Continuous Tail Swinging for Safe Landing

Xiangyu Chu, Jiajun An, and K. W. Samuel Au
Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong

I. MOTIVATIONS

Many tailed robots have been proposed where a tail is used for either energy pumping [1] or orientation control [2]. 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. When developing real-time orientation control, most work assumed that the robot had a zero total angular momentum at the initial moment, thus the tail would stop (the tail velocity would converge to zero) once the body was stabilized. In experiments, researchers normally considered a small non-zero angular momentum as disturbances. This treatment is acceptable when demonstrating the controller, however, in some situations, a large initial non-zero angular momentum cannot be ignored. For example, in nature, a kangaroo rat needs to take off within a short period to escape from a snake in desert [4], as shown in Fig. 1. The resulting non-negligible angular momentum may affect the body orientation and further fail safe landing. To achieve it, the rat continuously swings its tail before its landing (recorded in a YouTube Channel Ninja Rat). Such a continuous tail swinging can shift most of angular momentum to the tail, while leaving little angular momentum on the body. Thus, the rat can have its body orientation controlled and then achieve safe landing.

Unfortunately, few efforts have been made in explaining the continuous tail swinging and utilizing it to address non-zero angular momentum issues in the robotics area. Motivated by those, we develop a real-time feedback controller to copy with a tailed robot with non-zero angular momentum in flight phase. With this controller, we find that the robot body can be stabilized well until the robot lands and the tail has to keep swinging at the same time. This echoes what we have observed from kangaroo rats. Besides, the controller is also applicable to other inertia appendages if the robot is subject to non-zero angular momentum. We hope our method can facilitate robot safe landing in the side of body orientation.

II. METHODS AND RESULTS

For tailed robots in flight phase, their angular momentum will keep conserved if they are not subject to external forces and the aerodynamics is ignored. If the total angular momentum is non-zero, we have $\boldsymbol{H}_{body} + \boldsymbol{H}_{tail} = \boldsymbol{H}_0 \neq \boldsymbol{0}$. Rearranging it to a general form yields $\dot{\boldsymbol{x}} = \boldsymbol{J}\boldsymbol{u} + \boldsymbol{f}$, where $\boldsymbol{x} \in \mathbb{R}^3$ is the body orientation vector, $\boldsymbol{u} \in \mathbb{R}^2$ is the tail velocity vector, and $\boldsymbol{f}$ is a drift term asscoaited with non-zero angular momentum. In our previous work [3], we have solved the orientation control problem with zero angular momentum. Due to the generalization of our method, the drift term can be involved properly such that the body orientation can be stabilized to a neighborhood of the desired orientation.

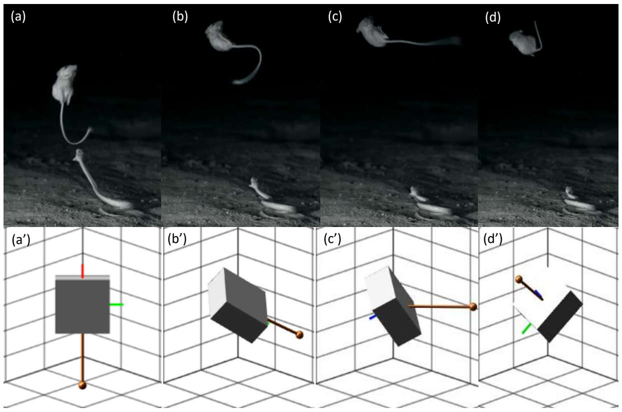

Fig. 1: (a-d): Kangaroo rat mid-air maneuver via tail swinging https://www.youtube.com/watch?v=aV8_iv6SXqc (Ninja Rat). (a'-d'): corresponding snapshots in our simulation. Although they are not precisely matched, our controller can still generate the tailed robot motion similar to animal motion based on a simplified model. Limited by space, continuous tail swinging is not presented here.

To demonstrate the controller for the case of non-zero angular momentum, we conducted a simulation based on the model provided in [3] without involving the effect of robot legs. In Fig. 2, the body orientation (pitch, yaw, and roll) converged to the vicinity of the origin (assuming such a configuration is corresponding to safe landing). Note that the tail kept swinging to absorb most of angular momentum.

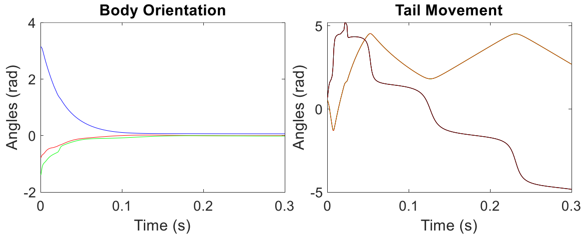

Fig. 2: Simulation of the robot with non-zero angular momentum.

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