Demo: ROARQuad: Robust, Open Academic Research Quadcopter

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ABSTRACT

Commercial off-the-shelf (COTS) unmanned aerial vehicles (UAV) are undesirable for academic research due to the difficulty of modification and the inability to readily program missions from a companion computer. Furthermore, open-source designs are scarce and unreliable. To address this gap, we present ROARQuad - a Robust and Open source Academic Research Quadcopter. Our quadcopter costs around $1,500, provides over thirty minutes of flight time, and has a maximum payload of nearly 2 kilograms. To support research into swarm coordination and planning, we have experimentally derived the power consumption profile of the vehicle. Our quadcopter not only addresses the limitations of existing COTS and academic designs but also provides a flexible and reliable solution for future UAV research and development.

CCS CONCEPTS

• **Computer systems organization → Robotics**.

KEYWORDS

Unmanned Aerial Vehicles, Quadcopter, Hardware Design

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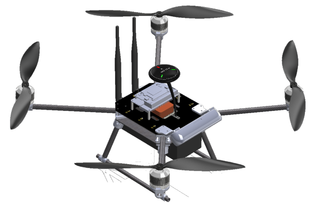
1 INTRODUCTION

Commercial off-the-shelf UAVs provide consumers with advantages such as ease of use, reliability, accessibility, and low-cost, but they often pose challenges for academic research due to difficulties in integrating custom algorithms for specialized applications such as computer vision, swarm coordination, or path planning. Their proprietary hardware is also restrictive, limiting researchers' ability to modify and optimize flight behavior for research purposes. To address these limitations, we previously designed and built our own platform [1], which was built on a pre-packaged airframe kit. However, this design was unreliable and prone to crashes.

To overcome the drawbacks of our previous platform, we designed and constructed ROARQuad – a quadcopter with a flexible configuration tailored for academic research. Weighing under 2 kg, our quadcopter can achieve a hover time of over 30 minutes and costs under $1,500. It can carry a payload of approximately 2 kg, allowing it to carry additional components, such as a companion computer, a camera, or other sensors. Our design is open source, with detailed assembly instructions and a full bill of materials provided on our website[1]. The ROARQuad serves as a reliable and cost-effective platform for academic research.



Weight	1.9 kg
Dimensions	41.3 cm × 41.3 cm × 21.6 cm
Capacity	2 kg
Max Speed	25 m/s
Hover Time	~30 minutes

Figure 1: Quadcopter CAD model and specifications

2 HARDWARE OVERVIEW

Our airframe has a modular design for ease of component replacement and customization. Polylactic Acid (PLA) 3D-printed joints connect carbon fiber rods and plates, to support the flight controller, radios, and possible companion computer payload. We optimized the print direction, infill, and shape of each joint piece to improve durability. In the event of a crash, the 3D-printed joints are designed to absorb most of the impact and break before the other major components of the airframe. Figure 1 shows a CAD rendering of the airframe design and a list of specifications.

2.1 Airframe

The frame consists of two parallel base-plates and carbon fiber tubes for legs and arms. The bottom base-plate is made of carbon fiber and the top plate is the power distribution board. The carbon fiber arms are mounted between the two base-plates and the carbon fiber legs are attached beneath the bottom plate, directly below the arm mounts.

2.2 Power Distribution

We designed a custom power delivery board (PDB) with surface-mount solder components. The PDB routes power from the battery to the four motors and steps down the high voltage from the battery to 5 volts to power the flight controller and the companion computer.

The main priority in the design of the custom PDB is ease of fabrication; however, we also wanted to perform energy-related

[1]www.mines-pecs-quadcopter.github.io

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studies on the quadcopter. We created a voltage divider circuit that powers the flight controller and the companion computer. This voltage is read continuously by the flight controller to track the voltage level of the battery and the load current used by the UAV throughout a flight.

