well, for example in a situation with childbirth typically the ones with a hemorrhage complication [13].

The current practice of delivering blood using ambulance, helicopter and the speed boat (in rural area) is able to fulfil the need of blood transportation. In emergency medical services especially blood delivery to the hospital, every minute between the incident and EMS response matters. These methods of blood delivery are good but may be delay the blood transfusion procedure due to distance, traffic congestion, terrain obstacles, lack of resources in the affected area. The presence of rapid delivery system especially through the use of drones, can save the need to set up and maintain expensive peripheral blood storage units. Advances in technology, decreasing costs and open-source platforms have led to increased use of unmanned aerial vehicles (UAVs) from the military to civilian sectors. Recently, many technology-based companies are using drone to deliver parcel and food to their customers.

Most of the drones available on the market do excellence works in their applications such as agriculture application, aerial mapping, infrastructure inspection and maintenance and survey, search and rescue and the hobbyist. However, the capability of these drones for blood delivery such as payload, take-off weight and flight time are the important parameters to explore. This motivated us to study the essential parameters and developed a drone that is capable of delivering the blood products to the hospital from the blood bank.

The main objective of this work is to develop a medical drone using an open-source platform and off-the-shelf hardware to meet the design specifications. The developed drone must be able to carry a 1.5 kg payload and have sufficient power for a 20 minutes flight time that expected to cover 8 km distance.

2 Materials and methods

The development of drone for blood delivery consists of hardware and software aspects. Several technical experiments were carried out to test its feasibility for blood delivery. The Hexacopter (6 rotors) can reach higher altitudes, more stable and travels faster than a quadcopter. Therefore, a Hexacopter drone was designed and built to meet the requirements and specifications for the purpose of blood delivery.

2.1 Hardware Aspects

The main components required to develop the drone are the frame, the flight controller, the motor, the electronic speed controller, the radio transceiver, and the battery. A Hexacopter with a diameter of 850 mm built from carbon fibers material known for its lightness and durability was used to conduct a series of flight test. The flight controller used on this drone was Pixhawk. This is an open standard that provides off-the-shelf hardware specifications and guidelines for the development of the drone systems. The drone is remotely controlled using 2.4 GHz 6-channel radio transceiver system. The motor and the electronic speed controller were selected to meet the payload requirements. The drone was powered by a battery of 16,000 mAh capacity with a charge and discharge rate of 15 C. The list of components used to develop the drone is given in Table 1.

Table 1. Total mass of drone

Descriptions	Quantity	Mass per item (g)	Total weight (g)
ZD850 full carbon fiber frame	1	1210	1210
Pixhawk 2.4.8 32-bit ARM Flight Controller	1	38	38
5010 360KV motor	6	80	480
ReadytoSky 40A OPTO 2-6S Brushless ESC	6	26	156
12”45 propeller	6	24	144
Battery 6S (22.2V)	1	1856	1856
Power Module	1	29	29
Shock absorber	1	24	24
FS-iA6 Radio receiver	1	6.4	6.4
Black Gps Holder	1	22	22
PPM Module w/ shell	1	12	12
5v/12v PDB	1	57	57
Battery Belt	2	12	24
Neo-M8N Gps Module	1	33	33
		Grand Total	4091.4

2.2 Thrust-To-Weight Ratio

A mobile application was built using MIT App Inventor to display the data acquired by the developed system. The mobile application resulted a comprehensible and user-friendly system. Temperature and humidity data can be displayed in a graphical and numerical form depending on the user needs. Figure 3 shows the flow chart of the mobile application development.

The calculation of thrust-to-weight ratio is paramount for the drone to take off so that it can fly stable without any problems with the desired payloads. The total thrust produced by the rotors must exceed the value of the total mass of the drone or twice of that for it to be able to take off properly as shown in Equation (1).

$$Total\ Thrust = 2\ \times Total\ weight\ of\ drone \tag{1}$$

The thrust generated by the drone can be calculated using Equation (2).

$$m = \frac{T}{g} = \frac{\sqrt[3]{\frac{\pi}{2}D^2\rho P^2}}{g} \tag{2}$$

where T is the thrust (N), D is the propeller diameter (m), ρ= density of air (1.225 kg/m³), g is the gravitational acceleration (9.81 m/s²), P is the power of rotor (W) and m is the equivalent mass of thrust.

