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AERIAL DREAMS OF QUADCOPTER: FROM BLUEPRINTS TO THE STARS

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Abstract
This project involved fabricating and testing a quadcopter using a custom 3D-printed frame. The process began with selecting the quadcopter's optimized frame, followed by the 3D printing using durable and lightweight materials like ABS plastic. The printed components were assembled with avionics, including the flight controller, motors, ESCs, and sensors, to create a fully functional UAV. After assembly, the quadcopter was configured for optimal flight performance, including calibration of the flight controller and tuning the control systems. The successful test flight demonstrated the viability of the 3D-printed frame and the effectiveness of the configuration process, highlighting the potential for rapid prototyping and custom UAV design using additive manufacturing technologies.

Keywords:
Additive Manufacturing, UAV, Drones, Flight, 3D printing, avionics

1. Introduction
The rapid advancement of Unmanned Aerial Vehicles (UAVs) has opened new possibilities in various fields, from aerial photography to search and rescue missions. Quadcopters have become popular among these UAVs due to their stability, maneuverability, and relatively simple design. This project focuses on developing a quadcopter UAV equipped with 10-inch propellers, with the frame produced through 3D printing technology [1].
The project began with selecting an optimized quadcopter frame design specifically tailored for enhanced flight performance and structural integrity. [2][3][4] Leveraging the precision and flexibility of 3D printing, the frame was fabricated, providing a lightweight yet robust structure. [5] The quadcopter was meticulously assembled following the fabrication, incorporating key components such as motors, electronic speed controllers, and a flight controller.
The configuration process ensured that the quadcopter's systems were properly calibrated for optimal flight performance. The final phase involved comprehensive testing, including initial ground tests and subsequent flight trials. These tests were crucial in validating the quadcopter's performance, stability, and responsiveness under various conditions.
This work demonstrates the effectiveness of combining 3D printing with an optimized design to produce a functional and efficient quadcopter. The use of 3D printing not only facilitated rapid prototyping but also allowed for customization and iteration based on specific performance requirements. The quadcopter's successful flight marks a significant achievement, showcasing the potential of integrating advanced manufacturing techniques with UAV development.

2. Additive manufacturing
Additive manufacturing (AM) or additive layer manufacturing (ALM) is the industrial production name for 3D printing, a computer-controlled process that creates three-dimensional objects by depositing materials, usually in layers.

2.1 Fused Deposition Modeling
Fused Deposition Modeling (FDM) is one of the most widely used 3D printing technologies, particularly valued for its accessibility, cost-effectiveness, and versatility in material usage. In FDM, a thermoplastic filament is heated to its melting point and then extruded layer by layer onto a build platform, where it cools and solidifies to form the final object. The process is highly precise, allowing for creating complex geometries and detailed structures.

FDM is especially suitable for applications requiring durable and lightweight components, making it an ideal choice for producing parts like drone frames. The ability to control the internal structure of the printed object, such as infill density and pattern, enables designers to optimize the balance between strength and weight, which is critical in UAV design. Additionally, FDM allows for rapid prototyping and easy iteration, enabling the development and testing of multiple design variations quickly.
In this work, FDM was instrumental in producing an optimized quadcopter frame, allowing precise control over the design and ensuring that the final product met the necessary performance standards. The use of FDM not only streamlined the production process but also contributed to the overall success of the quadcopter's development and testing.
3D printing of 10" frame GD I [4], is done on ELEGOO Neptune 4 max 3D printer, shown in Figure 2.1, which has a 420X420X480 mm build volume that works on FDM technology.

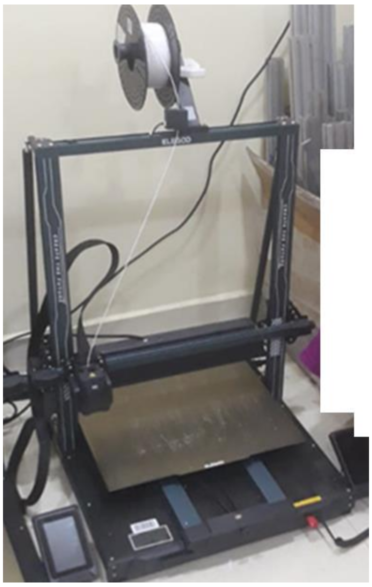

Figure 2.1 ELEGOO Neptune 4 max 3D printer

Filament: Tesseract 1.75 ABS Black
Nozzle temperature: 240°C
Bed Temperature: 92°C
Raster angle = 45°
Infill density: 40%
Infill pattern: Tri-Hexagonal

3. Assembly

At the core of a quadcopter's functionality lies a complex array of electronics and avionics that work harmoniously to ensure stable flight, precise control, and the execution of various autonomous tasks.

3.1 Electronics and Avionics

Table 3.1 shows the components mounted on the quadcopter frame and describes their use.

