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Multirotor for Medical Aid Kit Transport

N F M Salleh, W M W Mohamed, R E M Nasir, A B A Mutaáli, S Zainurin

Abstract**: *The popularity of the multirotor or unmanned aerial vehicle (UAV) is rapidly growing in the field of aerial robotics. In fact, multirotor has now become a standard platform for robotics research worldwide and it has been increasingly used for various constructive purposes across several sectors. Traffic congestion in urban areas has caused a longer time to deliver medical aid kits to the accident sites. Many patients in remote areas with limited road access will need to travel further and consequently take a longer time to reach healthcare centers for their medical needs. In view of this situation, medical drones have the potential to resolve these problems. However, Malaysia has limited regulations and studies regarding the transportation of medical aid kits using multirotors. This study is conducted to develop a multirotor for deployment of medical aid kits. The proposed multirotor is a hexarotor, equipped with Pixhawk flight controller and payload release mechanism, known as NAMTOR 3. From the preliminary flight tests to assess the performance of NAMTOR 3, it has been found that NAMTOR 3 is stable during flight and ready for deployment.***

Keywords**: *Medical UAV, ambulance drone, medical aid, kit transport, unmanned aerial vehicle.***

I. INTRODUCTION

The 20th century has seen fast progression in development of autonomous unmanned aerial vehicle (UAV). Between the years 2002 and 2014, there have been a significant increase in the number of global non-military UAV applications [1]. The use of this technology is gradually growing with utilizations in many constructive purposes across various sectors, including the medical sector. In some rural areas throughout the world, medical UAV has been successfully used to deliver medicines [2], supplies [3], biological samples for crucial disease testing [4], and others. Meanwhile, in some urban areas, this medical UAV is also known as the ambulance drone, which has been used to provide aid for out-of-hospital cardiac arrest (OHCA) patients by having automated external defibrillator (AED) on its system [5].

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* Correspondence Author
N F M Salleh*, Malaysia Institute of Transport (MITRANS), Universiti Teknologi MARA Shah Alam, Malaysia.
W M W Mohamed, Malaysia Institute of Transport (MITRANS), Universiti Teknologi MARA Shah Alam, Malaysia.
R E M Nasir, Flight Technology and Test Center (FTTC), Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam, Malaysia.
A B A Mutaáli, Flight Technology and Test Center (FTTC), Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam, Malaysia.
S Zainurin, Flight Technology and Test Center (FTTC), Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam, Malaysia.

Though UAV application for medical transport can be taken as extensive, very limited studies that are focused on the control system, payload release system, and operation procedures are currently available.

In aftermath of typical natural disasters such as landslides, earthquakes and also heavy rain, the damaged infrastructures or flooding make it very difficult to reach the affected areas to provide medical assistance. For such situations, medical UAV can easily be deployed to deliver the essential medical supply aids, assess the damage and also provide some insights for the ground emergency response teams. For instance, in the event of a mountain avalanche, a multi-purpose UAV equipped with avalanche beacon and payload deployment system can help in the search and rescue of missing persons in the woods and on snow [6]. Furthermore, deliveries of medical supply aids can also be hampered by limited road access in under-developed rural areas and for most cases within the areas, the healthcare centers or testing laboratories can be situated very far from the patient's place of residence. Such existing conditions increase the time taken to get from healthcare centers to the testing labs or patient's residence. The consequences of having a difficult and poor road access on healthcare are well-documented for low-income countries [7], as well as high-income countries [8]. On the other hand, UAVs have already been successfully used to transport medicines, vaccines [9], contraceptives to women [10] and blood products [11] in remote settlements in the world. Several studies have also been published regarding the conditions of various laboratory samples during flight and when held stationary at the test site. One study has concluded that the transportation via UAV does not affect the accuracy of routine hematology, coagulation and chemistry tests [12]. In other words, transportation of blood products using UAV does not affect the integrity of the samples [13]. Moreover, the microbiological samples also had no adverse impact on growth pattern when transported with UAV [14] and vaccines delivered using the UAV supply chain model could increase vaccine availability by 2% and generate about $0.08 savings per dose [15]. In Malaysia today, the ratio of ambulance to the population is effectively higher than in other Pan-Asian countries [16]. For examples, the ratio has been found to be 1 : 146,000 for Klang Valley, 1 : 17,000 for Kota Bahru and also 1 : 218,000 for Penang. Lack of robust transportation system in Malaysia has made it difficult for healthcare centers to be competent when handling emergencies. As the result, many emergency incidents have gotten out of hand and such situations lead to increasing response time for the emergency medical service (EMS). The long EMS response time in Malaysia has been often attributed to the high population density but it should also be noted that the number of ambulances to address the demands is very few.