Another option is to refer to the datasheet produced by the manufacturer of the rotors to find its appropriate take-off weight and calculate the Thrust-to-Weight ratio. For example, the 5010 360 KV motors can produce a maximum pulling force of 1640 g with a maximum current of 11.5 A according to Table 2. According to Table 2, the total equivalent mass of thrust, m is the maximum pulling force times the amount of motor on the drone, $m = 6\times1{,}640 = 9{,}840$ g. With this information, the total thrust produce by the drone can be calculated. Theoretically, the thrust to weight ratio of the drone without any payloads can be calculated using Equation (3). The drone developed in this study has thrust to weight ratio of 2.27.

$$Thrust\ to\ Weight\ ratio = \frac{Equivalent\ mass\ of thrust}{Totalweight\ of\ Quadcopter} \tag{3}$$

Table 2. Parameter for 5010 360KV motor.

No Load		**On Load**			**Load Type**
Voltage (V)	***Current (A)***	***Current (A)***	***Pull (g)***	***Power (W)***	***Propeller***
22.2	0.4	1.9	500	42.2	CF15×5.5 Prop
		5.3	1,000	117.7	
		11.5	1,640	255.3	
		2.3	600	51.1	CF16×5.5 Prop
		6.7	1,200	148.7	
		12.5	1,740	277.5	

2.3 Software Aspects

In this work, the autopilot software was selected by comparing the advantages and disadvantages of popular and well-known flight controllers in the drone community according to Table 3. Ardupilot is the prevalent autopilot software used by the community today, it is an open-source unmanned vehicle autopilot platform that is capable of various functions. The platform is more mature than any other autopilot and has been constantly evolving for longer periods. It has more features available, more users, and more reliability.

Table 3. Comparison of autopilot platforms

Platform	APM/Ardupilot	PX4 system	Eagle Tree Vector system
Pros	Can run much hardware including the Linux More features available in Ardupilot, more users and a more reliable code base.	The most flexible controller Constant community development and support	Easier to configure and maintain. Have superior OSD
Cons	Require more setup and lots of learning to use the system	The oversimplified PID loops tuning for PX4 generally result in low-performance flight	Less programmable and less flexible to modify the system
Support Multi-rotor drone	YES	YES	YES
Expandable (sensor and accessories)	YES	YES	YES
Support GPS allocation	5 or 10Hz GPS module	Support RTK GPS which increase the accuracy to a centimeter-level	The GPS/Magnetometer V2 simultaneously receives and monitors both GPS and GLONASS satellites
Support autonomous flight mode	GOOD	GOOD	AVERAGE
Support OSD	AVERAGE	AVERAGE	GOOD
Support large airframe for the heavy lifter	AVERAGE but better than PX4 system, having been in development for a longer time	AVERAGE	AVERAGE (support airframe not more than 650mm)

2.4 Flight Path Measurement and Drone Test

The flight path was measured based on actual location in Sabah, Malaysia from Queen Elizabeth Hospital to Hospital Wanita dan Kanak-Kanak, Likas. The distance using an ambulance was found to be 9.3 km while the distance measured in a straight line was 5.96 km, as shown in Figure 1. The flight path may not be a straight line to avoid public area and obstacles. As such the estimated distance to be 6-8 km.

The drone performance was evaluated on its capabilities, including payload test, battery endurance test, top speed test, automated flight test and flight test that mimic to the actual test location. Note that prior to each of these tests, the battery was fully charged (100%).

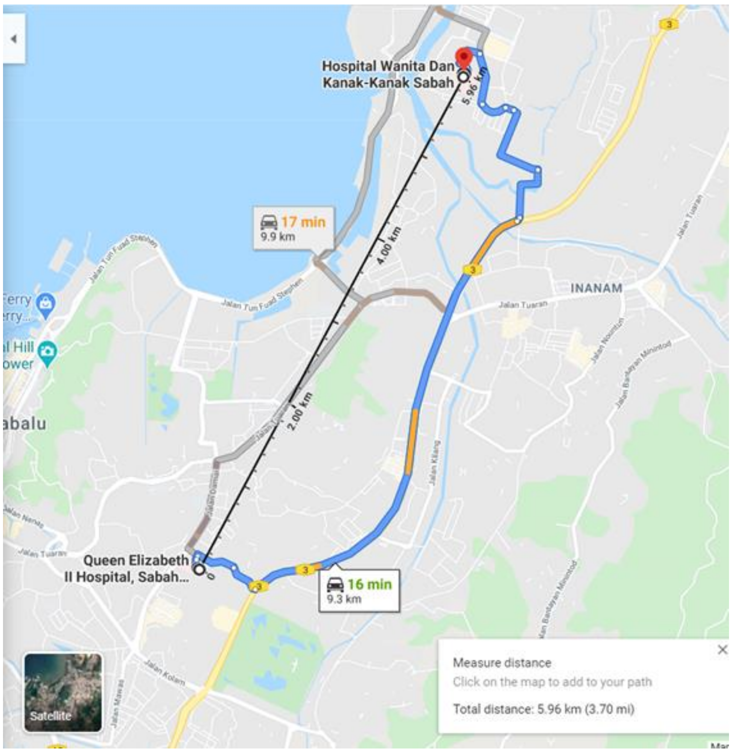

Fig. 1. Location and distance of test venue on Google Map

The payload test was conducted to test drone capability to carry a certain payload and its airframe durability to hold up that weight. Various payload weight was load on the drone to perform the test. Water bottles with their measured weight was strapped to the drone and taking off with that setup.

