Nature, smart structures, and morphing UAVs

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ABSTRACT

Nature through careful observation and tests of gliding avian species have resulted in new thoughts on how to design morphing uninhabited air vehicles (UAV) and what morphing motions might make for better performance. An understanding of avian flight stability suggests a new approach to morphing aircraft design. Of interest is how to create these motions using smart materials to replicate avian abilities. Coupled with new learning algorithms, methods for designing smart autonomous morphing airfoils for use in small UAVs are presented. Hardware based reinforcement learning (RL) techniques are used to teach a smart morphing wing to respond to gusts, following the inspiration of gliding gulls who respond immediately and autonomously to unknown changes in flow to maintain stability and control in unpredictable environments. We strive to translate this knowledge to flight control of UAVs. Last, a way forward is suggested to create new class of structures: autonomous multifunctional structures. An outline of what is needed in terms of future research is presented.

Keywords: UAV, Morphing, adaptive structures

1. INTRODUCTION

The flight differences between quadrotors and winged UAVs are the distinctions between agility/maneuverability and endurance. Multirotor UAVs can fly through dense forests, urban canyons and even into and out of buildings. However, they lack endurance limiting them to short duration flights (missions). Winged UAVs have larger endurance but are not able to negotiate dense areas. Avian species handle both tasks by their incredible ability to morph into a variety of shapes depending on the demands of the current environment. The research presented here examines how winged UAVs could be morphed to accommodate a variety of missions through morphing by investigating the mechanics and aerodynamics of morphing UAVs, as summarized in the published papers listed in the reference section.

A great deal of attention over the last few decades has focused on various types of morphing across various scales and applications[1]. Avian literature has been examining the various geometric shapes that birds take according to their environment and the two fields of avian morphing and aircraft morphing began to merge with avian studies inspiring morphing designs, and morphing flights and wind tunnel tests influencing the interpretation of avian species' geometry and aerodynamics[2]. One area that remains underdeveloped is that of large motion morphing with articulated wings and tails with the goal of providing the ability to switch between highly agile/maneuverable configurations and long endurance[3]. Stability in particular plays a role as endurance tends to imply very stable configurations and agile/maneuverable flight requires nearly unstable configurations[4].

Summary of Results

The results presented here show clear indications of how avian species use the flexibility and articulation of their wings and tail to fly within a variety of flight environments. Agility is defined as the ability to rapidly change the rotational rates and maneuverability is broadly defined as the ability to change magnitude or direction of the velocity vector. Agility depends on the inertia tensor of the structure, which changes with geometry as well as the roll, pitch and yaw moments. Maneuverability depends on the ability to quickly change velocity (both speed and direction). Other often

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neglected aspects of agility and maneuverability in translating avian inspired ideas to UAVs is the speed of actuation and the computing time required to quickly respond[5,6].

The results presented here focus on avian results showing how

- Gulls have the ability to use their joints (shoulder, wrist and elbow) to trade between stable and highly maneuverable flight
- Dynamic stability of some gull wing configurations
- Multiple avian species use changes in their inertia tensor to switch between stable and unstable pitch

We will also examine the use of machine learning to carry out active control in the presence of gusts on a morphing wing through wind tunnel experiments. Specifically, this work uses reinforcement learning techniques to achieve gust alleviation without explicit state estimation. Sensing is accomplished by piezoelectric flex sensors whose data is mapped to an estimate of the wing deflection (state) using long short-term memory (LSTM) neural network. Control through macro fiber composites is implemented via reinforcement learning.

Several other groups have made excellent progress on translating avian motions to UAVs. Specifically, two efforts are briefly summarized. The work of TU Delft University[7] whose researchers built a combined smart material and conventional actuation system focused on camber changing. Their work represents a complete approach to morphing, actuation integration, sensor integration, software and data integration, and control system integration. Further, work at the Swiss Federal Institute of Technology Lausanne (EPFL) built a flying drone based on goshawk morphing and showed wind tunnel, flight test and analysis data that addresses how birds use tail and wing morphing to make fast, tight turns. The basic result was that morphing has the potential to produce very tight, fast turns by combining tail lift, asymmetric wing folding and asymmetric wing twisting. Their drone relies on conventional actuation mechanisms to perform morphing motions and does not employ smart materials.

The current work in bioinspired flight and several attempts to build UAVs that have morphing functions for improved flight performance, including flying in multiple mission profiles motivates the way forward. The main take away from examining avian flight and looking at the requirements of smaller UAVs to function in dense areas is that they would benefit from articulated wings, employing folding, sweep and camber changes motivated by avian elbows, wrists, and shoulder like joints.

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