

Introduction

Unmanned aerial vehicles (UAVs) are increasingly ubiquitous in applications such as inspection, surveillance, and environmental monitoring, but limited battery capacity restricts flight duration and operational range. Increasing battery capacity adds mass, which reduces flight efficiency and provides small gains in total flight time. As a result, extended autonomous deployment requires an external charging solution.

Commercial docking stations from manufacturers such as DJI address this issue but often cost upwards of \$10,000 due to their reliance on specialized infrastructure such as real-time kinematic GPS for precise landing. A computer vision algorithm using a low-cost webcam and positional markers called AprilTags can achieve similar precision without expensive GPS systems (Jiang, 2019). Many commercial docks use wireless power transfer, which reduces power efficiency, limiting compatibility with off-grid solar operation (Detka & Górecki, 2022).

This project aimed to design and test a low-cost autonomous docking station that uses a vision-based landing algorithm with AprilTags and a contact-based charging system to maximize power efficiency and enable off-grid solar operation.

Methods and Materials

The system consists of three primary components: the autonomous UAV, the vision-based landing algorithm, and the charging base.

The UAV was constructed using a SpeedyBee F405 V3 flight controller stack running ArduPilot firmware. A downward-facing LiDAR sensor was used to measure altitude during descent, and a downward-facing camera was used for AprilTag detection. AprilTags (Figure 2), which function similarly to QR codes, were used as visual reference markers capable of providing six-degree-of-freedom positional and orientation info.

Figure 1 (below): Real-time AprilTag detection interface displaying computed pose information. Picture taken from onboard camera.

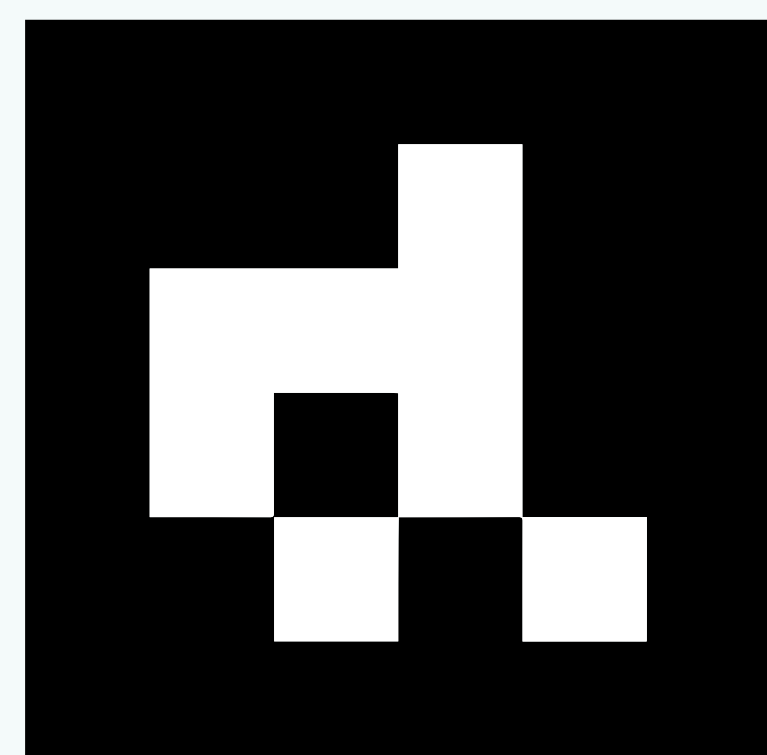
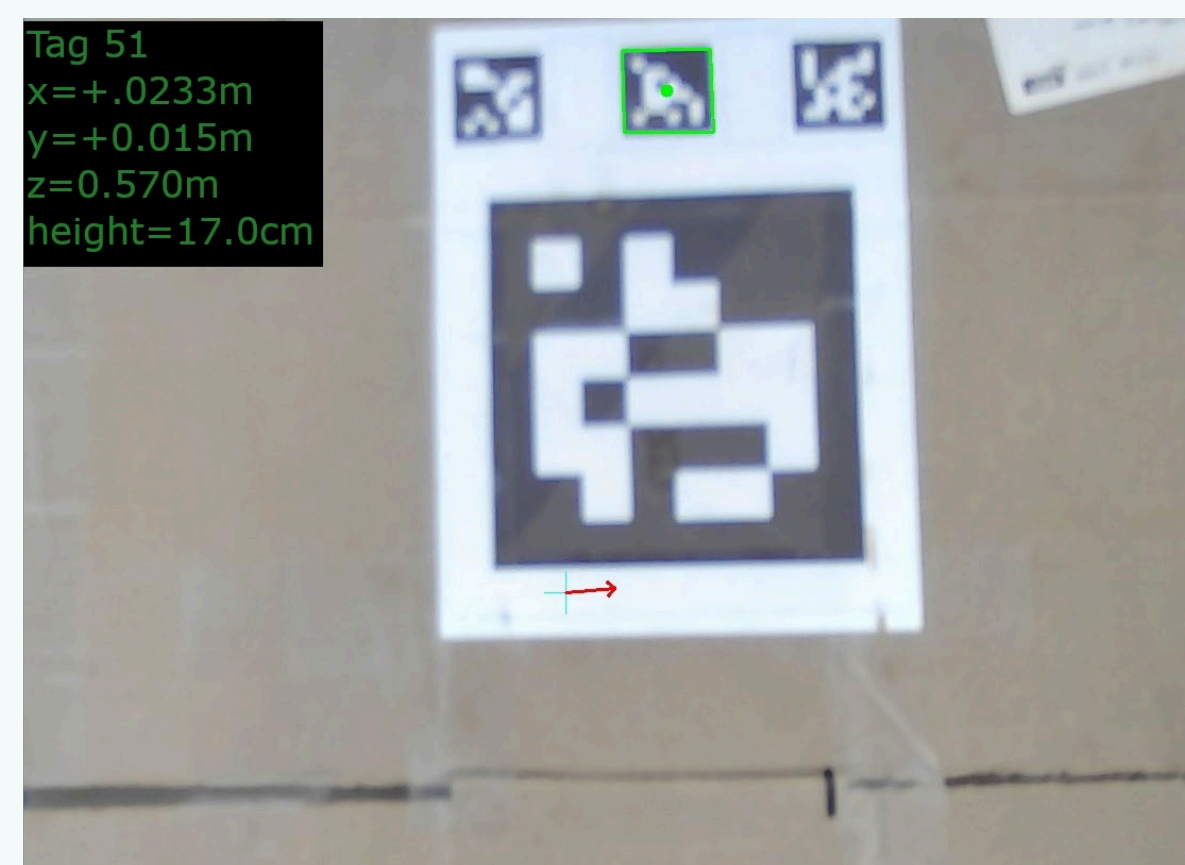


