Design, Modeling, and Control of a Flying-Insect-Inspired Quadrotor with Rotatable Arms

Jin Hu, Hao Xiong, and Xiumin Diao

School of Engineering Technology

Purdue University, West Lafayette, IN

Background

Quadrotors have become very popular in aerial manipulation and delivery, but they have experienced a common technical issue: the center of gravity (CoG) is usually offset from the symmetric center of the quadrotor due to the eccentric payloads carried. When the CoG of a conventional quadrotor with fixed arms (QFA) is offset from its symmetric center, the QFA suffers from two issues:

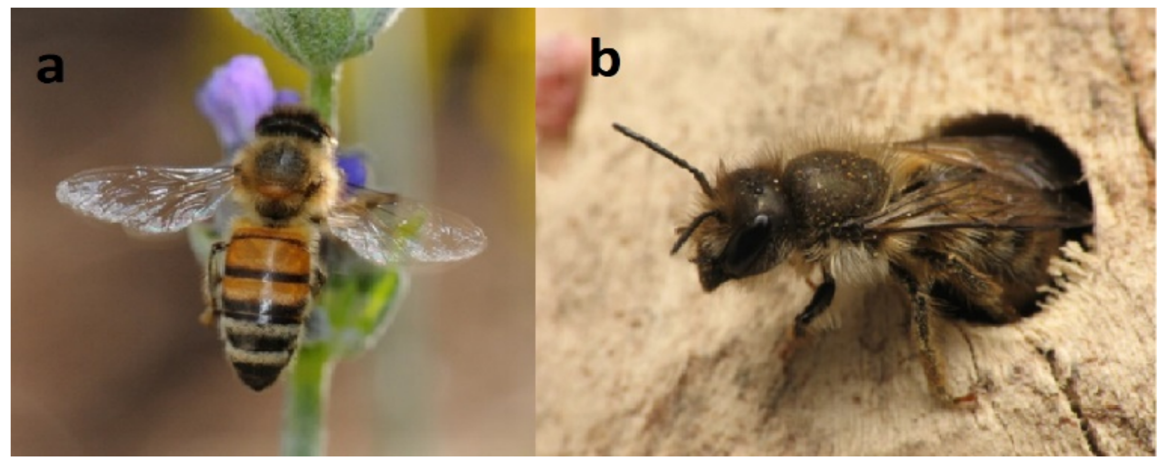
- Decreased stability
- Increased power consumption

Aerial manipulation

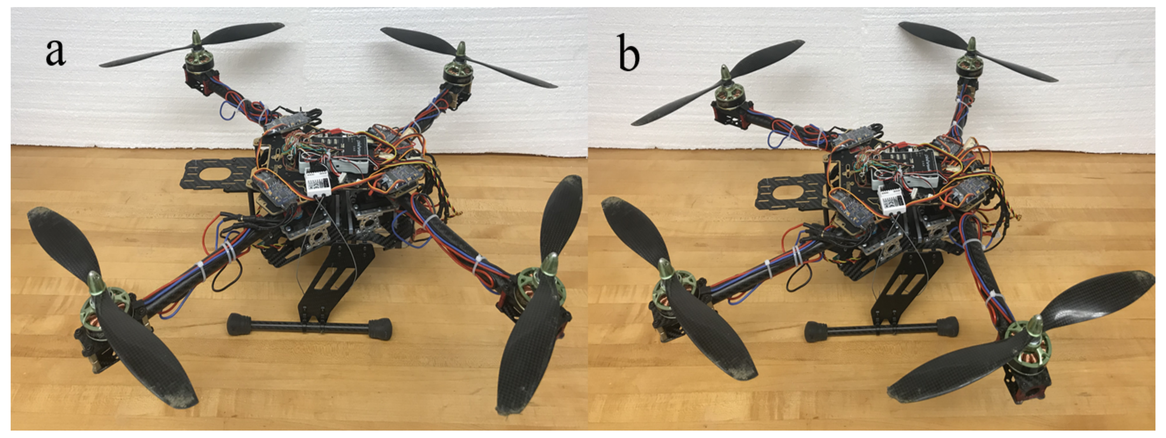
Aerial delivery

Objectives

Inspired by flying insects (e.g., bees) that expand their wings when flying and hide them when crawling, a quadrotor with rotatable arms (QRA) is proposed. By rotating arms, a QRA can move its symmetric center to its CoG while still keeping all rotor thrusts the same during flight. In this way, the stability and energy efficiency of the QRA can be improved in hovering or low-speed translation, compared to a QFA with the same arms, weight, rotors, and eccentric payloads.

