

Developing an autonomously-capable UAV compatible with high-efficiency charging base stations

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Introduction

Unmanned aerial vehicles (UAVs) have become essential tools across industrial, public safety, military, and consumer applications due to their rapid deployment capabilities, high mobility, and operational flexibility. However, most commercially available autonomous drone systems remain expensive, proprietary, and difficult to adapt to specific use cases. These constraints limit accessibility, particularly for small-scale or research-driven applications. In addition, precision-dependent tasks such as autonomous landing and recharging often rely on high-cost positioning systems such as RTK-GPS, further increasing system complexity and cost.

Although open-source flight control platforms (Aliane, 2024) and consumer single-board computers (Ebeid et al., 2018) have reduced entry barriers, fully integrated autonomous UAV architectures remain limited. In particular, end-to-end autonomy requires more than flight control alone; it depends on coordinated integration between onboard systems, mission planning, and external infrastructure such as docking and charging stations.

This project addresses these limitations by designing and implementing an autonomous UAV system based on three core principles: affordability, compatibility with autonomous charging base stations, and modularity to support diverse operational applications.

Methods and Materials

The autonomous UAV system was developed using a modular hardware and software architecture to minimize prototyping costs while enabling future scalability. Development was organized into three primary phases: airframe and propulsion, flight control and onboard computing, and charging station integration.

During the airframe and propulsion phase, a quadcopter configuration was selected for its simplicity and widespread support. The frame consisted of a carbon fiber body with custom components designed in Autodesk Fusion and 3D printed using a Bambu Lab A1 with PLA-CF filament. Brushless motors and electronic speed controllers were chosen to provide stable lift and ensure compatibility with a 4-cell lithium polymer battery.

Methods and Materials (continued)



Figure 1 (above): Final prototype UAV.

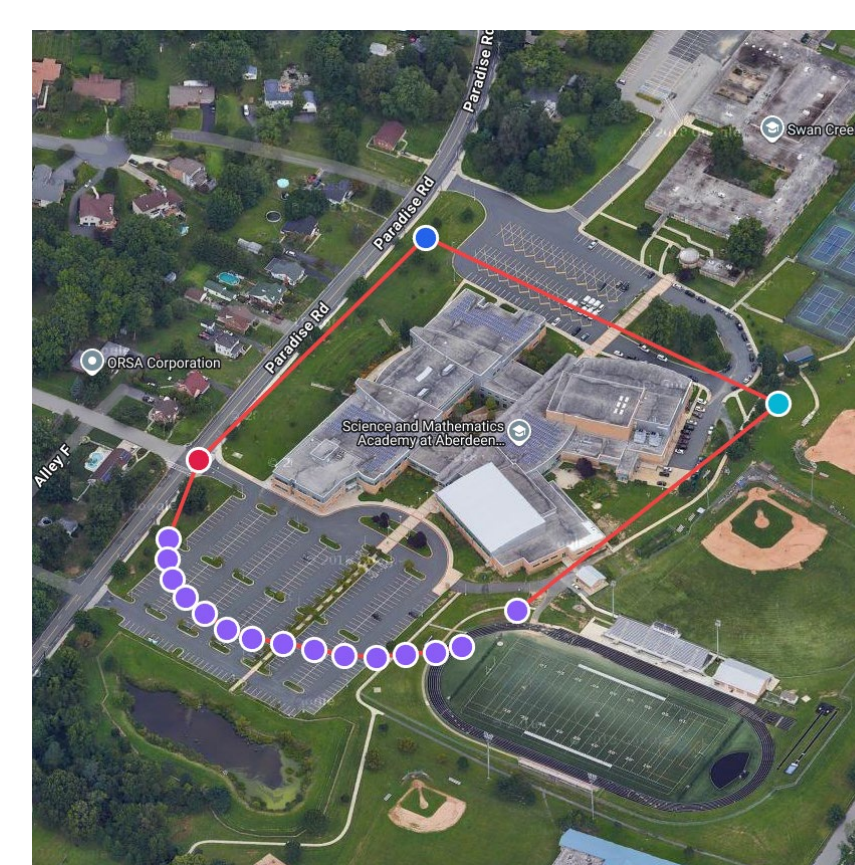


Figure 2 (left): Screenshot from the mission planning Flask web app.

