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Integration and Testing of Multi-Rotor Unmanned Aerial Vehicle

1. Ganesan S, 2. Shanthi C, 3. Sravanth Chandaka, 4. Neethu Sri Velangi, 5. Teja Akena, 6. Jathar Laxmikant Dattatray, 7. Jayavelu S

[1,3,4,5,7] *Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology.*

[2]*Madras Institute of Technology, Anna University*

[6]*Army Institute of Technology*

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Abstract: In the current trends of maturation, unmanned aerial vehicles have been the greatest innovation of technology because of their versatile capability of doing tasks with low complexity while delivering an efficient output. The main principles of flight for a quadcopter: pitching, rolling, and yawing they are analysed to control the quadcopter. The lift to the quadcopter is generated by a combination of four motors to which the propellers are mounted. The motors are attached to the end of the arms of the frame, which is in the shape of a cross. The required amount of thrust and torque generated by the motors is in rotational motion, and that force is used to displace and lift the quadcopter. The motors that are fixed to the arms rotate in coordination with one another such that the torque generated by one motor will be cancelled by another, resulting in maintaining the same speed. The whole mechanism is controlled by a pilot from the ground control unit (GCU) using a radio frequency controller called a transmitter. Besides this, an Android mobile device is assimilated with the GPS for tracking the position and getting visual feedback from the quadcopter. After the quadcopter is assembled, testing is done on the quadcopter to estimate its performance. Tests like stand tests, cage tests, and field tests are being done in order to ensure the performance of the quadcopter. Thrust generated by the motor is tested by using a load cell. The other tests are done using the mission planner application. The quadcopter that is made using the above-mentioned guidelines can be used for numerous purposes, like aerial surveying, firefighting, rescue mitigation, electric line inspection, domestic work like delivering things, defence, security checks, etc. As the trend is changing, people are researching ways to make it even smaller, lighter, cheaper, and more efficient, enhancing its capability of doing many more tasks and making it autonomous.

Keywords: Unmanned Aerial Vehicle, Pitching, Yawing, Rolling, GCU, Transmitter.

I. Introduction

Today, transportation is becoming a pivotal activity in human civilization. The quadcopter is a type of unmanned aerial vehicle that comes with versatile utilities like surveying, domestic deliveries, etc. There are many advantages to using it prior to the purpose. India has a wide range of geological regions, which include forests, deserts, hills, water bodies, mountains, etc. Among them, most of the places are sometimes inaccessible to humans. During such times, there will be a need for a machine that can do the task while ensuring the safety of humans. Such feet can be achieved by a quadcopter. This quadcopter is capable enough to reach places that are sometimes inaccessible. The main objective of this is to develop an efficient, budget-friendly, portable, and environment-adaptive vehicle. The quadcopter contains a flight controller, GPS, receiver, camera, microphone, and some primary electronic devices like an ESC, battery, motor, etc. The commands are given through a transmitter from the GCS (Ground Control Station) to it. Its location is monitored with the GPS unit installed on it. The audio and video feedback are obtained on the Android device at the GCU. The quadcopter also has tremendous applications in the defence sector as well. Many countries across the globe are developing these unmanned aerial vehicles for surveillance, finding hidden enemies, and sending messages. Hence, it is clear that there are huge opportunities for the growth of quadcopters for both civil and military purposes. Also, there is a decent quadcopter market place in countries like Singapore from an ethical perspective, which has some conflict using quadcopters. The UAVs can take different forms with different levels of operating altitudes and payload capacities. They are all subjective to different regulations that differ from country to country. These UAVs can be further developed by installing different types of sensors and advanced cameras for a variety of analyses and studies. There are many experiments going on today in several countries and industries within them to offer the easy completion of tasks like aerial monitoring, power line surveillance, vegetation growth, forest inspection, agricultural sector, etc. 3D mapping is used in designing new worksites and to evaluate the distance between places. Monitoring gas emissions. Thermal imaging to identify gas leaks, avoiding potential high-level dangerous operations and preventing workers from being exposed to toxic gases and costly shutdowns of the activity. There are a wide variety of configurations of UAVs based on size, shape, number of motors used, weight, etc.

II. Literature Review

The latest developments in the field of three-dimensional printing have significantly facilitated the manufacturing process of Unmanned Aerial Vehicle (Ahmed et al.., 2013). This has allowed for the creation of small-scale test models for wind tunnel testing and validation. The design and fabrication of UAVs have also been explored in the context of international aircraft design competitions, with a focus on meeting design requirements and achieving high vehicle performance (Khan et al., 2016). The impact of specific design features, such as raked winglets and wing fences, on the overall performance of UAVs has been investigated, with a focus on practicality (Mishra et al., 2021). Additionally manufacturing technology has been investigated for the UAV development, with particular emphasis on the 'Bubak' aircraft created for energy efficiency(Sykora et al., 2020). The successful design, development, and participation of a unique UAV in an international competition highlight its aerodynamic efficiency and successful launch at the competition site (Papon et al., 2013). The process of additive manufacturing provides an essential benefit over conventional production by facilitating the immediate manufacture of complicated structures without having to wait for a mold(Pascariu et al., 2020).

