Roll Stabilization on a Tailed Biped

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This talk presents a roll stabilization behavior implemented on the Penn Jerboa [1], a biped with a 2DOF tail. Previous work on this platform has focused on pumping the tail in the sagittal plane to energize the leg springs for hopping [2]. For this hopping gait, the robot was constrained to a boom that locked the body's angular degrees of freedom (with the exception of pitch, which was unconstrained for certain controllers). In this work, the robot has been reoriented to constrain pitch and yaw while allowing it to roll freely. Design of an effective roll controller may lead to future application of the stepping controller, shape controller, and parallel composition ideas from [2] to enable the Jerboa to move freely of the constraining boom.

In the frontal plane, the 12DOF Jerboa reduces to the 7DOF model in Fig. 1, which, for the purposes of this talk, is further restricted to the following 4DOF, two actuator reduced model. The robot has passive leg springs so its (presumed massless) toe positions are irrelevant in flight and can be read off as kinematic functions of the body frame coordinates when in (single or double) stance. The machine's lateral position is ignored, so the mass center frame in world frame coordinates is characterized by height, q_2, and roll angle, q_3, as depicted in the figure. Projecting the physically revolute-revolute tail [1] onto the frontal plane results in an effective revolute-prismatic kinematics that will be convenient to represent in cartesian coordinates (q_6, q_7), again as depicted in the figure. Since the hip motors impose torques only in the sagittal plane, the generalized coordinates (q_2, q_3, q_6, q_7) are subject to only two independent external forces acting directly on the tail DOF, arising from the (physically coaxially located) tail linkage motor pair [1].

Without any roll correction, the robot frequently flips itself over (fig. 1, top) after a small number (<5) of hops. Further, the robot loses energy during touchdown when its roll angle is non–zero because the first leg to touch the ground experiences a side load, which is not efficiently converted into potential energy in the linear leg spring. This suggests that a controller which corrects roll during flight before this energy is lost will be more effective than one that acts during stance, after the side loading has already occurred.

The present study is focused on exhibiting a frontal plane rolling control strategy that respects the primacy of the previously proposed sagittal plane hopper [2]. In this view, it seems natural to ”share” the two tail actuators in such a manner that the revolute behavior of the tail mass relative to the body is assigned the duty of frontal plane roll control, leaving its prismatic behavior free for the pursuit of the desired sagittal plane behavior. However, under the influence of the previously designed sagittal hopping controller [2], as the robot progresses through its flight phase — i.e., just when preliminary experiments suggest the frontal plane roll authority is most needed — the radial component of the physical tail's projection onto the frontal plane (i.e., the effective radius of the tail mass relative to the body mass in Fig. 1) shortens and affords decreasing influence over the robots roll.

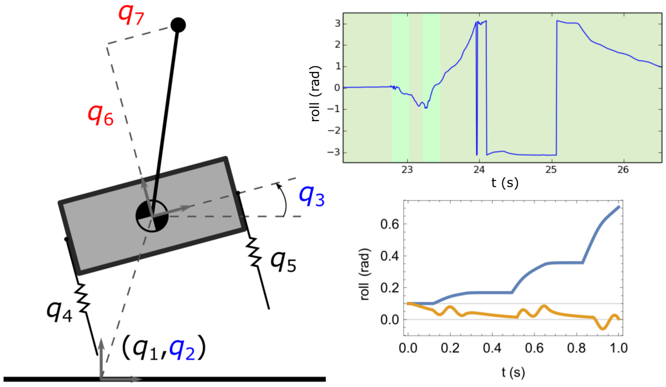

Fig. 1: **Left:** 7DOF frontal plane model of the Jerboa. Actuated coordinates shown in red, passive coordinates in black. **Top:** Plot showing the robot flip after 2 hops using the just sagittal hopping controller while attached to a boom. Light green background represents stance phase. **Bottom:** Simulation showing the robot's roll with (orange) and without (blue) the 'windmilling' control operating.

A naive controller that 'windmills' the tail has shown in simulation (Fig. 1) that roll stabilization is possible with this robot morphology. However, this controller ignores the desired sagittal plane behavior, causing the hopping to die out. Here, then, the idea of parallel composition will be applied to correctly utilize the severely under-resourced authority available for the control of these two intrinsically mechanically coupled planar subsystems.

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