Figure 2 (above): AprilTag marker used for visual pose estimation. The pattern allows for 6-DoF pose information.

Methods and Materials (continued)

A custom detection algorithm identified AprilTags, computing their real-time pose relative to the camera. Horizontal offsets (x, y) were transmitted to the flight controller. ArduPilot's precision landing algorithm used this data to make lateral corrections. Altitude was regulated via LiDAR, while a Kalman filter fused successive pose estimates to improve stability during final descent. Detected position and orientation data were displayed during testing (Figure 1).

To support reliable precision landing, the base station used a 15-tag AprilTag array (Figure 4). Eleven tags were positioned around the perimeter for long-range detection, while four inner tags provided close-range precision tracking. The base was framed using 2×3 SPF lumber and plywood, with 2×6 supports reinforcing the landing area. A $220 \text{ mm} \times 381 \text{ mm}$ central opening provided payload clearance.

In addition to structural support, the base incorporated a contact-based charging interface consisting of four contact assemblies. Each assembly used three spring-loaded pogo pins soldered to a copper plate. Upon touchdown, copper plates on the landing legs depressed these pins to establish electrical contact with a programmable charger (ISDT CM1620). 3D-printed guide cones provided approximately 10 cm of lateral tolerance (Figure 3), while hollow carbon-fiber legs allowed internal wire routing. A magnetic LED light bar illuminated the inner AprilTags for reliable nighttime detection.

After assembly, the system reliability was tested by initiating autonomous takeoff and then immediately executing a vision-based precision landing. Any landing within 10 cm was successful.



Figure 3 (left): CAD rendering of the UAV and charging base assembly. The funnel-guided docking system provides 10 cm of tolerance. The base measures 27.5 in. \times 29 in. \times 10.5 in.

