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Building an Unmanned Aerial Vehicle for Humanitarian Aid Delivery

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Abstrak

Ketika situasi darurat terjadi, respons secara cepat dan tanggap sangat diperlukan untuk membantu daerah terdampak. Sarana transportasi konvensional seperti truk maupun pesawat terbang sering menghadapi kesulitan membawa persediaan ke lokasi yang membutuhkan, terutama di daerah yang mengalami kerusakan infrastruktur yang parah.

Pada penelitian ini, kendaraan udara tak berawak semi-otonom kecil dirancang dan dibangun untuk melakukan misi bantuan kemanusiaan. Sistem yang dibuat menggunakan konfigurasi hexarotor terbaru dengan baling-baling yang tumpang tindih (overlap) secara vertikal, dimana dengan desain ini, dimensi total sistem berkurang tanpa mengurangi efisiensinya. Sistem ini juga dilengkapi dengan sistem pelepasan muatan dua cincin terbaru yang sangat ringan dan efisien untuk membawa dan melepaskan dua buah muatan dengan total berat 2 kilogram.

Secara keseluruhan, sistem ini mampu beroperasi secara otomatis untuk melakukan serangkaian tugas seperti terbang sesuai dengan navigasi titik arah (waypoints), mengirimkan muatan ke target lokasi, dan kembali ke pangkalan. Sistem yang telah dibuat mampu untuk membawa dua muatan berbeda dengan berat masing-masing 1 kg ke target yang ditentukan secara otonom. Sistem ini memberikan hasil yang menjanjikan untuk mendorong pemanfaatan UAV sebagai sarana pengiriman bantuan kemanusiaan.

Kata kunci*— kendaraan udara tak berawak, overlapping propeller, mekanisme pelepasan muatan, bantuan kemanusiaan*

Abstract

When an emergency occurs, immediate responses are needed for the affected areas. Conventional means of transportation often face difficulties carrying supplies to the location in need, especially in severely damaged areas.

In this project, a small semi-autonomous unmanned aerial vehicle (UAV) was designed and constructed to undertake a representative humanitarian aid mission. The system has a novel hex-rotor design with overlapping propellers. Half of the motors have been turned upside down with a slight overlap between each propeller, hence reducing the total dimension of the system without losing its efficiency. The system is also equipped with a new lightweight servo activated two ring release system, allowing it to carry and release two kilograms of payloads with only small physical force needed.

Overall, the system is capable to operate automatically while performing a series of tasks such as navigate waypoints and deliver payloads before returning to base. the system created in this project could deliver two individual payloads of 1 kg each to the pre-destinated target almost autonomously. The system provided promising results that encourage the utilization of UAV for delivering Humanitarian Aid.

Keywords—*unmanned aerial vehicle, overlapping propeller, payload release mechanism, humanitarian aid*

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1. INTRODUCTION

Emergency situations such as natural disasters and conflicts can occur at any time. When this situation happened, the relief organization play a critical role by distributing supplies such as food and essential medication [1]. However, the responder often faces difficulties in the process of transporting the supplies quickly and safely. For example, the occurrence of the disasters may cause damage to public or road infrastructure that can be problematic for land vehicle. On the other hand, air transportations such as plane and helicopter require a lot of time for preparation and readiness. Thus, they might not suitable for a time-critical situation [2]

The use of unmanned aerial vehicle (UAV) for humanitarian operations have been showing a great potential [3], [4]. UAVs are considered useful to help responders get to the scene of a disaster quicker and safer compared to traditional means of transportation [5]. Using UAV as a means of transporting commercial goods has been developed by a number of companies such as Amazon [6] and DHL [7]. Studies presented that the use of UAVs can help minimize cost due to lower transportation cost and shorter delivery time [8], [9] [10].

The development of UAV in the field of humanitarian response remains an active area of scientific research. The study in [11] shown the potential uses of UAV for transporting medical product including blood derivatives and pharmaceuticals in times of critical short-age. Similarly, [12] and [13] describe the possible use of UAV delivery system equipped with defibrillators might be a viable solution to treat victims of cardiac arrest. Efforts has been made to create fully working UAV for delivering aids [14] [15]. However, there are still many aspects that need improving. The major challenge of building an UAV for disaster situation is to find the optimum configuration between the hardware and software [3]. Therefore, there is need of further development to design and construct an UAV to accurately deliver humanitarian aid to areas in crisis.