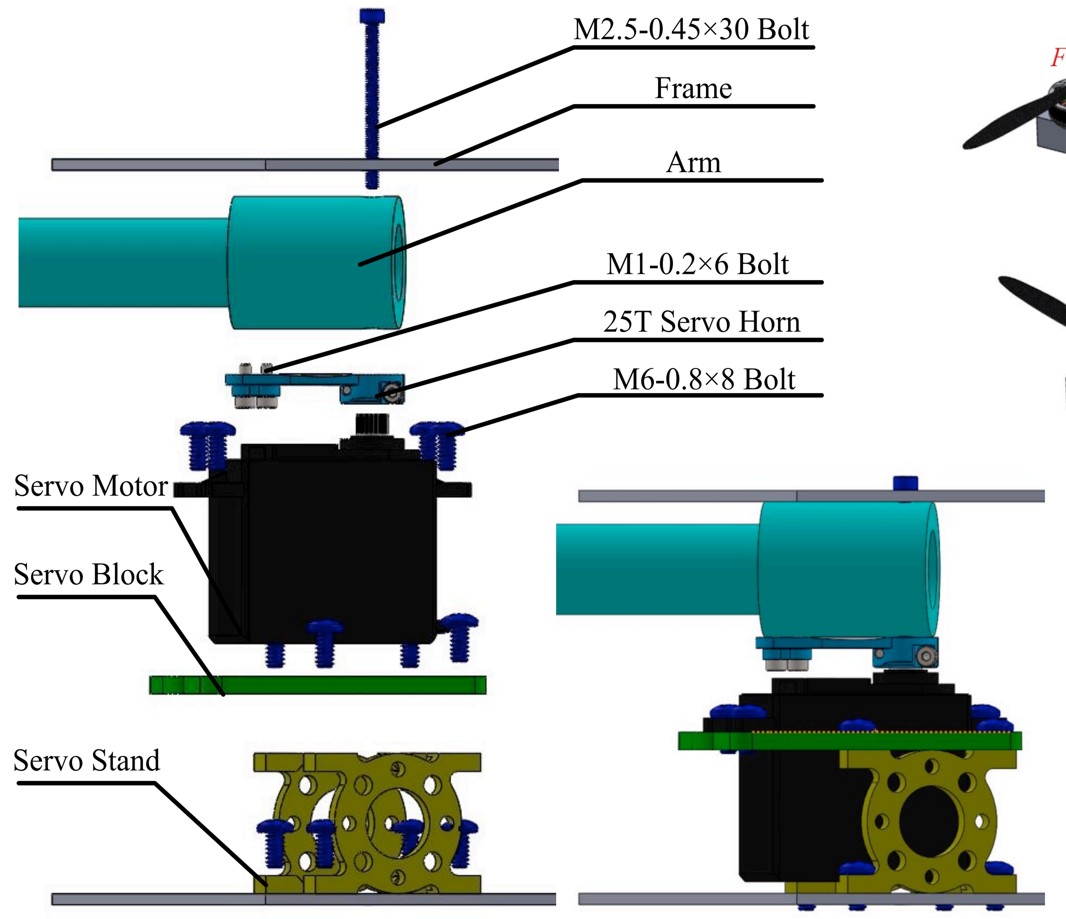


A bee with (a) expanded wings and (b) folded wings

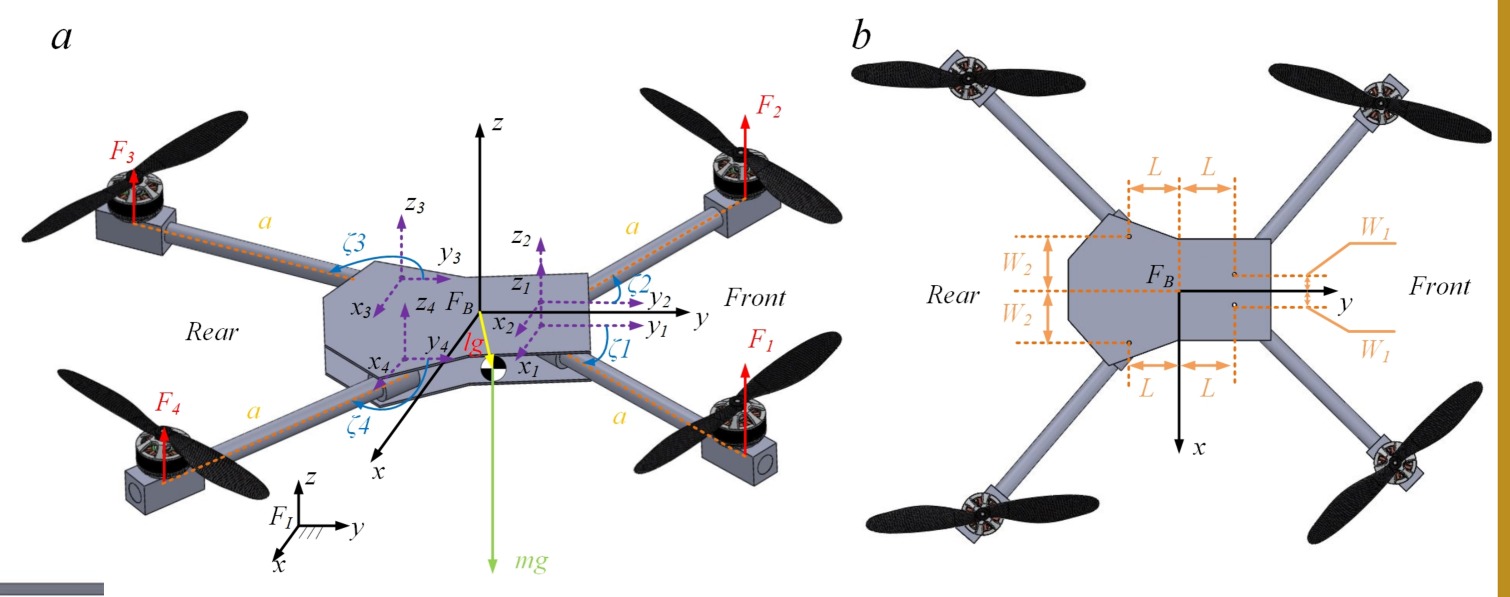


(a) A QRA prototype; and (b) Arms of the QRA are rotatable

Prototype Design and Dynamics Modeling



