Voxelcopter: Modular Autonomous Aerial Systems

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ABSTRACT

Different unmanned aerial system (UAS) applications, such as military reconnaissance, environmental monitoring, or commercial delivery, require different specifications such as payload weight and travel range, which typically require completely different designs. This means that it is difficult, if not impossible, to easily reconfigure an existing UAS for a new application without the redesign and reconstruction of the system. To facilitate easy reconfiguration of UAS, we present Voxelcopter, a modular construction kit for the rapid-prototyping and rapid assembly of multicopter UAS. We develop basic viable components for flight, including reconfigurable building blocks, termed functional voxels, that assemble into high-stiffness, lightweight structures with integrated power and data, a custom flight controller software library, propellers, and power storage. In this demo, a quadcopter is assembled, and we flight test the resulting vehicle, then disassemble it into components ready for reuse, demonstrating the easy reconfigurability of the system.

CCS CONCEPTS

• **Hardware → Electromechanical systems**.

KEYWORDS

UAS applications, modular robotics, assembly, rapid-prototyping

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1 INTRODUCTION

As of 2023, over 871,000 drones were registered in the United States alone, with over 307,000 certified Remote Pilots [FAA 2023]. The use of UAS will continue to grow, from commercial uses as large companies develop package delivery and manned air taxi services to military applications where UAS provide key situational awareness data [Gupta et al. 2013]. Today, traditional engineering design processes generate complete, single body systems to meet specifications such as payload weight, dimensions, flight time, speed, and more. However, if system requirements change, for example, as a response to changing environments or applications, users must either make compromises to system performance or invest in a new vehicle and design cycle, which is both costly and time intensive.

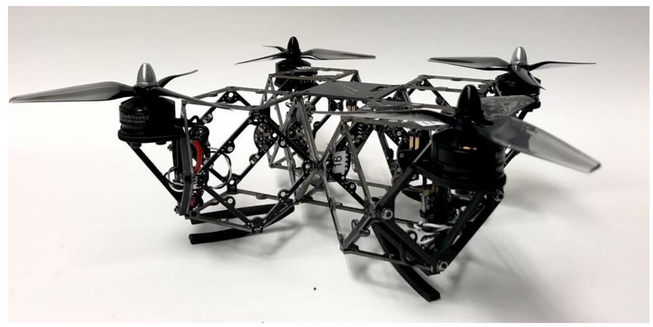

Figure 1: Complete UAS assembled using five voxels

The digital fabrication of drones has been explored by the hobbyist unmanned aerial vehicle (UAV) community. For example, the maker community has used 3D printing to fabricate light frames, such as in [Olejnik 2018]. Leveraging personal fabrication to develop UAVs increases the accessibility of UAS technology through sharing open-source, repliable designs with the broader community. However, 3D printing still involves long design and assembly times, requires new designs for new use cases, and only address the mechanical system. Further, most systems can only support small drones that can only support light payloads due to print material limitations, often supporting less than 100 g total, including its own frame [Olejnik 2018].

A mass-efficient approach to UAS design and construction is through the discrete assembly of lattice materials. [Cheung and Gershenfeld 2013] introduced discretely assembled lattices as a lightweight, high-stiffness building system. [Jenett et al. 2020] developed discrete additive manufacturing processes for the cheap mass-production of cuboctahedral unit cells, or voxels, that are robotically assembled [Jenett et al. 2019]. For a UAS application, the design of small unmanned aerial vehicles in which discrete components can be integrated with parametrically scaled and printed components enables mission-driven sizing, design, and synthesis [Mangum et al. 2015].

We expand the voxel system in [Jenett et al. 2020] to add electrical routing, building off the work in [Cameron et al. 2022], which used voxels with riveted joints to assemble into a 2.6 kg UAS. Our Voxelcopter is designed to be compatible with robotic, automated assembly presented in [Abdel-Rahman et al. 2022], adapting the functional voxel system in [Smith 2023] for aerospace application. Our approach achieves customized UAS assembly by (1) integrating power and data routing to voxels to remove complex and heavy wiring harnesses from UAS structures and (2) developing a library of

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lattice-compatible accessories including propellers, power storage, and a flight controller which draws power from and communicates using the voxel bus to perform real time monitoring and control of flight.