According to the study conducted by Pan Asian Resuscitation Outcomes Study Clinical Research Network (PAROS CRN), the median of EMS response time in Malaysia is found to be 17.4 minutes [16], which is notably longer as compared to that for Europe [17] and USA [18]. In the meantime, the study conducted by Malaysia Automotive Association indicates that there is 3.6% growth in the number of registered passenger and also commercial vehicles from 2017 to 2018 [19]. As this number increases, the amount of traffic congestion will also increase as well, especially in the urban areas. Additionally, the traffic congestion and illegal driving on emergency lanes are also presumably the reasons most EMS cannot reach the accident or emergency locations on time. This decreases the survival rate of the patients, for example the sudden cardiac arrest victims who are susceptible to brain damage and death if they are not being treated within 8 minutes; the likelihood of OHCA survival is decreased by 7-10% for every minute without resuscitation [20]. A medical UAV may be the solution for these problems.

The rules and regulations of multirotor flight in Malaysia are determined by the Civil Aviation Authority of Malaysia (CAAM), formerly known as Department of Civil Aviation (DCA). CAAM states that a UAV weighing more than 20 kg will need authorization from the Director General whereas a small UAV that weighs less than that will not be required to be registered and does not need any authorization if the pilot can satisfy that a safe flight can be made. A direct unaided visual contact must be maintained in order to monitor its flight path in relation to other people, vehicles, aircrafts, vessels and also structures for the purpose of avoiding collisions. In general, the flight of a small UAV is often limited to 120 m above the surface of the earth and not within any aerodrome traffic zone and controlled airspace such as class A, B, C or G airspace. In addition, no payload is allowed to be dropped from the UAV during flight. This entails that for medical aid kit transport in Malaysia, it is necessary to release the medical aid kit when the multirotor has landed. As the result, this land-and-release method operates with a high battery utilization. Take-off and landing of the UAV must be done more than 30 m away from any person and during flight, the UAV must be distanced with more than 50 m from any person, vehicle, vessel or structure that is not under the control of the pilot [21]. Nevertheless, the regulation has also dictated that no vehicle can fly in Malaysia without CAAM's approval. Thus, the deployment of UAV for transportation of medical aid kit still need CAAM's approval.

This paper aims to present the construction of a multirotor for medical aid transport. It covers the basic components of a multirotor and its design should be in compliance with rules and regulations in Malaysia regarding UAV flight operation for medical product deliveries. The assembled multirotor is then tested for its stability and performance.

II. METHODOLOGY

The proposed medical UAV platform, called NAMTOR 3, has been developed with the system architecture shown in Fig. 1. In brief, the basic components of the multirotor consist of the airframe, flight controller (FC), power, propulsion, remote controlled (RC) and also payload release system. The chosen airframe for NAMTOR 3 is Flame Wheel 550 (F550) by DJI. Weight of the frame is 478 grams with diagonal wheelbase of 550 m and it includes an embedded power distribution board (PDB) to distribute power to the propulsion system and flight controller.

FC in this multirotor is Pixhawk, which is compatible with multiple user interface software including Mission Planner, QGroundControl and many others to ensure the compatibility with Windows, Mac OS, Linux, Android and iOS platform. The UAV is also equipped with safety and alarm system, and there is a safety switch button for arming multirotor and alarm buzzer to indicate when there are malfunctions or low battery. GPS module can be assembled on designated port that allows the smart GPS multirotor navigation within the navigation and control loop such as altitude and position hold, autonomous flight, and return to home.

