Title	トンボプロペラ搭載型衝突許容ドローンの実現に向けた研究：モデリング・センシング・制御
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Doctoral Dissertation

Doctor of Philosophy in Materials Science

TOWARD COLLISION-ACCOMMODATED DRONE WITH TOMBO PROPELLERS: MODELING, SENSING, AND CONTROL

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Abstract

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.