Towards Agile Maneuver Generation for Terrestrial Robots in Flight Phase

Xiangyu Chu, C. H. David Lo, Carlos Ma, Jiajun An, T. Y. Chung, and K. W. Samuel Au
Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong

I. Motivations

Many existing terrestrial robots have the locomotion capabilities almost comparable to those shown by their biological counterparts, such as running, walking, hopping, and jumping. However, little attention has been paid to their mobility in flight phase. In nature, animals/humans show maneuverable behaviors on the ground, but most of them can also generate agile maneuvers in the air, e.g., human can do a flip in snowboarding (Fig. 1). Although some previous work touches this area, they are still primitive and their robots' performance still lags far behind animals/humans. Specifically, robots with a simple 1-DOF tail like [2] used their tails to adjust their landing postures in sagittal plane; robots with a 2-DOF tail like [3] used their tails to right themselves in free falling conditions. These basic agile maneuvers in flight phase were in real-time feedback control but their controllers were basically model-specific. More agile maneuvers have also been achieved. In [4], Mini Cheetah was said to execute a backflip, however, its flipping trajectory was prescribed by optimization and no significant change on body's momentum of inertia (MoI) was observed during flight phase. In [5], Atlas did a smooth backflip and its body collapsed to reduce the MoI and thus speed up the rotation in the air, which is the most agile and natural flipping to our knowledge.

Motivated by those, we realize that a unified, feedback control strategy is necessary. In this talk, to approach the generation of agile maneuvers for terrestrial robots in flight phase, we present an agile maneuver generation strategy based on a unified null-space-avoidance-based control framework to produce agile maneuvers for tailed robots.

II. Methods and Experiments

For terrestrial robots, their angular momentum will keep conserved in flight phase if they are not subject to external forces and the aerodynamics is ignored. The agile maneuver generation can be formulated as an underactuated control problem, i.e., $\dot{\boldsymbol{x}} = \boldsymbol{J}(\boldsymbol{q})\boldsymbol{u} + \boldsymbol{f}(\boldsymbol{q})$, where $\boldsymbol{x} \in \mathbb{R}^3$ and $\boldsymbol{u} \in \mathbb{R}^2$. To design $\boldsymbol{u}$ for generating agile maneuvers like body-only reorientation, we need to solve the inverse problem, i.e., $\boldsymbol{u} = \boldsymbol{J}^{+}\dot{\boldsymbol{x}}$ if the drift term is assumed as $\boldsymbol{f}(\boldsymbol{q}) = \boldsymbol{0}$. Thus, we find a non-trivial null space, i.e., null$[\boldsymbol{J}^{+}] \neq \emptyset$. Our previous work [6] has solved this problem systematically in terms of the orientation control of tailed robots.

To verify the generation strategy, two agile maneuvers were investigated. In Fig. 2, The body roll and tail configurations were stabilized to the desired zero orientation. An intuitive, agile spiraling movement can be observed. In Fig. 3, The body pitch and roll were stabilized to the desired zero orientation and the body yaw recovered to the initial yaw position, which demonstrated a safe landing behavior.

Fig. 1: Agile flipping maneuver in snowboarding [1].

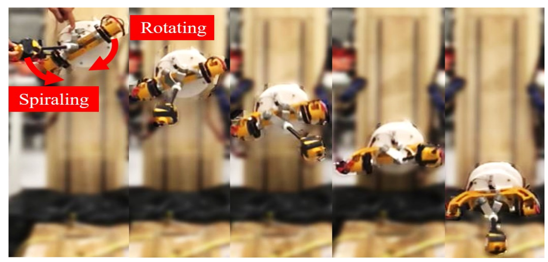

Fig. 2: Sequential snapshots of a body-tail stabilization trial [6].

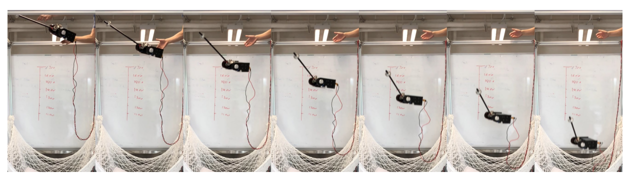

Fig. 3: Sequential snapshots of a body-only reorientation trial.

We admit that two discussed agile maneuvers are basic as compared to highly agile maneuvers like flipping, but the proposed generation strategy is instructional and the null-space-avoidance-based control framework is available for a class of underactuated control problems and is potential in solving more complex control problems (or generating more agile maneuvers). For example, a telescopic tail can be added to mimic the collapse of human body in snowboarding, thus spatial flipping may be tractable.

References

[1] 2019. [Online]. Available: https://medium.com/@maverixsnow/atml-the-key-to-breaking-down-freestyle-snowboard-moves-c21945a823ee.
[2] Evan Chang-Siu, et al. "A lizard-inspired active tail enables rapid maneuvers and dynamic stabilization in a terrestrial robot," *IROS*, pp. 1887-1894, 2011.
[3] Evan Chang-Siu, et al. "A nonlinear feedback controller for aerial self-righting by a tailed robot," *ICRA*, pp. 33-39, 2013.
[4] Benjamin Katz, et al. "Mini Cheetah: A platform for Pushing the Limits of Dynamic Quadruped Control" *ICRA*, pp. 6295-6301, 2019.
[5] 2019. [Online]. Available: https://www.bostondynamics.com/atlas
[6] X. Y. Chu, et al. "Null-Space-Avoidance-Based Orientation Control Framework for Underactuated, Tail-Inspired Robotic Systems in Flight Phase," *RA-L*, pp. 3916-3923, 2019.