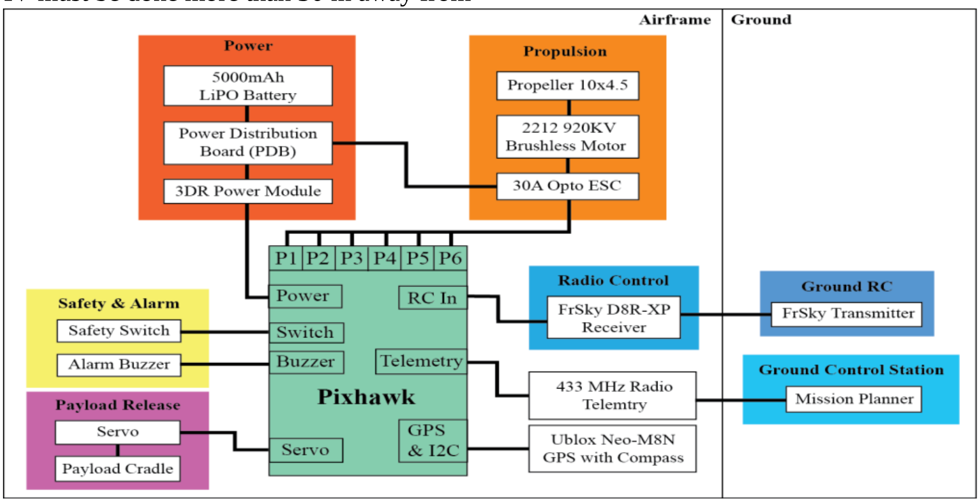

Fig. 1. System architecture for the proposed NAMTOR 3

For the propulsion system, it is comprised of the propellers, motors and also electronic speed controller (ESC). For F500 airframe, the motor stator size is recommended to be 23 mm x 12 mm with kV rating of 920 rpm/V (2212 920KV motor). Subsequently, the suitable propeller for the motor is 0.254 m x 0.114 m (i.e. 10 in x 4.5 in).

According to the results of an experiment conducted, the operating current for the motor is found to be 15-25 A.

Thus, the suitable current rating for ESC for this build is 30 A to ensure that the motor or ESC does not burn out during 100% throttle. With six motors, the maximum current pull for them is 150A. Bearing this in mind, selection of battery in power system should be able to provide 150 A. The power system of the UAV is composed of a battery and power module. Lithium polymer (LiPO) battery has been the most common battery to be utilized to power multirotor and it has linear discharge rate that makes it easier to approximately gauge remaining flight time. The battery used for this UAV is 5000mAh 30C 3-cell LiPO with 3DR power module. Power module is used to provide stable power supply (5.3V, 2.24A) to the FC and it includes measurements of the battery voltage and current consumption. The movement of the multirotor is controlled through RC transmitter and receiver via radio frequency. The RC receiver receives signal from the transmitter and channels the signal to FC, which controls the behaviors of the multirotor. Since the transmitter and receiver are not universal, it is crucial to select the ones that are compatible with each other. For the medical UAV at hand, the chosen receiver is FrSky D8R-XP that uses Combined Pulse Position Modulation (CPPM) output, which reduces the wiring to FC. In contrast, traditional receiver uses the Pulse Width Modulation (PWM) protocol, which requires one connection for each channel.In the meantime, the payload release system constitutes of servo and payload release cradle. The cradle is a right triangle cuboid made from polyvinyl chloride (PVC) foam board due to its lightweight, and its ease to design and assemble. On the other hand, the payload release system is constructed with a single servo that unlocks the opening of the payload cradle. The payload cradle is designed to have a diagonal bottom so that the onboard payload will fall due to gravity pull. The total weight of the cradle and servo is 182 g.All of the above mentioned power, propulsion, RC and also payload release system are assembled on the airframe. After all components and system have already been assembled, the FC is flashed with Arducopter firmware version 3.6.9 using the Mission Planner version 1.3.68 on a 64-bit Windows 10 computer. The accelerometer, gyroscope, compass, RC and ESC on the flight controller need to be calibrated for a smooth flight. The calibrations are done through an initial setup tab in Mission Planner. Another mandatory hardware configuration is the flight mode, which supports the automatic mission that allows the multirotor to follow a pre-programmed navigation command for transportation of medical aid kit.To verify that the chosen multirotor components and setup are suitable for flight, the theoretical static thrust is measured using momentum theory. Static thrust equation based on the momentum theory is shown in (1), where T is thrust, V is the velocity of propeller, ΔV is change in propeller velocity, D is the diameter of propeller and ρ is air density which is taken as 1.225 kg/m^3.

$$T = (\pi/4)\, D^2 \rho\, V\, \Delta V \quad (1)$$

A commonly used rule is that the velocity of the air at the propeller is half of the total change in air velocity. Therefore, (1) can be simplified into (2), where V_e is the exit velocity and A_{prop} is the area of the propeller. The exit velocity is found by using (3), where $V_{battery}$ is the battery voltage and P_{prop} is the pitch of the propeller.

$$T = \rho\, A_{prop}\, V_e^2 \quad (2)$$

$$V_e = kV\, V_{battery}\, P_{prop} \quad (3)$$

Based on the calculated available thrust, a suitable design for the medical UAV can be chosen and finalized. A flight test is then conducted to further verify the expected performance of the NAMTOR 3.