Table 3.1 Components of a drone

Flight Controller: The flight controller is the quadcopter's brain, processing input from sensors and the remote control to stabilize and control the aircraft. The flight controller used is the Pixhawk.	

Electronic Speed Controllers (ESCs): ESCs regulate the power supplied to the motors. They receive signals from the flight controller and adjust the motors' speed accordingly. Each motor typically has its own ESC.	
Motors: Quadcopters use brushless DC motors due to their efficiency and power. These motors generate lift and maneuver the drone by varying their speed.	
Propellers: These components convert the rotational motion from the motors into thrust. They are usually made of plastic or carbon fiber and come in pairs (clockwise and counterclockwise) to ensure balanced flight.	
Battery: The power source for a quadcopter is usually a lithium polymer (LiPo) battery, known for its high energy density and discharge rates. The battery's capacity and voltage determine the flight time and power available to the drone.	
Power Distribution Board (PDB): The PDB distributes power from the battery to the ESCs and other onboard electronics. It ensures that all components receive the correct voltage and current.	
Radio Receiver: The receiver picks up signals from the pilot's remote control (transmitter) and relays them to the flight controller. Commonly used frequencies include 2.4 GHz and 5.8 GHz.	
GPS Module: The GPS module provides the quadcopter with positional data, enabling features like autonomous navigation, return-to-home, and position hold.	

3.2 Assembly Procedure

The components mentioned above work together to ensure the quadcopter can fly stably, respond to pilot commands, and perform autonomous functions. Table 3.2 provides more detailed specifications and characteristics of the components used for the current work.

Table 3.2 Drone components and their specifications

S. No.	Name of the Component	Specifications	Characteristics
1	Each Motor	Rating:1400kV	Thrust = 10 N
2	Electronic Speed Controller (ESC)	Current rating: 30 amps	Medium to high-powered motors
		Input voltage: 7.4V to 14.8V	for 3S LiPo battery
		High refresh rate 400Hz	Maintains stability by providing rapid throttle response
3	Flight control board	32-bit ARM Cortex-M4 Processor	High processing power and efficiency
		Accelerometers and Gyroscopes	Integrated Inertial Measurement Units (IMUs) provide precise vehicle orientation and motion data.
		Magnetometer	Measures the Earth's magnetic field to determine heading
		Barometer	Measures atmospheric pressure to determine altitude
		GPS Module	Supports precise positioning and navigation
4	Radio Transmitter	6 Channels	Provides control for up to six different functions or servos
	It is used to send control signals to the drone	Frequency: 2.4GHz	Uses Automatic Frequency Hopping Digital System (AFHDS) 2A for reliable and interference-resistant communication between the transmitter and receiver.
5	Receiver	6 Channels	It provides a robust and interference-resistant communication link between the transmitter and receiver. It is used to receive signals from drones.
		Frequency: 2.4GHz	
6	Propellers	10 in	Generate thrust
7	Battery	3300 mAH	It gives power to the system
8	GPS module		Traces the location and guides the drone
9	Power Distribution cables		Connects all components
10	Frame	ABS Plastic	The structure of the drone that carries all the components mentioned above

B. The Assembly Process to make a Quadcopter drone of one rotor (motor + propeller) connection can be shown in Figure 3.1. A quadcopter has four rotors, each requiring an ESC. Figure 3.1 illustrates the connection for a single ESC in making a drone. For four ESCs of the quadcopter, the connections can be understood with the help of Figure 3.1.

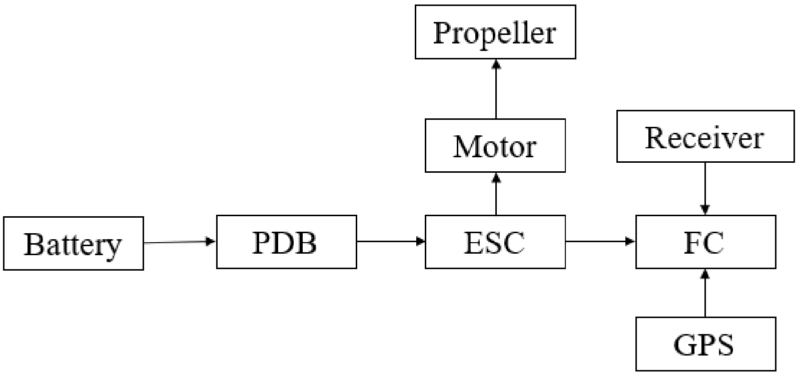

Fig 3.1 Connection of a single ESC

The assembly of a quadcopter drone involves integrating electronic components, each playing a critical role in the drone's operation. The approach followed while assembling and configuring the drone to ensure reliability, stability, and optimal performance during flight is as follows:

1. *Motor Installation:*

The motors, rated at 1400KV, are secured to the ends of the arms using screws.
Proper clockwise (CW) and counter-clockwise (CCW) motor orientation is ensured.