First test was carried out with two small bottles of 1.35 kg with an overall weight is 4.55 kg. Second test was done with addition one large bottle of 1.65 kg with the preceding bottles with a total weight of 6 kg. The entire test was recorded during the process of take-off to landing to observe the behavior of the drone while carrying that payload. Later, test data were extracted and analyzed to evaluate the IMU level, AHRS data, battery consumption and other significant data. Battery endurance test measures the drone's power consumption take-off process until it lands safely according to its specified payloads. To ensure the maximum power it can provide to the drone, the lithium-polymer battery has been fully charged prior to the start of the test.

A connection between the laptop and the drone has been setup to monitor the battery voltage level in real-time using a transceiver radio telemetry module and MAVlink connection between the drone and a laptop. The voltage of a standard fully charged 6-cell Li-Po battery is 25.2 V. The battery discharge was set to 85.7% (21.6 V) to ensure safe flight landing. The test was conducted by flying the drone into the air and landing it once it reached the minimum voltage level. The recorded data showed the time and the power consumption in the form of a graph and can be analyzed later.

For the automated test, the test was conducted in an open space where the drone can fly without any hindrance or obstacles. This task was accomplished by installing a pre-programmed flight route on the flight controller using the Mission Planner software by mapping the location points on the software user interface tab named 'Flight Plan'. The Google Earth map was loaded into the software from the server before programming the flight controller.

In the field, users can first take-off and change the flight mode to auto mode in the air. The drone will automatically read the mission pre-installed in the flight controller. The mission can be executed before take-off by a pre-programmed command for take-off and then perform the next command subsequently. The log data can be downloaded and analyzed to determine the accuracy of the GPS by calculating the difference between the planned path and the real path travelled by the drone.

Finally, the flight test is to mimic the distance of the real flight parameter as in Sabah was done. The distance between Queen Elizabeth II Hospital to Likas Hospital is about 6-8 km. The pre-programmed waypoints were constructed in Mission Planner by laying out a circle or rectangular cycle of the flight path to cover the required distance. By using this approach, no payload was installed on the drone to find the baseline of the drone capacity and Li-Po battery efficiency.

3 Results and Discussion

3.1 Automated Drone Test and Evaluation

A high-capacity Li-Po battery (TATTU, Grepow Inc.) with the specifications of 16,000 mAh capacity with a C rating of 15 C and weighted about approximately 2 Kilogram was used in this test flight. This will make the total take-off weight of the drone about 4.3 kg. Figure 2 shows the developed drone with cooler box ready for blood product delivery.

Fig. 2. Drone with cooler box for blood product delivery

Figure 3 shows the data extracted from the Pixhawk flight controller after the test. The purple line representing the mission route constructed before the test and the red and blue line indicated the route taken by the drone after the flight.

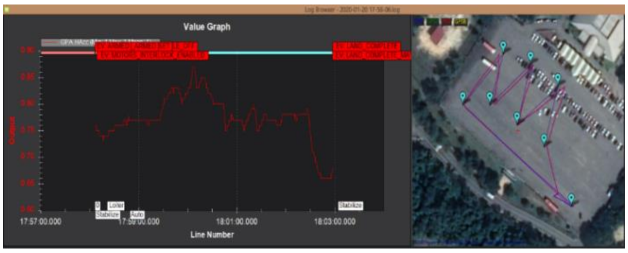

Fig. 3. Flight route and the horizontal accuracy data (GPA-HAcc)

The flight trajectory can be analyzed using Google Earth. The actual flight route (yellow line) travelled by the drone shown in Figure 4. It has a slight deviation from the original route (black line) about +/- 6 m from the entire flight.