2. METHODS

2.1 Design Of The Mechanical System

In terms of its configuration, UAV can be divided to three basic types, fixed wing, multi-rotor, and single-rotor [16]. While fixed wing vehicle have advantages on the range and endurance, it has several disadvantages when used for aid delivery. The disadvantages include portability issues, lower manoeuvrability, payload accuracy issues and inability to operate in rough terrain. Likewise, the single-rotor UAVs are mechanically complex and generally high cost compared to other systems.

By comparing two previous choices of airframes and taking into account all limitations along with mission requirements it has been concluded that the multi-rotor is a suitable option to effectively complete all the tasks such as accurate payload delivery, manoeuvrability, speed and being able to operate without a runway for take-off and landing.

The system created in this project is a multi-rotor design with a hex layout that has six arms and mounted on a circular base plate. Two arms on each side are fixed but the remaining four arms can be released and folded towards the fixed arms, making it a linear folding system. The bottom plate is fitted with a cargo support bay, payload release mechanism, and detachable landing gear. The top plate holds the battery, GPS module, payload servos and the flight controller. These modules have all been made weather-proof by applying epoxy on circuit boards or using 3D printed weather shields.

The center plates are made from painted plywood while the arms and landing gear are made from carbon fibre tubes held by 3D printed abs plastic components. On the hinge where the arms fold on, there is a rubber damper fitted inside a printed part to absorb vibrations from each arm individually. The motor and flight controller mounts are commercial off-the-shelf (COTS) components but all other parts of the airframe have been designed and manufactured by the team.

One of the unique features that this system has is the overlapping propellers design. Every second has been turned upside down with a slight overlap between each propellers to minimize total dimension. A study [17] shown that losses due to overlap were unnoticeable up to 25% overlap, therefore in our hexacopter design we use 10% overlap between propellers.

2. 1.1 Airframe Structural Design

The airframe was carefully designed by taking serious consideration in safety and robustness. The center plates were made using 6mm plywood sheets, where the top and bottom plates were cut so the grains in the wood would be perpendicular to each other to increase robustness.

During forward flight, the aircraft is tilted so airflow will hit the top of the center frame. In order to make the system as aerodynamic as possible, surface area facing in the forward direction has been minimised to reduce drag.

Between the two center plates is the power distribution board (PDB), and the anchor points for the motor arms. The anchor points for the arm poles also serve as the main structure that hold the frame together. To increase robustness and support, additional spacers were placed between the arms and around the PDB.

The inner anchor point for the arms can rotate in order to make the arms foldable, for maximum support, the anchor piece is a 3D printed piece that is fitted on the end of the carbon tube. A rubber tube was fitted inside the piece, which the bolt that holds in then runs through, this was done to dampen any vibrations caused by the motors to minimize its effect on the FC.

By designing the airframe in such way that it only takes 4 thumb screws to secure it in unfolded position, making the landing gear so that the legs clip on using magnets and fitting self-tightening adapters on the propellers, the whole system can be fully assembled from the box by one person within 5 minutes.