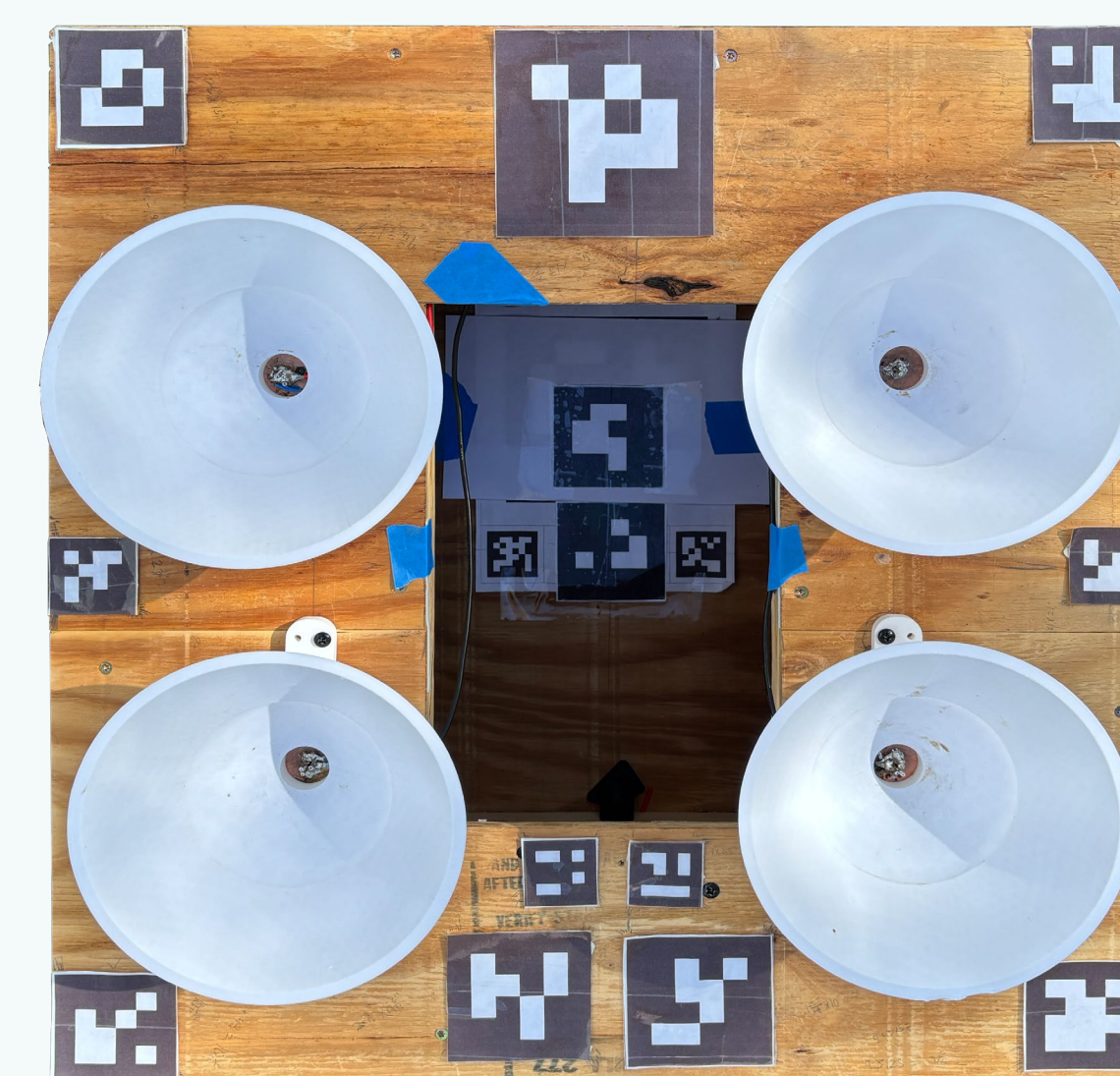


Figure 4 (right): AprilTag configuration on the charging base. Eleven perimeter tags enable long-range acquisition, while four inner tags maintain tracking during close-range descent.