2.3 Wireless Communication

There are two antennas on the testbed platform. The first antenna is used by the CubePilot flight controller to receive instructions from a radio controller. The second antenna is used by the CubePilot to interface with ground control software, such as Ardupilot and MissionPlanner. This antenna broadcasts position and speed data, and can receive mission inputs (such as waypoints to fly to) and accept new UAV firmware parameters (such as changing maximum speed or performance characteristics).

The Federal Aviation Administration (FAA) requires that all UAVs be equipped with remote identification modules that broadcast safety information at all times[2]. To comply with this rule, we employ CubePilot's CubeID module[3], a cost-effective way to comply with the FAA's regulations.

2.4 Propulsion and Payload

Our UAV is powered by four 535-watt quadcopter motors. These motors are more powerful than the minimum requirement for a quadcopter this size, allowing for increased performance and increased payload capacity. To power the motors, we are using a 10000 mAh 4S Lithium Polymer battery.

The theoretical maximum payload is approximately 1.9 kilograms, calculated by subtracting the weight of the UAV plus its payload from the maximum thrust of the four motors while maintaining a 2:1 thrust ratio. We developed a mount for a Raspberry Pi (RPi) or Nvidia Jetson to sit on top of the UAV, as well as various camera mounts. There is also a large payload area beneath the drone, between the legs, where a larger sensor package could be mounted.

3 SOFTWARE OVERVIEW

The flight of the UAV is controlled by a CubePilot Orange[4], a commercially available flight controller. The CubePilot allows for radio-controlled flights with any standard UAV remote control. It can also run autopilot programs created from a separate computer running software such as ArduPilot's Mission Planner. The CubePilot also has I2C, CAN, and Serial ports, allowing for a diverse range of companion computers to be used onboard the UAV.

Our main purpose for our UAVs is to evaluate planning algorithms and prototype research problems. We attached a RPi4 to the aircraft to act as a companion computer, which can run more computationally intensive path-finding algorithms. The RPi4 uses the DroNS3 autopilot from [2], which uses the MAVLink protocol[5] to send movement commands to the CubePilot.

[2]www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-89
[3]docs.cubepilot.org/user-guides/cube-id/cube-id
[4]www.cubepilot.com/#/cube/specs
[5]www.mavlink.io/en/

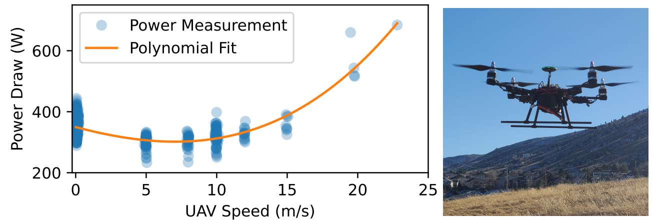

Figure 2: ROARQuad power profile experiments

4 PERFORMANCE & DEMONSTRATION

Without any payload, the quadcopter can hover for approximately 30 minutes. With a RPi4, it can hover for approximately 24 minutes in moderate wind. The highest speed that we have clocked the UAV at was 24 meters per second, but we are limited by the size of our test field and believe it can fly significantly faster. The UAV accelerates at roughly 2.5 meters per second squared.

4.1 Power Profile

The energy consumption of quadcopters depends on the design and the speed [3], which can be approximated as a third-order polynomial [4]:

$$\mathcal{P}_a(v) = c_3 v^3 + c_2 v^2 + c_1 v + c_0.$$

We flew the UAV at various constant speeds (ranging from 5 m/s to 25 m/s) several times, recording the power draw at each speed. Figure 2 shows the results of these experiments. We experimentally derived $c_3 = 0.0262$, $c_2 = 0.597$, $c_1 = -12.3$, and $c_0 = 349$, using a least-squares 3rd-degree polynomial fit on the data collected from the power draw tests.

4.2 Demonstration

For this demonstration, we will display one of our ROARQuads and play recordings of it in flight. A short demonstration video is also available online[6]. Due to safety considerations, the drone will not be flown live.

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[6]https://youtu.be/GYE9v-H6Too