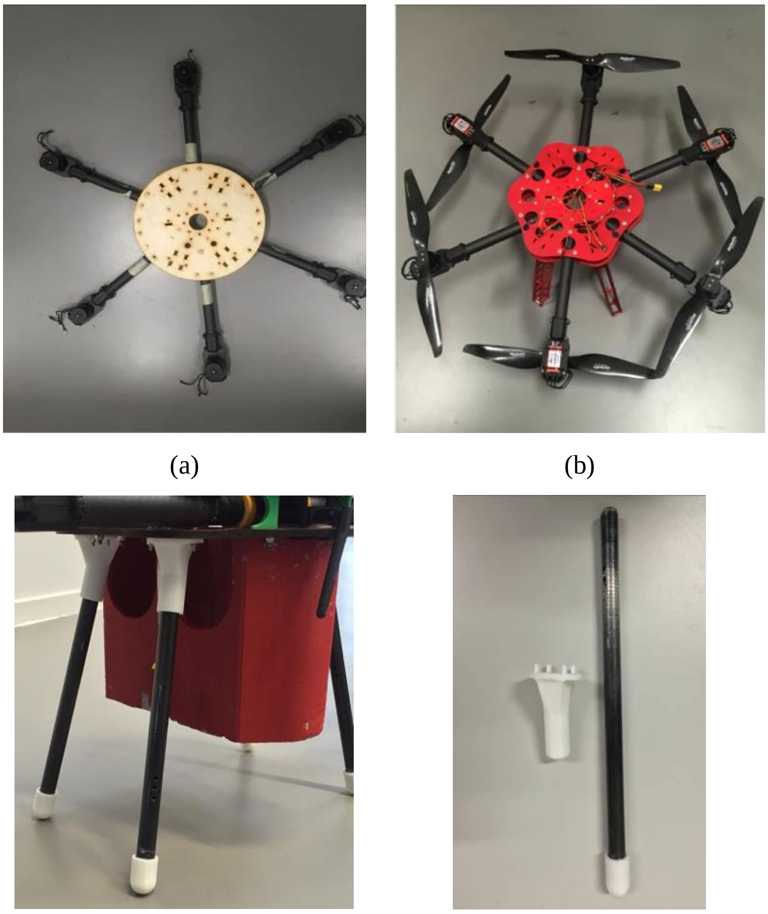
2. 1.2 System Propulsion

In order to get the best propulsion efficiency brushless motors were the focus of comparison. RC Timer X5 motors were finally chosen due to their high-power density and high power per unit cost. Folding propellers were chosen as this meant a smaller transport box and added a safety factor within the design. To keep the diameter and mass of the platform as small as possible, we turned half of the motors upside down with a slight overlap between propellers.

2. 1.3 Undercarriage Design

The landing gear was originally made from plywood, but proved to be too fragile when the aircraft was performing auto landings in wind so they were replaced with legs made from carbon tubes that clip into a socket, they are held in place by two magnets capable of holding up to 5 kg. The arm poles were made using 25mm carbon tubes for maximum strength.

The payload bay is mounted under the bottom plate of the airframe since the payloads are vertically dropped from the aircraft and the camera for the image system is mounted next to the cargo bay. The flight controller is mounted at the front end of the top center plate and covered with a 3D printed weather shield and the GPS module next to it. The battery is mounted at the center of the top plate to keep center of mass as close to the center as possible. The servos for the payload release are also mounted on top of the center frame.



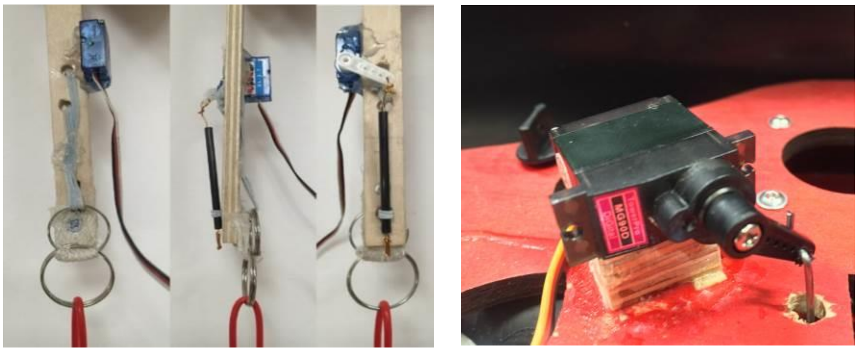
(a) (b)

(c) (d)

Figure 1 (a) Initial design, (b) optimized design with inverted overlapping propellers, (c) payload bay, (d) detachable magnetic landing gear

2. 1.4 Payload Release Mechanism Design

A new payload release mechanism was designed based on equipment used for parachutes called the three ring release [18]. The mechanism is designed so it reduces the strength needed to hold the payloads with every ring. Since the mass of the payload is significantly less than the mass a parachute needs to carry, only two rings were required. The mechanism works so that there is a large ring attached to the payloads, and then there is a smaller ring threaded through a small patch of nylon that is attached to the anchor point on the UAV witch then is threaded through the large ring so the payload ring rests on the nylon. A piece of string also attached to the anchor is then threaded through the smaller ring and through a hole in the anchor where the actual release pin goes through the loop on the string. The force needed to pull the release pin has now been reduced so much that a 6-gram servo can easily do the job. To hold the payloads in place to avoid them from swinging around a supporting Styrofoam frame is used. The main advantages to this mechanism are that it is quite simple in design, affordable and lightweight.



