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論文題目	Bio-inspired Propellers toward Safety Collision for Unmanned Aerial Vehicles
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論文の内容の要旨

There is an increasing demand for vertical take-off and landing vehicles, including drones, that are safe to use and can handle collisions. These vehicles face risks of damage from collisions with humans, environmental obstacles, and other drones. To address this issue, researchers have been looking to nature for examples of resilient structures that can be used to design propellers that reduce these risks and increase safety. My proposed solution is a bio-inspired drone propeller called the *Tombo* propeller, which is inspired by the flexibility and resilience of dragonfly wings. In this study, the design and fabrication process for the *Tombo* propeller is presented, which allows it to withstand collisions and recover quickly while still providing sufficient thrust to hover and fly. The performance characteristics of the propeller, such as thrust force, collision force, recovery time, lift-to-drag ratio, and noise, were also investigated through the development of an aerodynamic model and experiments. Additionally, a control strategy was designed for a drone equipped with *Tombo* propellers that could collide with an obstacle, recover from the collision, and continue flying. The results show that the maximum collision force generated by the *Tombo* propeller is less than two-thirds that of a traditional rigid propeller, indicating the potential for using deformable propellers on drones in cluttered environments. To enhance the collision sensing capabilities of the propeller, a novel hub was also introduced, with details on its design, fabrication, force modeling, and preliminary experiments with potential results. This research has the potential to inform the design of flying vehicles for agile and resilient performance.

Keywords: Bio-inspired design, Collision accommodation and sensing, Deformable propeller, Soft robotics, Drones' safety

論文審査の結果の要旨

Animals have evolved their body shapes, locomotion gait, or interaction method with the surroundings to ultimately adapt to the living environment. Meanwhile, there is an increasing demand for vertical take-off and landing vehicles, including drones, that are safe to use and can handle collisions. These vehicles face risks of damage from collisions with humans, environmental obstacles, and other drones. To address this issue, researchers have been looking to nature for examples of resilient structures that can be used to design propellers that reduce these risks and increase safety. In this thesis, a completely different solution inspired by dragonfly's wing is elaborated for the first time. In details:

1) Various samples and related fabrication methods of a bio inspired propeller, called *Tombo* propeller, are presented. Such propellers have partially soft parts, which allows it to withstand collisions and recover quickly while still providing sufficient thrust to hover and fly.
2) The performance characteristics of the propeller, such as thrust force, collision force, recovery time, lift-to-drag ratio, and noise, were also investigated through the development of a simplified aerodynamic model and verification experiments.
3) A control strategy was designed for a drone equipped with *Tombo* propellers that could collide with an obstacle at a specific location, especially RECOVERED from the collision, and continued flying. This is considered as a crucial function that significantly increases the safety of drone beyond the collision.
4) To enhance the collision sensing capabilities of the propeller, a novel hub was also introduced, with details on its design, fabrication, force modeling, and preliminary experiments with potential application to support the *Tombo* propeller in detection of collision, enhancing the overall safety of the drone.

Overall, the thesis succeeds in proposal of a scalable design of a novel propeller and thorough elaboration of its characteristics and operation. A reflex control prevents the drone from fatal falling after collision. Also, obtained results contribute to fulfilling knowledge of soft morphology in interaction with surrounding environment. The research content in this research paves a way to wide application in drones, rotating propellers at different size. The student could prepare papers, thesis, and present the content in English without any problem. Therefore, this thesis is sufficient to be rewarded as doctoral thesis.