III. RESULTS AND DISCUSSION

Using the information regarding the selected components and system for the medical UAV to solve (2) and (3), the exit velocity has been found to be 18.72 m/s while the static thrust is 21.03 N. Ideally, this means that each set of the propeller and motor will produce thrust of about 21.03 N ~ 2.1 kg. Due to friction and heat, there will also be losses on the motor and this will decrease the kV to approximately 50%. With 50% kV (460 kV), the V_e will be 9.36 m/s and subsequently the thrust produced is about 5.25 N ~ 525 g. For four sets of propeller and motor, this will give a total thrust of 2.1 kg while six sets of propeller and motor will give a total thrust of around 3.15 kg. Based on this finding, hexarotor design with six propellers has been chosen for its larger thrust. The total weight of the frame and system is estimated to be 2 kg. Thus, a maximum of 900 g of medical aid kit can be loaded as the onboard payload. Even though the NAMTOR 3 can indeed handle more than 1 kg of payload based on the calculation, it is advisable to avoid full loading to prevent stress on the motors. With this weight limitation, it is expected that the medical aid kit contents will mostly be the basic first aid kit materials, which are suitable for minor injuries.The final design of the proposed NAMTOR 3 is shown in Fig. 2, which has been developed at Flight Technology & Test Center, Universiti Teknologi MARA Shah Alam, Malaysia.

Fig. 2. Proposed NAMTOR 3 medical UAV

Several flight tests are conducted throughout the months of September – October 2019 at the Rugby Field, Universiti Teknologi MARA Shah Alam, Malaysia. Among others, the tests are carried out to analyze the performance and also the stability of the NAMTOR 3 during flight through observation. During the first flight, although is considered as successful, it is found that the multirotor was not stabilized as NAMTOR 3 moved forward (pitch) on its own without the pilot's input. It is suspected that the center of gravity of the multirotor was not balanced due to the heavy landing gear.

Some modifications are then made by changing the payload cradle material and the landing gear. The previous landing gear was made from PVC pipes and it was not properly balanced. The new landing gear, in contrast, is an off-the-shelf component made from plastic and carbon fiber. Because this new landing gear is a factory manufactured product, the parts are made with good precision and balance. As for the payload cradle, the previous one was made of honeycomb plastic panel. The new cradle is made of PVC board with similar dimensions. With these two changes, the overall setup is found to be lighter by 100 grams. All in all, the performance of NAMTOR 3 is summarized in Table I.

Table-I: NAMTOR 3 performance summary

Parameters	Value
Weight (without payload)	2.1 kg
Maximum take-off weight	3.0 kg
Maximum speed	10 m/s
Flight time (hover)	15 minutes
Radio control distance	1.5 km

IV. CONCLUSION

In this study, the NAMTOR 3 has been constructed as a medical UAV and the design is able to fly with 900 g medical aid kit. The performance of NAMTOR 3 has been evaluated through several conducted flight tests and it has been found to be stable. Nevertheless, based on observations made during the flight tests, it is advisable that the multirotor be upgraded to a larger airframe and payload cradle to enable it to carry a heavier payload. The multirotor can also be upgraded with a new flight controller for better flight stabilization with added 4G monitoring and control. It should be noted that this paper does not directly evaluate the effectiveness of NAMTOR 3 to transport medical aid kit. Hence, the future arrangement of the flight tests should include a simulated accident scenario to test the ability and effectiveness of the multirotor to assist in the emergency response. In conclusion, if NAMTOR 3 is able to successfully transport medical kits, it is believed that current policy regarding such operation can be improved. In return, it could assist governing bodies to manage and regulate medical multirotor use in local airspace. Businesses can use the policy as a guideline for provision of medical multirotor services.