Exploded view of the arm-driving mechanism

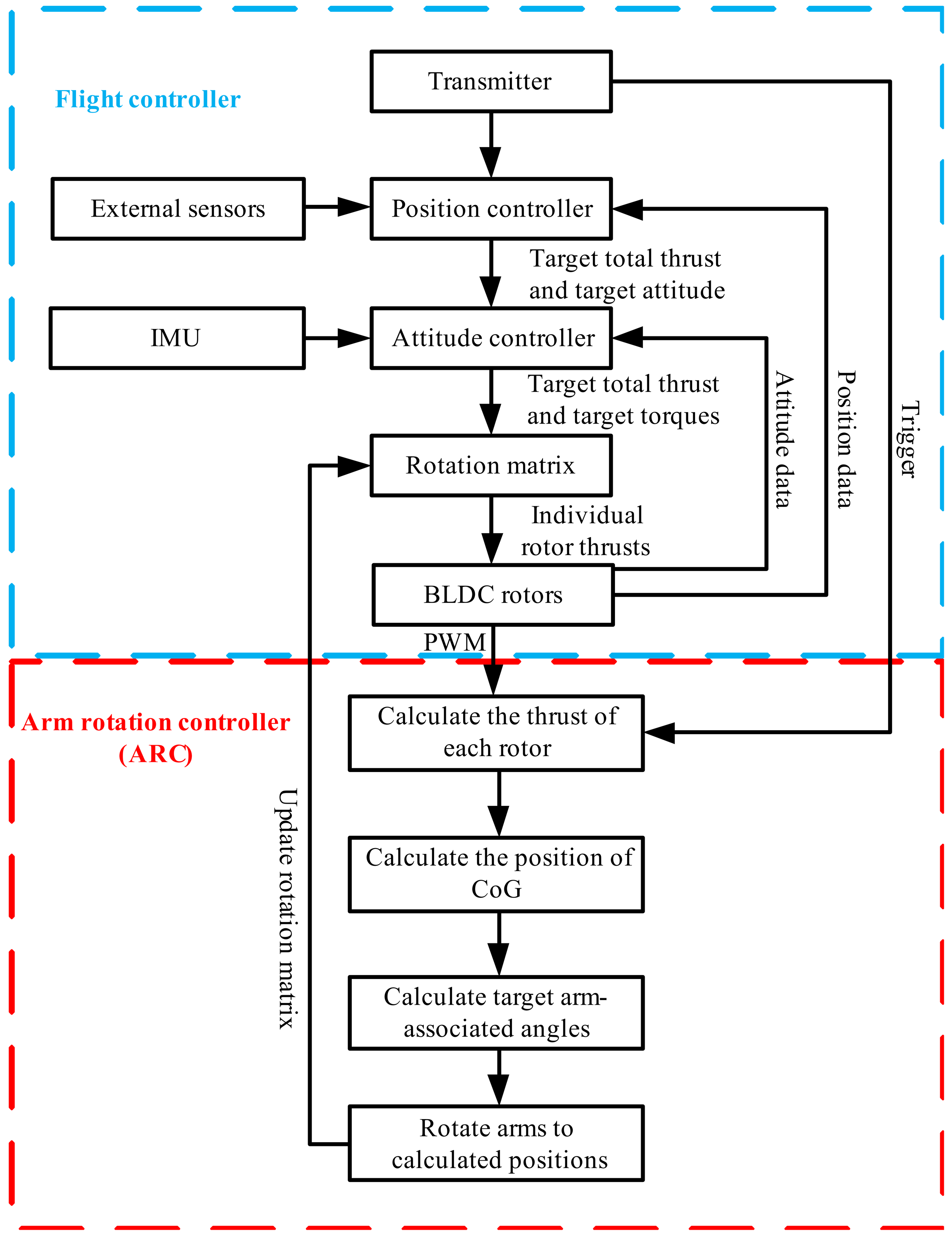


Dynamics notations of a quadrotor: (a) side view; and (b) top view

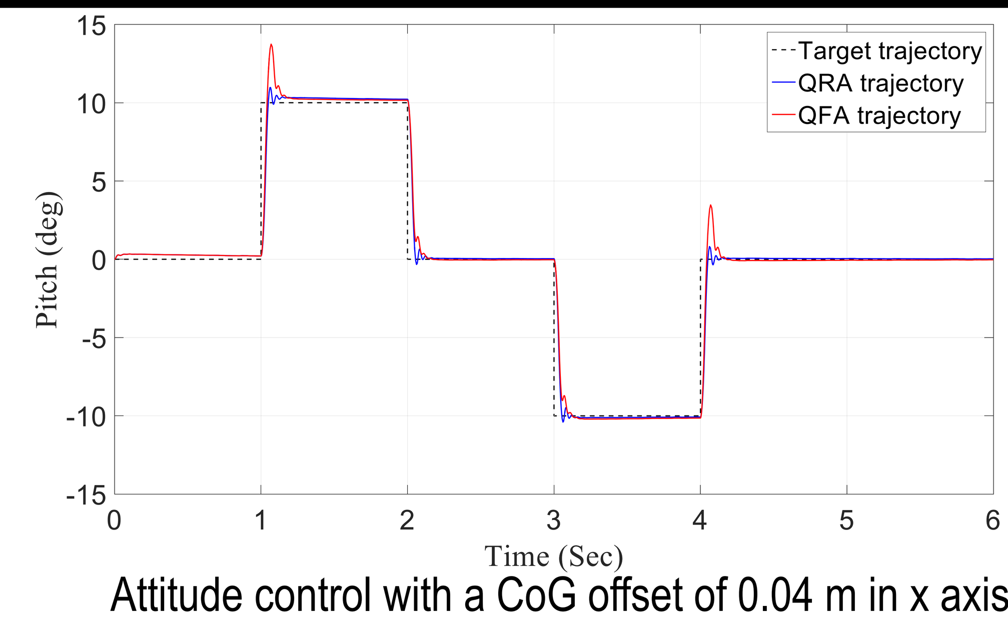
The position of a quadrotor's CoG in the body-fixed frame F_B:

$$\begin{cases} l_x = \frac{1}{mg}\left[a\sum_{i=1}^{4} sin\zeta_i F_i + W_1\sum_{i=1}^{2}(-1)^i F_i - W_2\sum_{i=3}^{4}(-1)^i F_i\right] \\ l_y = -\frac{1}{mg}\left[a\sum_{i=1}^{4} cos\zeta_i F_i + L\sum_{i=1}^{2} F_i - L\sum_{i=3}^{4} F_i\right] \end{cases}$$