The new framework for job-oriented, adaptable design as well as manufacture of mini-UAVs using advanced additive manufacturing techniques allows agile design methodology and rapid prototyping, with a focus on tailoring designs to specific mission requirements and showcasing various vehicle configurations (Bronz et al., 2020). The design and development of a UAV with the objective of being efficient during emergencies, dropping packages from a minimum height of 100 feet, using a vision-based control strategy, and being capable of multi-mission tasks while ensuring cost-effectiveness and safety (S. Khan et al., 2018). The design and manufacture of a Miniature Unmanned Aerial Vehicle (MUAV) using a specific 3D rapid prototyping machine showcase rapid product development capabilities with Acrylonitrile-Butadiene-Styrene (ABS) material, emphasizing reduced time for design, fabrication, and deployment (Taha et al., 2011).Using additive manufacturing techniques, a UAV has been effectively built and tested, demonstrating stability, an extensive spectrum of speeds, good aerodynamics, and great manoeuvrability. The UAV model was designed for search-and-rescue missions in mountainous areas, with specific characteristics such as a take-off mass of 11 kg, a wingspan of 3.4 m, an autonomy of approximately 50 min, and a control distance of about 100 km (Zaharia et al., 2023). A laboratory stand for testing UAV systems using hardware-in-the-loop simulation to check essential parts, reduce costs, and reduce risks related to flight tests is discussed, with further development possibilities discussed (P. Grzybowski et al., 2012). An innovative solution to the problem of test stands adding extra burden to vehicles by designing a passive gravity-balanced test stand was verified through a simulation study (Qi Lu et al., 2008). The development of a mobile test stand to evaluate electric power plants for unmanned aircraft, addressing the common issue of the absence of accurate performance data among UAV power plant producers, with successful data collection for estimating powerplant performance characteristics and improvements in data acquisition system accuracy (Serbezov et al., 2017),.

A range of studies have explored the development and testing of multi-rotor UAVs. (Cvisic et al., 2013) and (Deters et al., 2017) both focus on the testing of these vehicles, with Cvisic specifically looking at the development of UAVs with redundant rotors and the testing of control algorithms, while Deters examines the static performance of propulsion elements. (Yamada et al.,2017) present a novel two-wheeled UAV design with a cage that was tested for bridge inspections, and (Sinha et al.,2015) discuss the design and testing of a VTOL UAV with a unique wingtip-mounted electric lift propeller concept. These studies collectively contribute to the understanding of multi-rotor UAVs and their potential applications.
A range of studies have explored the thrust calculation and control of multirotor unmanned aerial vehicles (UAVs). (Hwang et al., 2015) conducted numerical investigations into the aerodynamic performance of a quadrotor UAV, observing higher inflow and unsteady thrust variations due to rotor interactions. (Bangura et al..,2017) proposed a novel control algorithm for fixed-pitch rotors, improving disturbance rejection and gust tolerance. (Yoon et al. (2015) developed an automatic thrust measurement system for small battery-operated multirotor helicopters, enabling precise and efficient static thrust and speed measurements. (Ding et al., 2021) introduced a tilting-rotor UAV design with enhanced maneuverability and stability, featuring dual-level adaptive robust control and thrust force optimization. These studies collectively contribute to the understanding and advancement of thrust calculation and control in multirotor UAVs.

III. FABBRICATION OF QUADCOPTER

The frame is one of the main components of the quadcopter, which consists of four arms. The frame is made in such a way that it should be light and rigid enough to hold a LIPO battery to power the quadcopter, four BLDC motors with propellers attached to them, which produce thrust, a flight controller, a camera, GPS, and other sensors. The speed of the motors is controlled by the Electronic Speed Controller (ESC) by varying the voltage that is supplied by the battery. The centre of gravity should be considered while installing the components on the frame. For better stability, i.e., to have a lower C.G., the battery is placed in the lower half. And the motors are placed equidistantly from each arm diagonal to one another. As there is a flow interaction between the propellers, there are some chances of aerodynamic interaction between them. In order to prevent that, the distance between them is altered accordingly. All the quadcopter parts are listed in table 1. The frame is made of plastic material. This paper is mainly focussed on the tests done to a quadcopter before going to the application. Besides, we are going to integrate this into an Android mobile, where we can get to know the location, altitude, and aerial view of the region where it is flying. The GPS and 3G communication technologies are used to gather real-time audio-video geolocation information. The vertical take-off and landing can be established by controlling the thrust vector of the motors.