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AUTHORS PROFILE

Nur Fahimah M Salleh obtained her Bachelor's degree in Mechanical Engineering at Universiti Teknologi MARA (UiTM). She is currently pursuing her Master of Science (MSc) in Transport and Logistics at the Malaysia Institute of Transport (MITRANS), Universiti Teknologi MARA (UiTM) Shah Alam. Her involvement in multirotor started during her undergraduate studies in 2016 and her ongoing research is construction of multirotor for transport of medical aid kit. Under leadership of Flight Technology & Test Centre (FTTC), UiTM, she and her team won 2nd place in MyDroneX University Drone Competition for their project NAMTOR 3: Medical Drone.

Wan Mazlina Wan Mohamed is currently the Head of Training & Continuous Professional Development (CPD) Program at Malaysia Institute of Transport (MITRANS), Universiti Teknologi MARA (UiTM), and Senior Lecturer at Faculty of Mechanical Engineering, UiTM Shah Alam. She has received her degree in Aerospace Engineering and Aircraft Maintenance Engineering from the Parks College of St. Louis University, USA in 1989, MSc in Air Transport Management from Cranfield University, UK in 1998, and also PhD in Airport Operations from Universiti Teknologi MARA (UiTM), Malaysia in 2016. She started her career as an Aircraft Planning Engineer at Airod Sdn. Bhd. in 1989, and was promoted as Aircraft Superintendent in charge of the C130H modifications in 1993 and Technical Training Manager in 1995. She has more than 21-year experience as an academician. She was appointed as Deputy Dean of Post Graduate and Research, School of Aerospace Engineering, USM in 1998-2001 and joined the Department of Mechanical Engineering, UNITEN as Senior Lecturer in 2001. She joined Faculty of Mechanical Engineering, UiTM Shah Alam in 2003 as a Senior Lecturer, and is actively involved in aviation research and consultancy besides teaching and supervising students in UiTM.

Rizal E. M. Nasir is a Senior Lecturer in the Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia. He holds a PhD degree in Aeronautical Engineering, specializing in flight dynamics and aircraft design. He currently leads Flight Technology & Test Centre (FTTC), a division in Smart Manufacturing Research Institute (SMRI), focusing on the research and development of unmanned aerial systems (UAS). He is a former Head of Thermofluid and Energy Department in the faculty and has published more than 100 journals, conference and technical papers, appears in various mass media as aerospace engineering expert, won medals in trade expositions and UAV competitions, and also appointed as advisors to government agencies, companies and organizations on many matters related to aviation industry, aeronautical engineering, automotive engineering, unmanned aerial vehicles and flying car.

Atikah B. A. Muta'ali has obtained her Bachelor degree in Mechanical Engineering from Universiti Tun Hussein Onn Malaysia, Malaysia. She has worked as an industrial engineer for three years before furthering her studies in the Masters of Science in Mechanical Engineering program in Universiti Teknologi MARA Shah Alam. After graduated with her Master's degree, she continues as PhD candidate in the Faculty of Mechanical Engineering, Universiti Teknologi MARA. She and her team won 2nd place in My DroneX University Competition for their project Namtor 3: Medical Drone and a Gold Award at Pencipta 2019 for the Blended-Wing-Body Unmanned Aerial Vehicle with 4G Internet-based Command, Communication and Navigation research. She also scored Best Paper Award in the SAWAE 2019 Conference in Kuala Lumpur. She is a registered Graduate Engineer with Board of Engineers Malaysia since 2012.

Shahrean Zainurin has obtained his diploma degree from Universiti Kuala Lumpur-Malaysian Institute of Aviation Technology (MIAT) in Aircraft Maintenance Technology (Manufacturing). He is currently pursuing his Master of Science (MSc) in Mechanical Engineering at Universiti Teknologi MARA (UiTM) Shah Alam, Malaysia. With 15 years of experience in the aviation industry, mainly within pilot training and flight simulation industry, his research has been focused on UAV avionics system and flight simulation under the collaboration with the Flight Technology and Test Center (FTTC) of UiTM Shah Alam. To date, under the flagship of FTTC, his team has won 2nd place in My DroneX University Competition for NAMTOR 3: Medical Drone project and a Gold Award at Pencipta 2019 for Blended-Wing-Body Unmanned Aerial Vehicle with 4G Internet-based Command, Communication and Navigation research study. He has been granted the status of Member with Royal Aeronautical Society (RAeS) in United Kingdom since 2019 and is currently working as Senior Flight Simulator Engineer at Ryanair, United Kingdom.