Quadcopter Dynamics and Power Limitation

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For the Gold Team's senior design project, a quadcopter is being used to inspect GPS-denied areas on bridges for defects, requiring a precise and comprehensive flight-control algorithm whose development is facilitated by the team's research. By explaining the fundamentals of an individual rotor, our research develops an understanding of the dynamics of a multi-rotor system—specifically, a quadcopter.

Introduction

The term quadcopter, or quadrotor, refers to a member of the rotorcraft family which is comprised of four, symmetrically-spaced rotors, usually in a rectangular layout, around a central control unit that allows for power to be supplied to the rotors as well as providing a physical mechanism to facilitate take-off and landing. Today, quadcopters are primarily used as unmanned aerial vehicles (UAVs or drones) to assist in tasks which are tedious, dangerous, or otherwise expensive for humans to perform, such as surveying, search-and-rescue, and payload delivery. Quadcopter designers now also have their pick from an assortment of additional functional components such as high-definition cameras, various sensors, and Wi-Fi networks to equip their machines with.

The first quadcopter, called Gyroplane No. 1, was built in 1907 by Louis and Jacques Breguet with Professor Charles Richet; it required humans to be situated at the end of each of the four arms supporting the rotors to keep it steady. Gyroplane No. 1 was the first device to lift itself vertically off the ground using a rotating-wing system of lift (Pacheco, 2015). In the 1990s, robotics enthusiasts started resurrecting the quadcopter model for its numerous advantages: maneuverability, simple rotor dynamics, reduced gyroscopic effects, and capability of load increase (Pacheco, 2015).

An example of a typical modern drone is one that houses a high-definition camera which can record up to 30 frames per second supporting real-time frame transmission between the control station and on-board processor. For the Gold Team's senior design, a drone of this kind is used to develop a bridge inspection UAV to inspect GPS-denied areas on bridges for defects. The team's research provides a necessary understanding of the dynamics and power limitation of quadcopters in order to develop an effective fight control algorithm for very tight spaces.

Quadcopter Dynamics

In order to understand the three-dimensional flight of a quadcopter, it is first helpful to understand the three main types of movement a quadcopter may perform—roll, yaw, and pitch. Each of these motions corresponds to a different axis on the quadcopter (Figure 1).

The roll motion is about the axis running down the center of the quadcopter and is characterized by one side of the quadcopter rising or falling and the other side doing the opposite. The pitch motion is about the axis perpendicular to the roll axis—that is, the line from the middle of the left side of the quadcopter to the middle of the right side. This motion is characterized

Figure 1. The Gold Team's Quadcopter Prototype

by, similar to the roll motion, either the top half of the quadcopter rising or falling and the other side doing the opposite motion. Finally, yaw refers to the motion about the axis perpendicular to the roll axis, or the axis coming from the bottom and going up through the center of the quadcopter. This motion is similar to that of one's car when turning. It is characterized by the nose of the quadcopter swinging to the left or to the right. By adjusting the angular velocities of each of the four rotors of a quadcopter, one can achieve these three basic movements (Beginner's Guide to Aeronautics, n.d.).

For quadcopters that include a camera, such as the quadcopter used by the Gold Team, computer vision techniques can be used to enhance flight. One specific technique that the Gold Team explored was using template tracking algorithms in order to look out for potential collisions during flight. Template tracking works by scanning the individual pixels of two images and then comparing them in order to determine a match [see related Tech Note by Gold Team member Posholi Nyamane].

Power Limitation

Although the field of UAV technology is expanding rapidly, there are important limitations that have brought innovation to a slowed pace. One of these, perhaps the most important, is power. Quadcopters and their various UAV counterparts derive large quantities of power thus requiring large batteries than can still only sustain, in some cases, eight to ten minutes of continuous flight. This makes modern quadcopter design a delicate balance of size, in-air time, and cost with each trade-off serving the needs of certain real-world quadcopter and general UAV applications.

As the usability and effectiveness of UAVs continues to be realized and proven in nearly all aspects of life, researchers along with industry professionals are faced with the challenge of mitigating these limitations which significantly slow down the progress of improving quadcopter performance. Researchers at Singapore Polytechnics have designed an autonomous battery swapping system that works to automatically refuel multicopter systems at the ground station so as to reduce the amount of down time within flights (Lee, 2015).

Conclusion

Quadcopter and other UAV technology is continuing to be explored and developed at a dramatic pace as potential applications continue to emerge at the same rate. Our research provides the Gold Team with the necessary working knowledge of the dynamics and power limitation of quadcopters in order to develop an effective fight control algorithm for very tight spaces. Improving quadcopter dynamics and mitigating limitations currently affecting flight will surely improve the overall effectiveness and expand the list of potential applications for quadcopters and UAVs.

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