TABLE I: COMPONENTS AND SPECIFICATION

Sl. No	Component	Specification
1	Frame	S500
2	Motor	emax 835kv
3	Battery	3S Lipo 5200mah
4	ESC	emax 30 amp
5	Flight Controller	Pixhawk Cube orange
6	GPS	Here3 M8P-2
7	Transmitter	Flysky I6S 10 channel 2.4 Ghz
8	Receiver	Flysky 10 channel
9	Propeller size	1045
10	Telemetry	3DR Radio Telemetry,915 hz

IV. TESTING

The testing procedure is described with the help of a flow chart, as shown in Fig. 1. The frame was made bit-by-bit. The motors are tested at different speeds with the ESC, and the thrust characteristics have been determined. A load cell arrangement that is connected to the motor will accomplish this. When the motor is powered, it produces thrust, which causes a change in displacement due to the load caused by thrust force. The overall force applied is displayed in the display unit. The transmitter is calibrated, which ensures that the motor gets the same pulse at the start of take-off. If any mechanical inaccuracies are noticed, then the motor should be trimmed. In order to ensure proper functioning of the components and the safety of the quadcopter, all the components are tested with various tests, both individually and as a whole. Generally, there are three test stages carried out on a quadcopter. They are,

1. Stand Test
2. Cage Test
3. Field Test

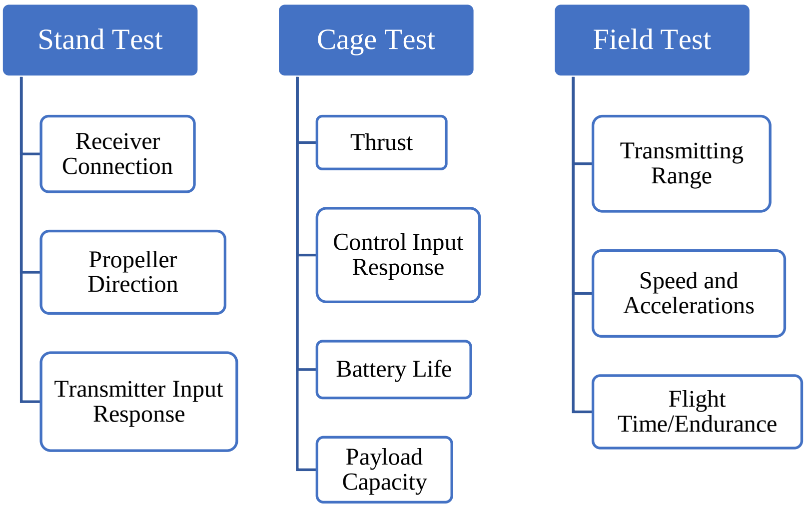

Fig. 1. Flowchart of Testing

A. Stand Test

The stand test is a typical test that is conducted by keeping the quadcopter on the ground. The components like motor, ESC (electronic speed controller), and transmitter input response are undergone. The propeller direction attached to the motor is tested by operating with the transmitter. The ESC is calibrated by varying the voltage and monitoring the motor speed. The input transmitter response is done by calculating the real-time time between stick inputs and the receiver on the quadcopter. The stand test is most likely called manual calibration of the quadcopter.

B. Cage Test

This is a pre-flight test that is done to calculate the total amount of thrust produced, control input response, battery life, and payload capacity of the quadcopter. The thrust force can be determined either by conducting a bench test on the motor or by using the dynamic propeller thrust equation as mentioned below. The control input response is tested by trimming the motors. The battery life is tested by operating the quadcopter from 100 to 5 percent of its capacity. The payload is predetermined through the thrust calculation, yet the overall C.G. and stability of the quadcopter are checked by placing it manually.

C. Field Test

The flight test is carried out by taking the quadcopter to an open area. The quadcopter is flown, and the parameters involved in the test, like transmitter range, speed, acceleration, and endurance, are tested.

D. Calculation of Thrust

The thrust force is calculated by using a test rig set up. The test rig consists of a load cell integrated into a microprocessor. The load cell is connected to the computer. By powering the motor, the thrust value is displayed in the window. The thrust force can also be calculated by using the formula mentioned below:

$$Thrust = 4.392x10^{-8} . RPM \frac{d^{3.5}}{\sqrt{pitch}} (4.233x10^{-4}. RPM. pitch - V_0) \quad (1)$$

Where;

d the propeller diameter

V_0 is the propeller forward airspeed (m/s)