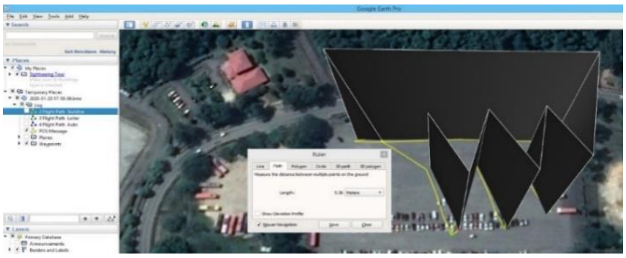

Fig. 4. A slight deviation from the point location

3.2 Battery Endurance Test

On the other hand, the battery endurance for Li-Po battery (TATTU, Grepow Inc) can reached 25 minutes flight time (Fig. 5). The voltage drops steadily throughout the flight and although the graph showed a sharp drop at the end of the test, it can be neglected because of an accidental switch from ‘Auto’ mode to ‘Loiter’ mode but it is resolved quickly by flipping a failsafe option to Return-to-Launch protocol. The duration of the flight time was 25 minutes and 11 seconds with the distance covered of 8.38 km which confirm that the developed drone is able to fly from QE Hospital to Likas Hospital

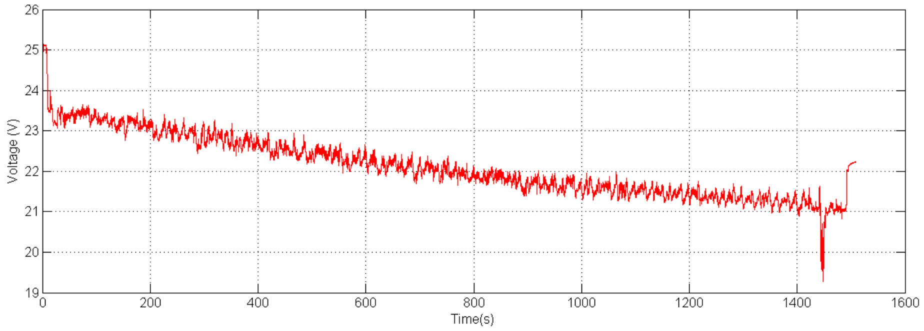

Fig. 5. Battery consumption from the flight test

3.3 Drone Performance Test

The drone's average speed and the top speed during the flight mission were 5.52 m/s and 8.51 m/s, respectively as obtained from Figure 6. Note that because of the rectangular flight path the drone must decrease its speed every turn of the corner, and this affects the distance and duration result for the test.

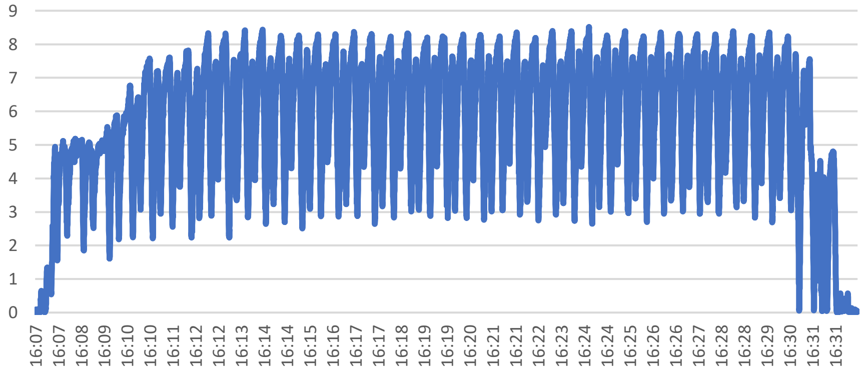

Fig. 6. Drone speed with respect to time during the flight misssion

The vibration from the drone can be evaluated by analyzing the VIBE messages and IMU messages from the data flash log. The VIBEX and VIBEY values are desirable but the VIBEZ value differs from the normal values of 15 ms^{-2}. Although it is still within the maximum acceptable value of 30 ms^{-2} as shown in Figure 7.