Results

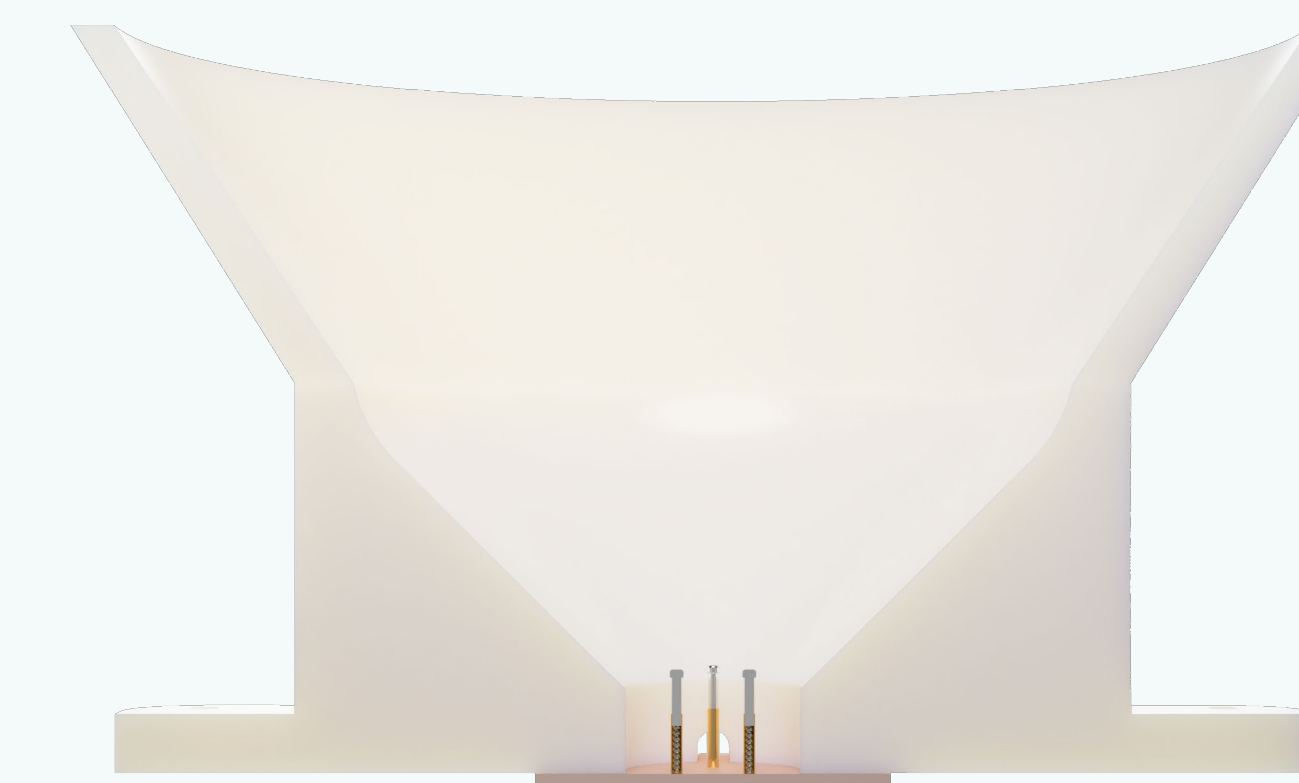


Figure 5 (left): Cross sectional view of funnel-guided docking system and pogo pins. The springs in the pogo pins kept constant pressure upwards which preserved continuity throughout the charging cycle.

The system was evaluated using autonomous land-charge-takeoff cycles, defined as landing, fully charging, and taking off without human intervention. Using the precision landing algorithm, the UAV successfully aligned and landed on the charging base in all 20 test trials, resulting in a 100% success rate. The funnel-guided docking system (Figure 5) mechanically corrected minor pose error during descent, ensuring reliable contact with the spring-loaded pogo pins. The contact-based charging system charged a 4-cell LiPo battery from 3.5 V to 4.2 V per cell in an average of 12 minutes.

Conclusion

This project developed and validated a low-cost autonomous drone docking and charging system. The total cost of the landing system was under \$600, a significant reduction in cost when compared to modern commercial docking solutions. The vision-based landing algorithm yielded a 100% success rate. This level of reliability is crucial for autonomy since inconsistent performance undermines the purpose of removing human intervention in the first place. The contact-based charging interface recharged the 4-cell battery in 12 minutes, significantly faster than the approximately 37 minutes that is required for typical commercial docks using wireless power transfer. In addition to the reduction of charging time, the contact-based system also minimized power loss, making the platform more suitable for off-grid operation. Further work could focus on expanding the system to support coordinated swarm operation and optimize uptime.

References

- Detka, K., & Górecki, K. (2022). Wireless power transfer—A review. *Energies*, 15(19), 7236. <https://doi.org/10.3390/en15197236>
- Jiang, Z. (2019). An autonomous landing and charging system for drones (Master's thesis). *Massachusetts Institute of Technology*. <https://dspace.mit.edu/handle/1721.1/123029>