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ESTIMATION AND CONTROL OF A BIO-INSPIRED MORPHING AIRCRAFT

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ABSTRACT

An unmanned aerial vehicle has been developed with the ability to reconfigure its structure through morphing, to provide increased performance that will allow the aircraft to perform a bio-inspired perching maneuver similar to those performed by birds. Investigations into the accuracy and computational requirements of methods of estimation and control are needed to determine how various methods can be used for safe, reliable control of the aircraft. This paper discusses various estimation and control methods that could be used to allow the morphing aircraft to perform a desired maneuver. Simulations present some control examples of the aircraft following a set of trajectories, both for the nonlinear aircraft model and its linearized dynamics.

INTRODUCTION

New designs push forward the boundaries of aircraft capabilities and performance to enable new and more challenging maneuvers. Suitable control methods must be used with these improvements to allow the aircraft to operate safely and reliably over an expanded flight range. Advances in technology have allowed for unmanned aerial vehicles to be on a forefront of aviation research. New developments and capabilities are continuously being sought to increase the usefulness of these platforms.

The ability for an aircraft to identify suitable landing locations and land is a key task that supports autonomous operations. Many research programs have looked into the task of autonomous landing, both for fixed-wing and rotorcraft vehicles. The dynamics and characteristics of the various aircraft types affect the landing process. Fixed-wing aircraft traditionally use long, straight runways for take-off and landing. Research by Schell *et al.* [1] took advantage of these uniform, highly-structured environments to develop visual techniques for the autonomous landing of an aircraft. In a more recent work, Proctor *et al.* [2] used a visual approach to guide an aircraft toward the known, structured environment of a window that served as a landing target. Rotorcraft, such as helicopters, often use thrust to directly generate the lifting force required for flight. This ability allows the aircraft to move with slower velocities that can aid the landing process. Slowly approaching a landing site also allows for the more complex task of determining whether a selected area is suitable for landing. Garcia-Pardo *et al.* [3] evaluated the image contrast of potential landing zones to determine acceptable landing sites, while Saripalli *et al.* [4] applied a vision-based technique to identify, track, and land on a moving target. Vision is not the only sensor available for landing, although it is convenient and may be necessary. Positioning signals, such as those from the Global Positioning System (GPS), are commonly used to aid the navigation of aircraft. Coordinates of waypoints may be set to mark a path for an autonomous vehicle to follow. A critical assumption when using a satellite positioning system is that the signals are always clearly received in the area of operation. However, aircraft missions may take place in GPS-denied areas, or coordinates for a target may not exist with sufficient precision. Vision-based landing methods help to overcome this challenge, by providing the critical relative information used for aircraft navigation and landing. For instance, in Barber *et al.* [5] incorrect landing coordinates were given but the visual system was able to correct the error. The works mentioned above deal with fairly conventional aircraft of differing scales. However, unconventional aircraft, such as morphing aircraft, have the potential for more advanced landing techniques and will require more complicated navigation and control schemes.

One maneuver of particular interest is the perching maneuver, similar to that performed by birds. The ability to perform such a maneuver could enable an aircraft to land in locations often disallowed due to vehicle dynamics. The increased lift during the pitch-up phase preceding the perch landing allows the forward velocity to significantly decrease to enable the aircraft to perform short or planted landings, without powered-lift capabilities. Although simple for some living creatures, these types of motions are difficult, if not impossible, for conventional fixed-wing aircraft due to the aerodynamics interactions and airframe structures. In birds this maneuver is initiated and controlled through their natural morphology, such as wing flare and tail tucking. The inclusion of additional, non-standard control surfaces could enable an aircraft to morph its structure in order to perform similar maneuvers. These