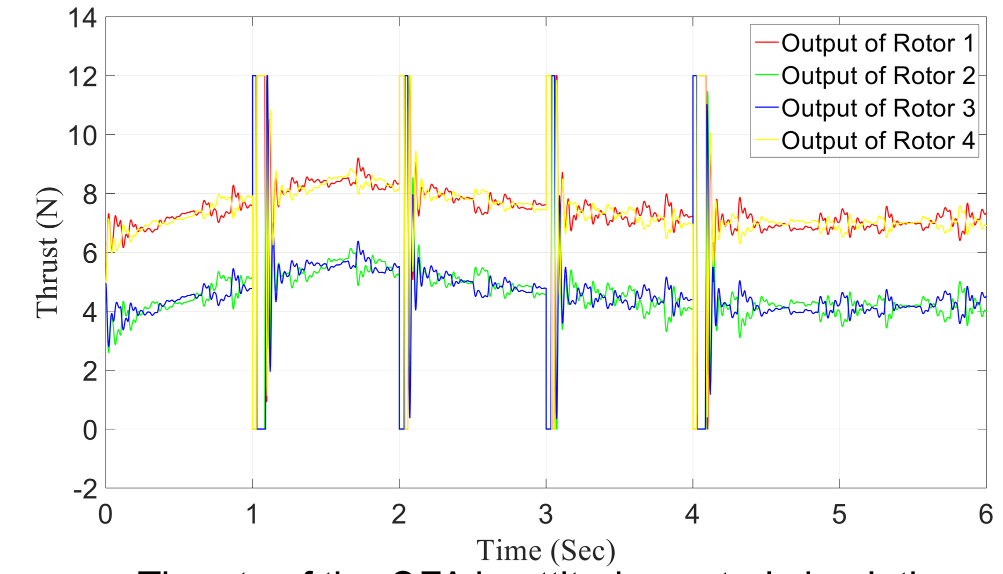
Control Diagram and Simulation Results



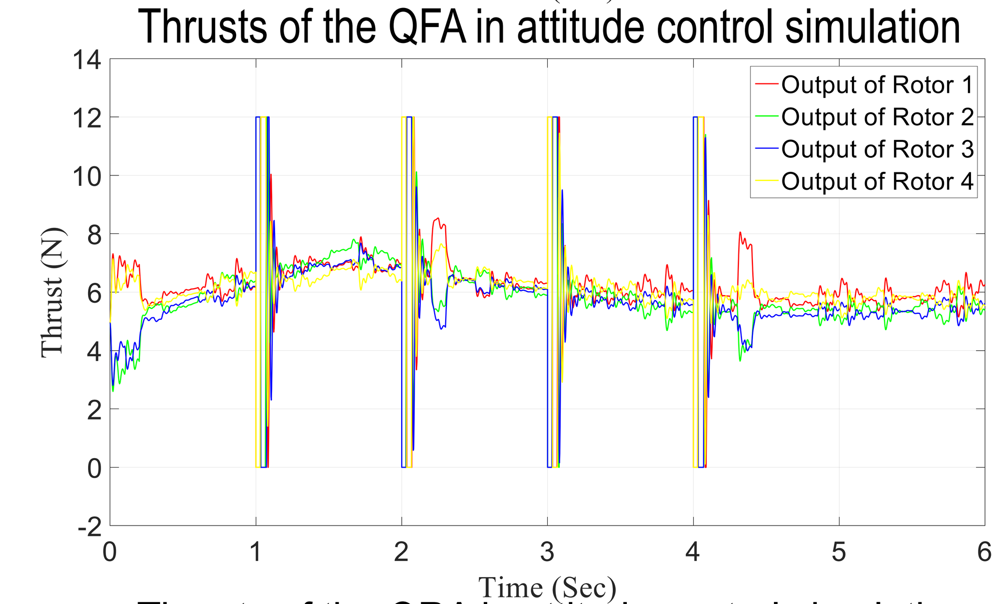
Control Diagram of a QRA



Attitude control with a CoG offset of 0.04 m in x axis

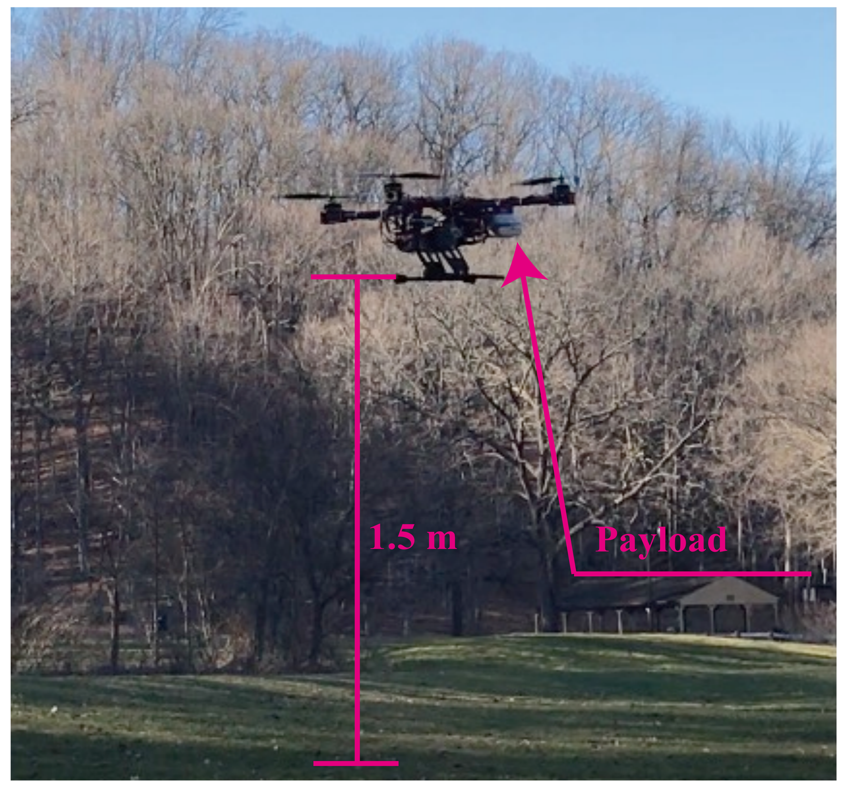


Thrusts of the QFA in attitude control simulation