(a) (b)

Figure 2 Payload release mechanism: (a) concept and (b) implementation to the system

Figure 3 Image sequences of payload release mechanism

2. 2 Design of The Electrical System

2. 2.1 Flight Controller and Electronics

The figure 4 shows the system of the vehicle that contains a fully working flight controller, propulsion, and navigation system to ensure the UAV follow the pre-programmed mission from base station.

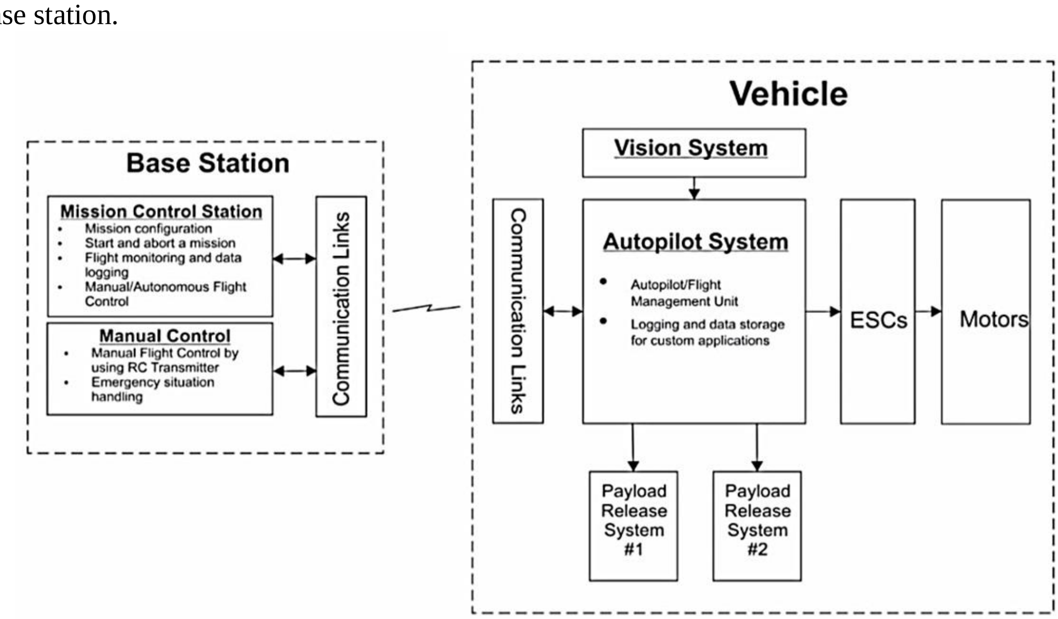


Figure 4 The UAV system architecture and data flow

The flight controller is the most important part of the UAV avionics system. Therefore, it needs to have decent accuracy, reliability, programmability and hardware compatibility. There are several controllers that have these attributes. Pixhawk version 1 [19] Autopilot was selected due to its reliability and processing power that has been proven in previous researches [14], [15], [19].

Besides the autopilot, the U-Blox M8 GPS/Compass module is used to support the system. The main advantage of the module is because it is supported GPS/QZSS, GLONASS, and BeiDou. Also, the navigation sensitivity is quite high, reaching maximum value of -167dBm.

In addition, we used Mini PC Odroid XU4 for operating the flight mission strategy, processing USB camera, and communicating with ground control station.

The figure 5 presents the complete avionics system of the vehicle that contains a flight controller, ESCs, communication, and navigation system to ensure the UAV follow the pre-programmed mission from base station.