2. *ESC Installation:*

The SimonK 30A ESC power leads are soldered to the Power Distribution Board (PDB).
The ESC signal wires are connected to the Pixhawk flight controller.

3. *Mounting Propellers:*

The 10-inch propellers with a 45-degree pitch angle are attached to the motors, ensuring correct orientation (CW and CCW).
The propellers are tightened securely but not over-tightened.

4. *Flight Controller Setup:*

The Pixhawk flight controller is mounted on the central frame using vibration-dampening pads.
The ESC signal wires, GPS module, telemetry module, and other sensors are connected to the flight controller.

5. *Power Distribution:*

The battery connector is soldered to the PDB.
The PDB output is connected to the flight controller and other components.

6. *Radio Receiver Installation:*

The FlySky FS-iA6B receiver is mounted on the frame, ensuring antennas are positioned for optimal signal reception.
The receiver is bound to the transmitter following the manufacturer's instructions.

7. *Battery Installation:*

The 3300mAh Lithium-Polymer (LiPo) battery is secured to the frame using straps.
The battery is connected to the PDB, ensuring correct polarity.

8. *Initial Setup and Calibration:*

The drone and the transmitter are powered on.
The flight controller sensors (accelerometer, compass) are calibrated.
The flight controller settings, including ESC calibration and fail-safe settings, are configured.

9. *Pre-Flight Checks:*

All connections are verified as secure.
The propellers are checked to spin in the correct direction.
The functionality of the transmitter and receiver is checked.

10. *Testing and Calibration*

a. Ground Tests:
Initial tests without propellers ensure motors respond correctly to transmitter inputs.

b. Flight Tests:
Short, low-altitude test flights in Stabilize mode are conducted to verify stability and responsiveness.

3.3 Configuration

Configuring a drone is done using Mission Planner, which involves a series of steps to ensure all components and sensors are calibrated correctly and the flight controller is appropriately set up. Following the steps below, a reliable and stable configuration is achieved, and the drone is ready for safe and efficient flights.
Mission Planner, a comprehensive ground control station software, configures and manages drones with ArduPilot firmware. It provides various initial setup, calibration, mission planning, and real-time monitoring tools.
Mission Planner is launched to connect the flight controller to the computer via the USB cable. To establish a connection, the appropriate COM port and baud rate 115200 are selected in Mission Planner. Then, the following steps are taken.
The frame type of drone selected is Quad-X for a standard quadcopter and is specified under the "Frame Type" section. The accelerometer is calibrated by selecting "Calibrate Accel," on-screen instructions are followed, which involve placing the drone in various orientations. "Compass" is clicked for compass calibration, and the live calibration is performed by rotating the drone in all directions. Accurate transmitter input is ensured by calibrating the radio. "Radio Calibration" is selected, and all sticks and switches are moved to their maximum extents to record the endpoints.