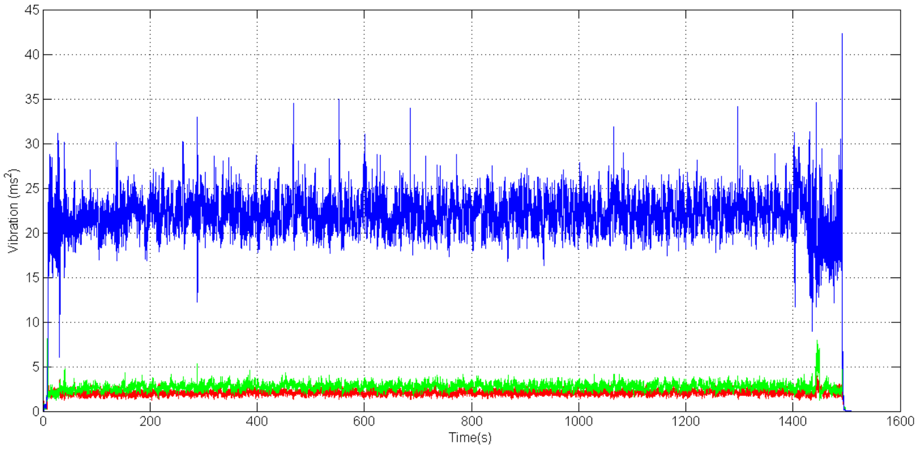

Fig. 7. VIBE parameter value for X, Y, and Z axis

The GPS accuracy can also be evaluated by comparing two data messages from the log ‘CMD’ and ‘GPS/AHR2’ messages. The latitude and longitude of CMD represent the input waypoints before the drone took-off and the latitude and longitude of GPS/AHR2 represent the captured location waypoints during the whole flight missions. Based on the comparison of the graphs from Figure 8, the pattern quite matches with each other and varies only by 0.00006 degrees for both latitude and longitude which is ±6 meters. Thus, we can conclude that the waypoints assist by the GPS module were fairly accurate and reliable.

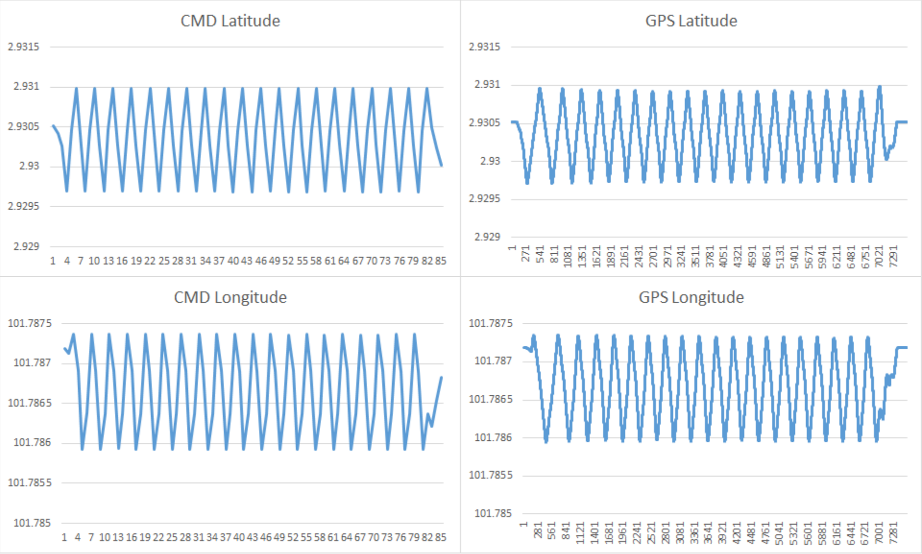

Fig. 8. CMD (Left) and GPS (Right) comparison

4 Conclusion

This paper presents an assessment of drone development solely for medical delivery purposes. The proposed assessment was evaluated by analyzing the data obtained from a flight test by simulating the flight distance planned in the region of Sabah, Malaysia. The drone system built consists of a Hexacopter type for better stability, Ardupilot platform as the software which is the most versatile platform among its peers, and a 16000mAh Li-Po Battery (TATTU, Grepow Inc.) which is the high-end battery on the market for optimum performance. Several tests were conducted to appraise the baseline performance and limitation for the developed drone which is the payload test, battery endurance test, top speed test, automated flight test and simulated flight test. The result obtained from those tests revealed the following points:

- The thrust-to-weight ratio must be calculated properly before the drone development as it plays the most vital part for the system to produce an optimum flight performance especially for a delivery application that requires the drone to stay in the air for a longer time.
- The maximum flight speed of the drone obtained from the flight test establishes the speed limitation of the developed drone which is 30 km/h, which then can be considered to determine the delivery distance for the next flight.
- The GPS guidance performance from the current technology presents fairly accurate and reliable assistance following the planned path with only a slight deviation within the ±6 meters range with no connection loss.
- From the simulated flight test, it can be concluded that with no payload settings the developed drone can cover a distance of 8.38 km with an average speed of 19.8 km/h and the value of parameters to evaluate the drone performance are all within an acceptable and reliable range.
- However, there exist some limitations from the developed system that one can notice that the duration of flight time is respective to the payload weights and insufficient power supplies to provide a longer flight time.
- In the future, the proposed drone system should be upgraded with a more powerful, heavy-lifter rotor for extra thrust to balance the thrust-to-weight ratio and with an additional Li-Po battery (dual battery system) to provide ample power supplies for the flight mission.

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