Design and Flight Testing of an Autonomous Variable-Pitch Quadrotor

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Abstract— **This video submission presents a design concept of an autonomous variable-pitch quadrotor with constant motor speed. The main aim of this work is to increase the maneuverability of the quadrotor vehicle concept while largely maintaining its mechanical simplicity. This added maneuverability will allow autonomous agile maneuvers like inverted hover and flip. A custom in lab built quadrotor with onboard attitude stabilization is developed and tested in the ACL's (Aerospace Controls Laboratory) RAVEN (Real-time indoor Autonomous Vehicle test ENvironment). Initial flight results show that the quadrotor is capable of waypoint tracking and hovering both upright and inverted.**

I. INTRODUCTION

The importance of unmanned vehicles has been increasing and more agility is demanded from vehicles to satisfy constraints on navigation and operability. Missions such as surveillance in adverse environments and search-rescue missions can require the full maneuver capacity of the aircraft. Rotorcraft are especially preferred for these tasks due to their take/off, landing, and hovering capabilities.

Quadrotors are an especially appealing type of rotorcraft. In a traditional, fixed-pitch quadrotor, stability and flight control are achieved by changing the relative rpm of each of four fixed-pitch propellers. Quadrotors are widely used as experimental platforms due to their mechanical simplicity and inherent robustness. However, since fixed-pitch quadrotors are controlled purely by differential motor rpm, control bandwidth is limited by the rotational inertia of the motors. Also, fixed-pitch quadrotors are inherently unable to achieve reverse thrust. Control bandwidth limits the agile maneuvers a quadrotor can perform, therefore limiting the future applicability of quadrotors in agile intensive missions. These limitations in fixed-pitch quadrotors are overcome with the addition of variable-pitch propellers. While variable-pitch propellers add complexity to a simple and robust quadrotor, the advantages of increased controller bandwidth and the addition of reverse thrust capabilities justify the design.

Controller bandwidth can be a significant problem for quadrotors. As noted by [5], controller bandwidth becomes an issue for quadrotor stability as the size of the quadrotor increases. Larger quadrotors require larger motors which, in turn, have larger inertias and cannot be controlled as quickly as smaller motors. Eventually, as the size increases enough, the quadrotor can no longer be stabilized through rpm control alone because the torque required to change the rotational velocity of the motor quickly exceeds the capacity of the motor. Thus, variable pitch blades may be necessary for larger quadrotors merely for stabilization purposes.

For small quadrotors (less than about 2 kg), however, motor inertias are small and significant control bandwidth can be achieved with fixed-pitch propellers. Fixed-pitch quadrotors have even demonstrated relatively aggressive maneuvers in [2]. However, traditional pod-and-boom autonomous helicopters are still much more agile than small fixed-pitch quadrotors as seen in [6] and [8]. The proposed variable-pitch quadrotor attempts to bridge the gap between simple, robust fixed-pitch quadrotors and aggressive, complicated, and fragile helicopters. The variable-pitch quadrotor presents a simple, yet agile platform for robust, aggressive maneuvering. The variable-pitch propellers yield a substantial increase in control bandwidth and thrust can be reversed almost instantaneously, greatly increasing the quadrotor's agile potential.

The concept of a variable-pitch quadrotor is not completely novel. The proposed HoverBot [7] used variable-pitch propellers to vary the thrust of each propeller. The HoverBot, however, never achieved flight beyond tethered hovering. Some large-scale rotorcraft such as Convertawing's Model A quadrotor in 1956 achieved flight with variable-pitch propellers. The proposed variable-pitch quadrotor, however, is the first documented small variable-pitch quadrotor to demonstrate autonomous stable upright and inverted hovering and waypoint tracking.

II. HARDWARE

The variable-pitch quadrotor uses four Futaba digital high-speed servos to control the pitch angle of the blade, each weighing less than 10 grams. Brushless motors are driven by Hacker electronic speed controllers that maintain a near constant RPM under varying load conditions. The combination of closed-loop RPM control and servo pitch actuation substantially reduces the vehicle's sensitivity to variations in motor parameters. Inertial measurement, filtering, and high-rate attitude stabilization is achieved using a 12 gram autopilot developed by Unmanned Innovation. The autopilot connects to a quadrotor specific breakout board which houses and xBee radio modem, power regulator, and connectors.

III. FLIGHT TESTING

Flight testing of the variable-pitch quadrotor is done at the ACL's RAVEN indoor testbed [1]. RAVEN utilizes Vicon Motion capture cameras to track reflective markers attached

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to each vehicle in real-time, providing the position and velocity information that outdoors would be measured by a GPS system.

Early flight test results have proven the feasibility of the variable-pitch concept. The vehicle performs comparably to standard fixed-pitch quadrotors in nominal waypoint tracking experiments. In another experiment, the quadrotor is inverted and resumes normal flight upside down, demonstrating the fundamental improvement in capability over current fixed-pitch vehicles. While the vehicle is still in the early stages of development, future experiments will seek to push the envelope of performance well beyond what is currently possible with fixed-pitch vehicles. Immediate next steps should demonstrate aggressive maneuvers such as tick-tocks and constant-altitude flips which are beyond the flight envelope of conventional quadrotors.

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