2 SYSTEM DESCRIPTION

The Voxelcopter, shown in Figure 1, has two main components: (1) lightweight, stiff functional voxels that route power and signal throughout the multi-copter frame and (2) a library of flight accessories. We use a cuboct unit cell which assemble into electromechanical voxels. The voxel faces, made from PCBs, route power, ground, and two communications lines. Connections between within a voxel are formed through orthogonal solder joints. Connections between voxels are formed by activating a resistive heating circuit to reflow aligned solder pads, attaching or detaching voxels. Voxels weigh 47 g with side length 65 mm.

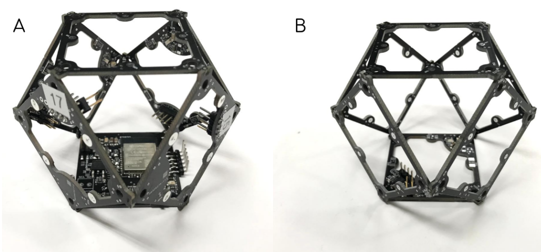

Figure 2: Primary controller voxel (a), Secondary voxel (b)

As shown in Figure 2, we develop two functional voxel types: (1) a primary controller voxel which sends commands and receives feedback throughout the UAS structure and (2) secondary voxels which control installed motors. The primary controller voxel is equipped with ESP32 and ATtiny412 microcontrollers. The ESP32 receives commands over WiFi, relaying commands to the other microcontrollers on the bus. The secondary controller voxel has one ATtiny412 microcontroller on board to control the propellers.

Once the voxel frame is assembled, which can be automated, users manually install BLDC motors, ESCs, propellers, an IMU, and landing feet to complete the UAS. A custom flight control software library runs on the ESP32, which stabilizes the Voxelcopter's position along the pitch and roll axis. Users control throttle and motor state through a web hosted GUI. We additionally develop a 3D printed tabletop testbed to tune the flight controller.

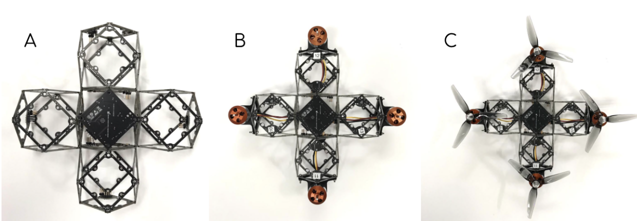

Figure 3: Assembly sequence of Voxelcopter: attach secondary voxels to four faces of primary voxel (a), install motors (b), install propellers, power unit, and IMU (c)

3 DEMO REQUIREMENTS

This demo will showcase a Voxelcopter quadcopter controlled by a GUI, demonstrating modularity and in-flight performance with a video. The video will additionally illustrate the easy assembly and disassembly of voxels, as in Figure 3. User interaction is enabled by inputting throttle and motor state in a web-based application, showing real-time communication with the multi-copter as the flight vehicle ascends, stabilizes, and descends according to user defined parameters.

4 CONCLUSIONS

This demo shows the discrete, modular construction of a small UAS, and develops accessories including power storage, motors, and controllers to add functionality to the electromechanical lattice. The objective of the prototype system is to achieve in-flight performance requirements, at a faster fabrication time than current 3D printing approaches. Further, our system does not require continued access to rapid prototyping tools to reconfigure the system to new applications, once the initial modules are made. After flight, the system can be disassembled into original unit cells and modular accessories and re-used repeatedly to build new systems with different geometries. A discrete, modular approach to UAS further additionally challenges the paradigm of completely defined, single body solutions in aerospace applications. The ability of this system to scale without compromising functionality or requiring large machinery for construction offers the potential for on-demand increase and reduction in capacity.

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