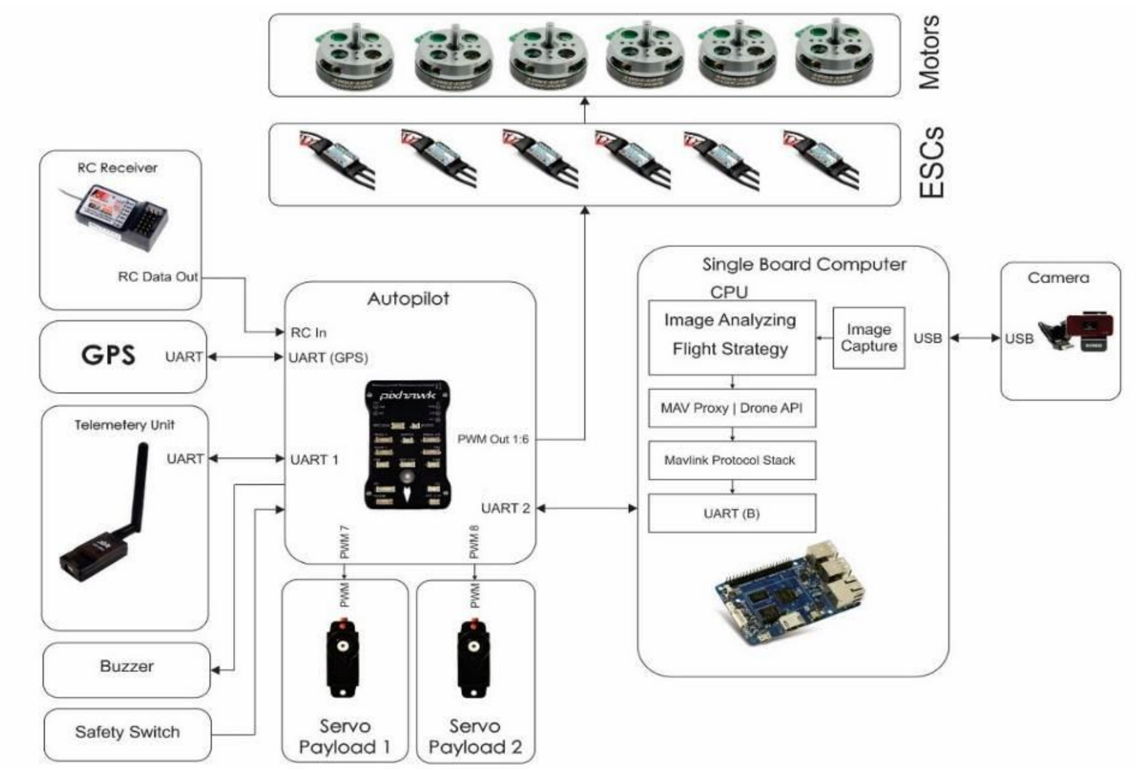


Figure 5 System architecture and data flow of the unmanned vehicle

For the UAV, we use 12000 mAh LiPo battery as the main power source. The output from the battery then used to power the motors and Universal Battery Eliminator Circuit (UBEC). Next, the UBEC will regulate the input from LiPo battery (22.2) to 5V output which will be used to power the single board computer (Odroid), Pixhawk, and servos for payload release mechanism. Finally, the additional peripherals required for the autopilot system, such as GPS, RC Receiver, and telemetry unit, are powered directly from Pixhawk (using internal 5V to 3.3V regulator). The power wiring diagram of the system is presented in figure 6.

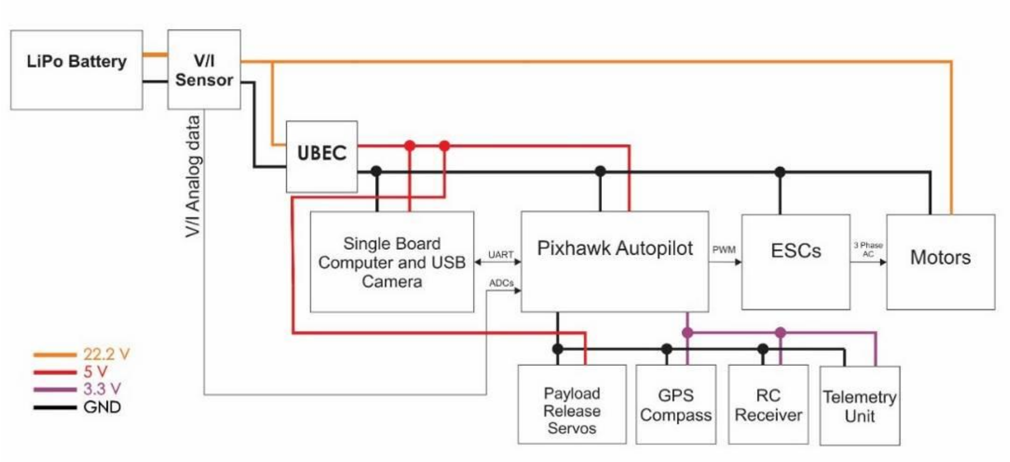


Figure 6 Power wiring diagram

For the communication part, The UAV is connected to both ground control and remote control. We used FrSky 2.4 GHz Taranis X9D for our remote controller transmitter and X8R receiver. The transmitter specification is adequate for our application as it is equipped with 16 frequency channels, 60 internal model memories, 9 flight modes and 64 mixers.