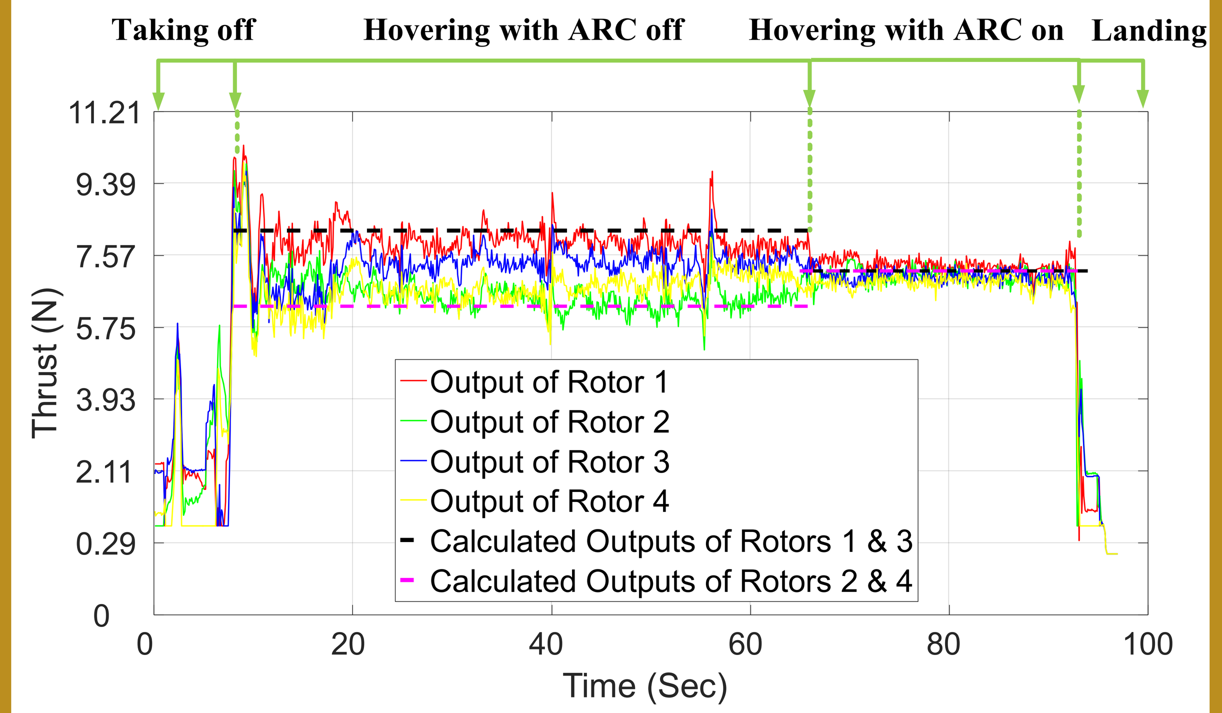


Thrusts of the QRA in attitude control simulation

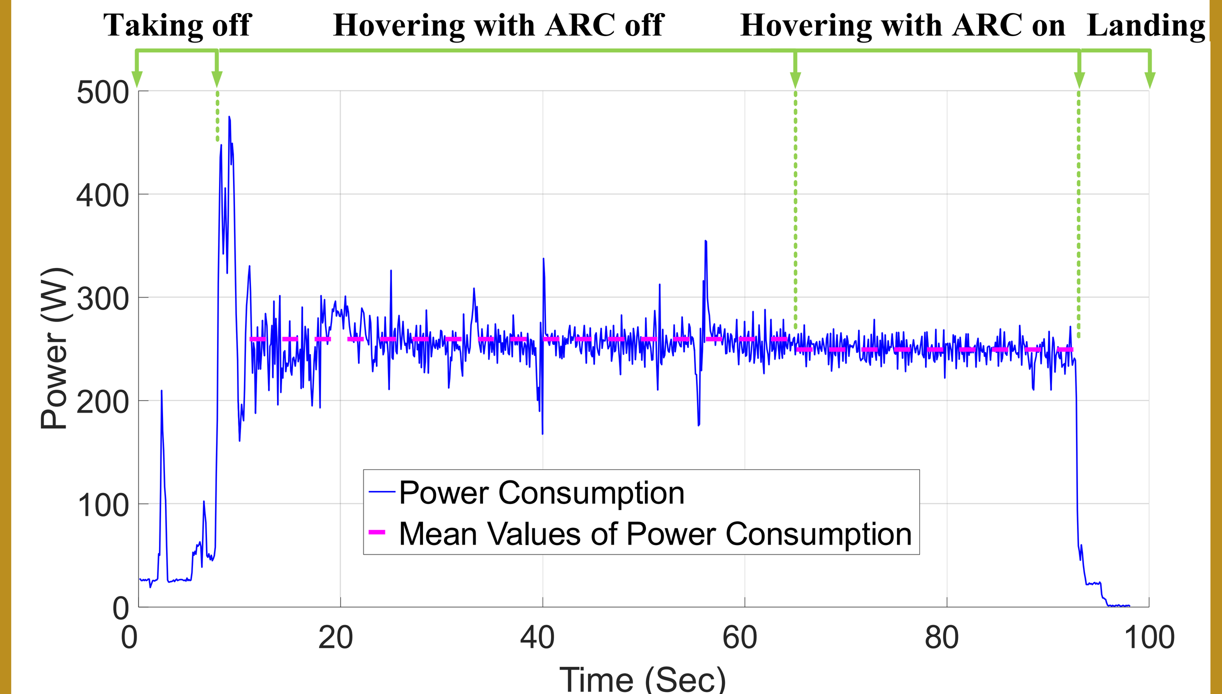
Experiments and Validation



Field experiments



Thrusts of the QRA when hovering with a CoG offset of 0.04 m in x axis



Power consumption of the QRA when hovering with a CoG offset of 0.04 m in x axis

Conclusion

- The proposed QRA can automatically compensate its CoG offset by rotating arms.
- Flying performances on stability and energy efficiency of the QRA are improved, compared to a QFA with the same arms, weight, rotors, and eccentric payloads.