V. RESULTS AND DISCUSSION

The main objective of this study was to create a quadcopter that could be used for many surveillance purposes. As India contains different geographical terrains, the finest use of a quadcopter helps a lot during some critical times like floods and some other natural disasters, epidemic conflict, etc., when some locations are impassable to rescue the victims. This unmanned aerial vehicle will be capable of reaching the locations and enabling the services to be provided to the people over there. The initial goal is to create a vehicle that is cost-effective, efficient, and can be easily adapted to the environment. The main electronic components are attached to the frame, and the camera and landing gears are attached to the bottom part of it. The telemetry module is installed for connecting it with the Android device. The hovering mechanism can be implemented well by adjusting the payload over it. The communication between the smartphones tends to be delayed sometimes due to the surrounding frequencies. This can be prevented by choosing a strong signal and operating it in an open space where there are no other frequencies around. The whole control is done by the ground control unit using a transmitter. There is no delay in the live video, and the images clicked are saved to the Android device in a named folder. The performance of the quadcopter is great and stable during its entire mission. The maximum thrust force produced is 7.44 N (1 motor) at the 2000 cut-off rate. It was able to get close to the desired targets. The discharge rate of the battery is 28C. The overall payload capacity is 800 g to 1000 g. After performing the field test, the maximum range obtained was 2km with no payload. It was found that if the payload is increased, the range will drop to 1000m. The speed of the quadcopter is around 15 m/s. The speed decreases with the increase in payload to accommodate the endurance. This quadcopter has a vital role in many countries for military surveillance and transportation of military goods, traffic monitoring, and city planning. The ultimate goal of this work is to study the complete design and fabrication process of a quadcopter from an engineering perspective and improve the control interface by introducing those applications to smartphones.

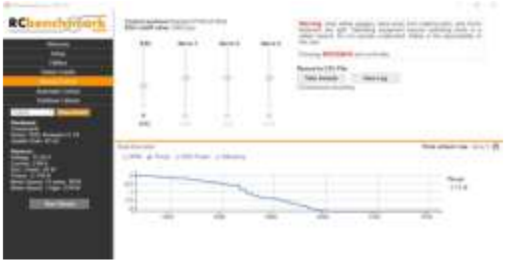

Fig.2. Maximum thrust at 1000 μs cut-off value

Fig.3. Assembled quadcopter

Fig.4. Transmitter Input Response

Fig.5. Control Input response

Fig.6. Field Test on quadcopter

Fig.7. Calculation of thrust using loadcell

Fig.8. Aerial Mapping Using quadcopter

Fig.9. Image Taken by quadcopter

TABLE II: FIELD TEST PARAMETERS OF MULTICOPTER

S.No	Parameter	Value
1	Transmitting Range(m)	2000
2	Speed (m/s)	15
3	Acceleration (m/s^2)	5
4	Endurance (min)	17
5	Battery Discharge Rate(C)	28

TABLE III: THRUST AT DIFFERENT CUT-OFF VALUES OF ESC

Sl. No	ESC Cut-off Value	Thrust (N)	ESC Power (W)
1	1000	0.0259	1.2
2	1200	1.12	10.1
3	1400	2.59	28.9
4	1600	4.1	53.3
5	1800	6.59	105
6	2000	7.44	127

VI. CONCLUSION

The quadcopter is a versatile unmanned aerial vehicle that can be used in a wide range of applications. In this study, The testing of a basic quadcopter using a DIY kit that follows the basic principles and aerodynamics of flight. The main purpose of this project is to introduce a control application for controlling the quadcopter. The pictures and videos are recorded according to the need. This application will be possible only after introducing a telemetry to the quadcopter, which is connected to a smart phone via 2.4 GHz. This wavelength is strong and is used for getting a good connection over a longer distance. Today, quadcopters are being upgraded and adopted by most commercial markets, which include precision agriculture, logistics, and infrastructure, even in disaster situations like floods and cyclones and to monitor traffic in busy cities. Further, the technology is focused on increasing endurance, payload, and better communication with the pilot at the GCS (ground control station) and regulating the rules for the safe and secure operation of the UAV. Alongside integrating them with AI (artificial intelligence), which makes them autonomous.

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BIOGRAPHY

Ganesan S: Dr. Ganesan S is currently working as a Professor in Aeronautical Department at Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology. He completed his B.E in Mechanical Engineering, M.E in Aeronautical Engineering and Ph.D. in Solid Propellants.
Mail Id: ksganeshme@gmail.com

Shanthi C: Dr. Shanthi C is currently working as an Assistant Professor in Instrumentation Engineering at Madras Institute of Technology. She completed her B.E in ECE , M.E in Instrumentation and Ph.D. in Image Processing.
Mail Id: cgshanthi@gmail.com

Sravanth Chandaka: Mr. Sravanth Chandaka is currently pursuing his B.Tech degree in Aeronautical Engineering at Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology.
Mail Id: sravanthchandhaka@gmail.com

Neethu Sri Velangi: Miss. Neethu Sri Velangi is currently pursuing her B.Tech degree in Aeronautical Engineering at Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology.
Mail Id: velangineethu@gmail.com