On the other hand, the 3DR radio telemetry kit will provide communication link between the vehicle and ground control station software. The telemetry kit operates in 433 MHz with 100 mW maximum output power and -117 dBm receive sensitivity. In addition, lightweight Mavlink protocol is used to establish reliable communication.

Table 1 presents our flight termination system and fail-safe strategies. Most of its features were derived from Pixhawk's and mission planner's Advanced Failsafe (AFS) configuration [20].

Table 1 Fail Safe Strategies

Types of Failure	Handling
Low battery	Land immediately
GPS signal loss / error	(Soft Failure) Loiter at the current location. Then continue when the GPS signals healthy again
	(Hard Failure) Land immediately
Telemetry data signal lost	Land immediately
RC signal lost	Land immediately
Image recognition system failure	Using GPS Location as a reference for dropping the payload. or Pilot manually drops the payload
Geofence failsafe	Land immediately
Automatic payload release mechanism failure	Manual dropping from Pilot's RC controller or Ground Control Station

2. 2.2 Mission Control System

The mission control system is basically a PC or laptop that run ground control system software performing navigation, including waypoints register and mission configuration. Additionally, the mission systems are used for monitoring the UAV system health, logging flight data, reading or editing flight parameter, and viewing or mapping position and graphical images.

The whole mission configuration, planning, and analysis are done on ground control software. First, the UAV is set to the location when the copter was armed. This location will be the place where the UAV returns if RTL (Return to Land) command is executed. Then, the ground control officer will enter waypoints and other mission commands such as loiter, and payload drops for the specific mission requirement.

Once the UAV is connected to the mission ground control station, all vehicle status including position, air speed, heading direction, altitude, artificial horizon, and battery status can be monitored online. This will help GCS officer to observe the current flight and ensure the mission goes well as planned.

Post-mission analysis can be carried out from either data logs or telemetry logs. Data flash logs are stored on Pixhawk on-board memory while telemetry is stored during the flight. Both can be directly downloaded and analysed after the mission finished. Common failures such as mechanical failures, vibrations, compass interference, GPS glitches, power problems, and failsafe mode can be examined from the data logs.

A personal computer running a mission control software will be used as our ground control system. Mission Planner [20] was chosen as the GCS for the mission because it is easy to use, quite stable, widely used by developer or UAV enthusiast.

3. RESULTS AND DISCUSSION

Aerodynamic parameters were estimated for a typical multi-rotor UAV with drag coefficients oscillating between 1-1.5. An approximated value for the wet area at different angles of attack was used. Wind and atmospheric conditions were assumed to be constant. Using these assumptions cruise velocity was calculated. It is worth noting that these values are a rough estimation and would need experimental testing to retrieve realistic data to provide a more accurate model.

In the calculations for performance and endurance, the parameters used were taken from performance tables issued by the motor manufacturer. It is safe to assume some errors since those tables are based on different types of propellers and the reliability of the data is unknown. The endurance test performed by the team showed that the endurance was actually 20% less than we had calculated but there were multiple factors that affected the results including different types of propellers. Figure 7 presents the endurance of the system with respect to payload carried, while figure 8 shows the UAV’s cruise velocity compared to the angle of attack (AOA).

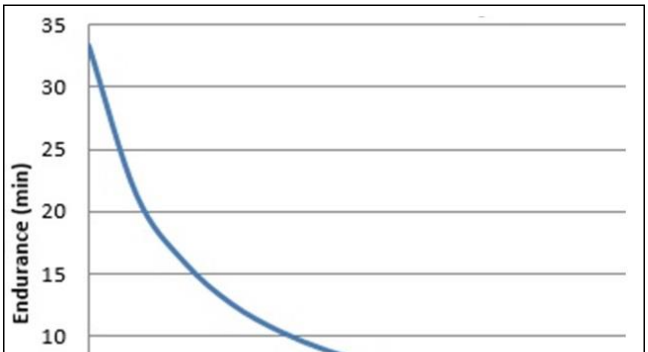


Figure 7 Flight endurance (minutes) versus mass of payload (minutes) with 12Ah battery