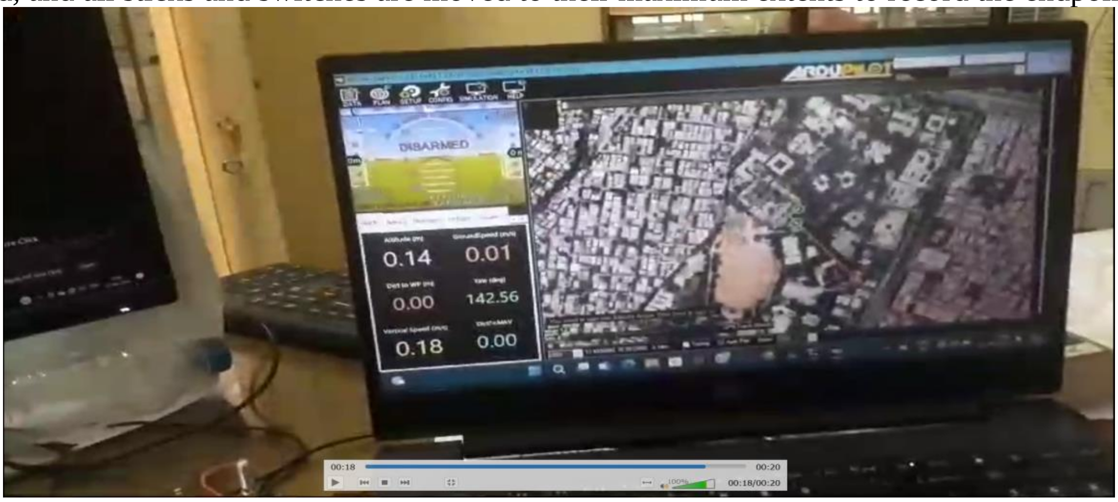

Figure 3.1 Calibration of Quadcopter

The Electronic Speed Controllers (ESCs) are then calibrated. The "ESC Calibration" section is navigated, and the instructions are followed to synchronize the ESCs, ensuring the motors operate in harmony. Afterward, the flight modes are configured by selecting "Flight Modes" under the "Initial Setup" tab. Different flight modes (e.g., Stabilize, Loiter, RTL) are assigned to the transmitter's switches, allowing mode switching during flight. Fail-safe options are set up by clicking "FailSafe" and configuring actions for low battery, loss of signal, and other critical situations to enhance safety.
Battery monitor setup is crucial for accurate battery status monitoring and warnings. The "Optional Hardware" tab is accessed, "Battery Monitor" is selected, and battery specifications are entered. Proper configuration of the GPS module is ensured by going to "GPS" settings and verifying that the GPS is detected and functioning. Other sensors (e.g., barometer) are checked and configured under the "Optional Hardware" tab.
Before flight, ground tests are conducted to verify that all sensors are working correctly and motors respond accurately to transmitter inputs.
Following the above steps completes the configuration and calibration of the drone, which makes the drone ready to take off.

4. Taking Off

Step 10 of Section 3.2 B checks whether the quadcopter is ready to fly. After completing the preliminary tests, the drone heads skyward.

Figure 4.1 Quadcopter ready to fly

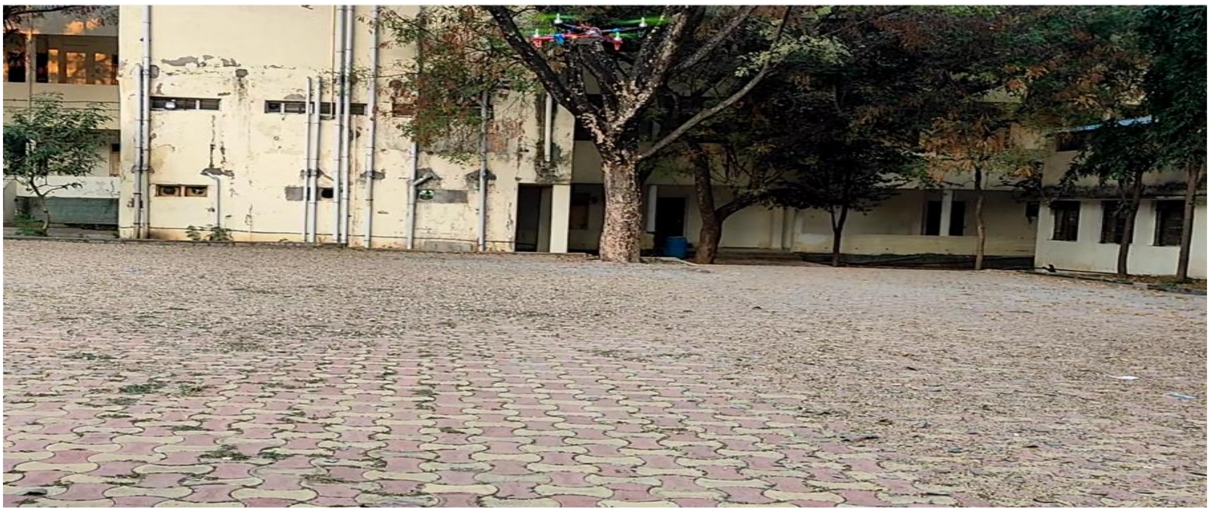

Figure 4.2 Quadcopter on Flight

5. Conclusions

The successful design, fabrication, and testing of the quadcopter with a 3D-printed frame demonstrate the effectiveness and practicality of using additive manufacturing techniques in UAV development. The project highlights the potential of 3D printing for rapid prototyping and customization in drone design, offering significant flexibility in material selection and structural optimization. The smooth integration and configuration of avionics, followed by a successful flight, validate the structural integrity and aerodynamic performance of the 3D-printed frame. This work suggests that 3D printing can be a valuable tool in the iterative design and development of UAVs, providing a cost-effective and efficient approach to producing highly tailored aerial platforms.

Scope for Future Work

Future work could explore several avenues further to enhance the capabilities and performance of 3D-printed quadcopters. One potential area is the investigation of advanced materials for 3D printing, such as carbon fiber-reinforced composites, to improve the frame's strength-to-weight ratio and overall durability.

Another area of interest could be the integration of more advanced avionics and sensors, enabling autonomous flight capabilities and more sophisticated control systems. Further research could also focus on developing modular frames that allow for easy reconfiguration or replacement of components, enhancing the quadcopter's versatility and maintenance.
Finally, extensive field testing under various environmental conditions would provide valuable data on the long-term performance and reliability of 3D-printed UAVs, paving the way for broader applications in commercial and industrial sectors.

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