Construction of the UAV (Figure 1) completed with the addition of a 360° obstacle avoidance LiDAR and a downward-facing LiDAR rangefinder. The flight control system was built around a SpeedyBee F405 running the ArduCopter autopilot, responsible for PID-based stabilization and low-level maneuvering. High-level control was handled by a Raspberry Pi 5 running a custom modular Python framework, which includes a set of Flask-based web applications for user interaction (Figure 2). A cellular modem was integrated, enabling long-range command and control.

For charging station integration (Figure 3), electrified landing legs incorporated copper contacts to establish reliable electrical connection with the base station. An onboard Python script utilizes AprilTag positional markers (Figure 4) and a Skydroid C12 camera to achieve sub-10 cm landing accuracy, ensuring consistent docking.

To meet the project's versatility goal, multiple industry-focused autonomous applications were developed using the same modular Python framework. For instance, an autonomous search-and-rescue pipeline was implemented with YOLOv8 object detection. Additionally, a photogrammetry mapping system utilizes established modular capabilities to support commercial needs.

Figure 3 (right): Aircraft landed atop its compatible charging base station.

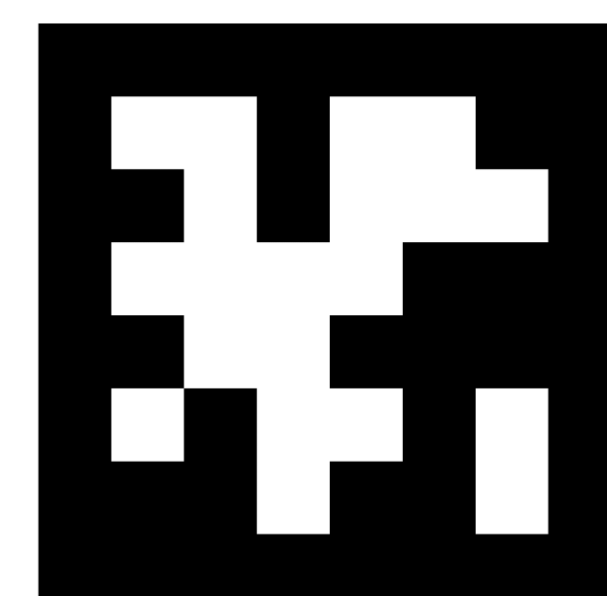
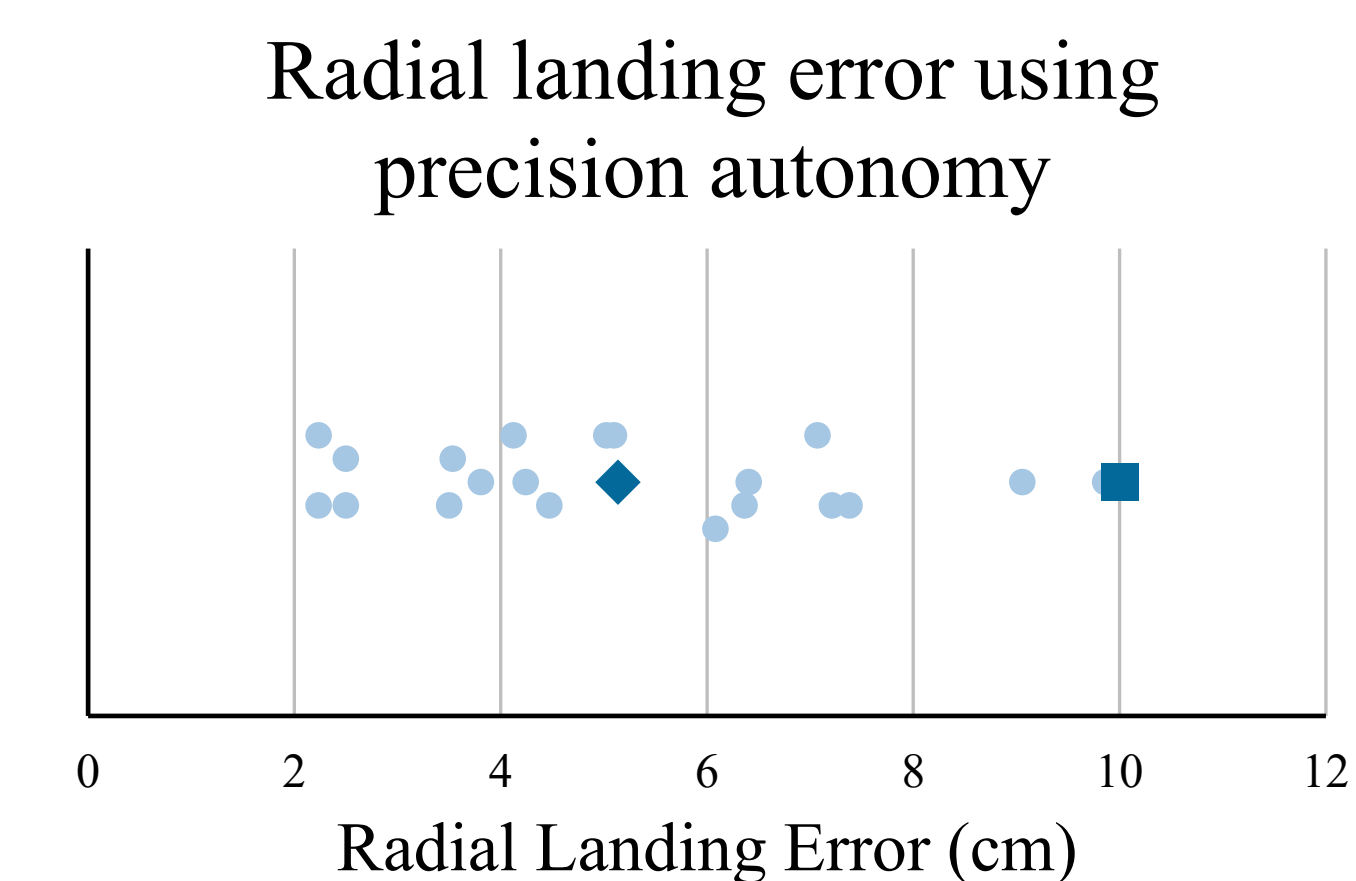
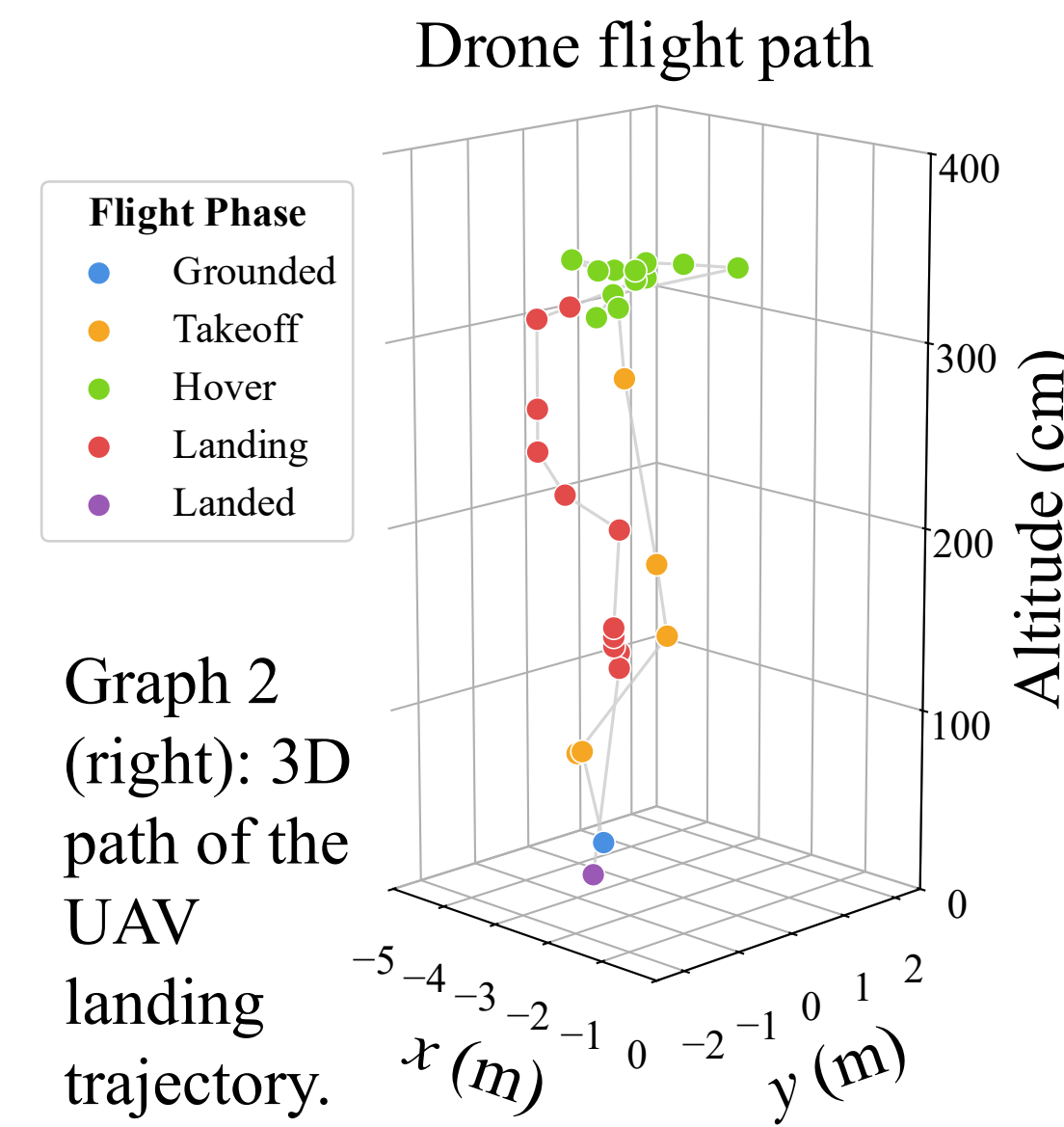