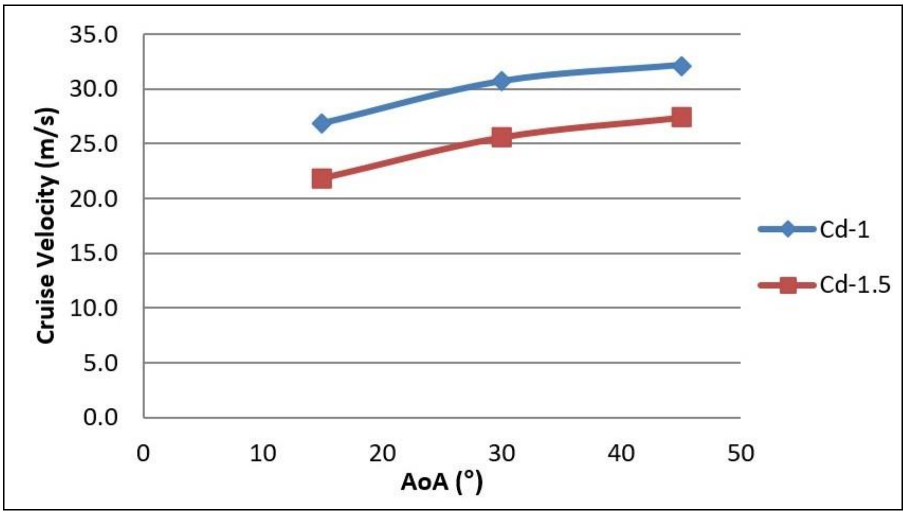


Figure 8 Angle of Attack versus Cruise Velocity for different drag coefficient

After a series of design process, we have successfully created a fully assembled UAV as in Figure 9 (a). the total mass of UAV without payload is 4.82 kg. Overall, the system is designed for a quick and effective humanitarian operation. The system is easy to assemble with total time taken for flight preparation of less than 10 minutes.

(a) (b)

Figure 9 (a) Fully assembled UAV with a novel inverted proppelers configuration (b) Flight Test

Flight test was done by simply taking off and hovering and checking if all controls respond correctly. During the second flight test, different flight modes are tested to see whether it can maintain altitude and do a GPS fixed hover. After all systems have been checked in flight, endurance and maximum take-off mass are tested. Finally autonomous features are tested by making the aircraft do an auto take off, fly a short distance before turning around to land. When testing autonomous flight features, distances and speeds are gradually increased in order to get maximum performance before flight tests are completed.

Figure 10 Sequences of drop test

The various tests and analysis have shown that system can perform the mission requirement with success. However, we notice an increase of vibration and cavitation due to the non-uniformity of the increasing inflow of the overlapping propellers. In future design, improvements shall be made to optimize the system. First, the current design has equipped with camera but still not implemented with image recognition software. Next, the 3D printed parts of the current design are easily broken. Therefore, these parts should be replaced with stronger and lighter materials such as carbon fiber or aluminium. Finally, further tests need to be done in the future to analyse the system performance under different weather condition.

4. CONCLUSIONS

Overall, we have created a new configuration of hex copter with overlapping propellers that designed to carry and release two independent payloads of 1 kg each. The total mass of fully assembled is 4.82 kg without payload. The UAV has flight endurance of approximately 15 minutes in hover when fully loaded and 22 minutes without payload.

The system was able to perform series of tasks autonomously such as take-off, navigate to waypoints, deliver payloads, and return to base. The UAV has been equipped with camera to give responder the ability to visualize the condition.

We also demonstrated a new servo-operated two-ring release mechanism that able to perform well to carry and release payloads. This mechanism is lightweight, quickly made, and affordable. In addition, for ease of transportation the UAV is capable of folding, the landing gear and cargo bay are removable and the assembly of the airframe from the transport box is tool free and takes less than 5 minutes.

However, there are many aspects that need improving such as incorporating the UAV with image recognition software. Further investigation is needed to find the optimal velocity for a variety of mission ranges and endurances. These includes tests under different weather conditions.

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