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論　文　題　目	TOWARD COLLISION-ACCOMMODATED DRONE WITH TOMBO PROPELLERS: MODELING, SENSING, AND CONTROL
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論文の内容の要旨

The growing demand for VTOL aerial vehicles, including UAV, emphasizes the importance of ensuring operational safety and the ability to accommodate collisions during flight. Such vehicles often operate in environments where contact with surrounding obstacles is likely, posing a significant risk of damage that can compromise mission success. To enhance safety in the event of collisions—particularly those involving the propellers—prior studies have explored the use of soft materials in propeller design to absorb impact forces and prevent mechanical failure, allowing the drone to remain airworthy after impact. One such development is the 9-inch deformable propeller (Tombo propeller), designed in our laboratory, which combines a rigid base with soft silicone tips to provide structural flexibility. Despite these advances, no unified control framework has been proposed to detect random collisions at the propeller level and respond accordingly. This thesis addresses this gap by integrating rotary encoders into each motor to enable real-time measurement of propeller speed, allowing for reliable collision detection and the activation of a reactive flight mode to avoid the obstacle and continue the predefined trajectory. Furthermore, while Tombo propellers offer mechanical robustness, their inherent deformability introduces flight instabilities due to shape fluctuations during sudden acceleration, deceleration, or minor impacts. These disturbances can significantly affect flight dynamics and trajectory tracking. To address this issue, the thesis implements the $\mathcal{L}_1$Quad control strategy, which enhances geometric control with $\mathcal{L}_1$ adaptive augmentation, enabling rapid compensation for modeling uncertainties and external disturbances. This ensures that the UAV can maintain stability and recover its planned path even after unforeseen collisions. Together, this work presents a comprehensive solution that integrates novel sensing and control strategies for collision detection and recovery, representing a significant step toward realizing a UAV capable of safe and reliable operation in complex and dynamic environments.

Keywords: Quadrotor collision detection, deformable propeller, collision reaction strategy, drone

safety, $\mathcal{L}_1$ adaptive control.

論文審査の結果の要旨

With the growing use of VTOL vehicles and quadrotor drones, collision tolerance and operational safety are critical because operations near obstacles risk damage and mission failure. Prior work introduced our 9-inch “Tombo” propeller (rigid hub with soft silicone parts) to mitigate impacts; however, the effects of geometry and material properties on its impact dynamics were not explicitly studied. Moreover, the uncertainties induced by the Tombo propeller in maintaining stable flight were uncharacterized, leaving no unified framework for real-time, propeller-level collision detection and response. This thesis investigates two complementary control schemes—one for stability under nominal flight and minor impacts, and one for reactive control under significant collisions—advancing toward a unified, safe, and efficient Tombo drone. *First*, because the propeller’s deformability can introduce instabilities during abrupt maneuvers or light contacts, L1Quad (geometric control with L1 adaptive augmentation) was deployed to rapidly compensate for propeller-induced uncertainties and external disturbances, thereby stabilizing the drone and restoring trajectory after light collisions. *Second*, an electromechanical model of the Tombo propeller–motor system is developed to analyze nonlinear impact dynamics, from which a rotary-encoder-based sensing system is proposed for efficient collision detection, and a simple recovery controller is implemented and validated in indoor flight and collision tests. *Finally*, further discuss was made for a potential benchmark for evaluating post-collision recovery, laying the groundwork for experimental assessment in the development of soft drones. Collectively, these sensing and control contributions provide a comprehensive solution for safe, reliable UAV operation in complex, dynamic environments.

The student prepared papers and the thesis and presented the work in English without difficulty; accordingly, the dissertation merits the award of the doctoral degree.