Figure 4 (left): AprilTag fiducial reference marker used for landing.

Results



Graph 1 (above): An individual value plot comparing mean radial error (diamond) to the hypothesized 10 cm maximum (square).



A one-sample t -test was conducted to evaluate whether landing accuracy (measured by comparing center point of UAV and landing zone) was significantly below the 10 cm hypothesized threshold. Across 20 landing trials (such as in Graph 2), the UAV achieved a mean radial error of $M = 5.1$ cm ($SD = 2.2$ cm). Results indicated error significantly below the threshold value, $t(19) = -9.74$, $p < .001$, 95% CI [4.3, 5.9].

Conclusion

This project successfully achieved its aim of developing a modular UAV platform capable of end-to-end autonomy for real-world applications. Autonomous mission software enabled complex operations with no human in the loop, validating a fully hands-off pipeline for applications such as search and rescue or delivery. Sustained independence, key to affordable autonomy, was confirmed through landing tests, eliminating the need for expensive RTK-GPS. The result of this project is a scalable platform for further research and addition of further autonomous capabilities using its modular framework.

References

- Aliane, N. (2024). A survey of open-source UAV autopilots. *Electronics*, 13(23), 4785. <https://doi.org/10.3390/electronics13234785>
- Ebeid, E., Skriver, M., Terkildsen, K. H., Jensen, K., & Schultz, U. P. (2018). A survey of open-source UAV flight controllers and flight simulators. *Microprocessors and Microsystems*, 61, 11–20. <https://doi.org/10.1016/j.micpro.2018.05.002>