Tail design and control for a tail- and hip-energized and -stabilized bipedal hopping robot

Figure 1

While manipulators used as arms or legs have been studied extensively in prior work, the tail appendage has only recently started to make a mainstream appearance in robotics research. Moreover, tail appendages are distinct from limbs in their typical (but not exclusive) function in the following ways: they are used in an inertial-only regime without any contact with the environment, and so it is important for them to possess significant inertia, whereas an optimal leg design would strive for minimal mass. Additionally, tails can operate at a higher duty cycle (versus legs, which typically only exert large forces when in contact with the ground), so must typically be sized for more "continuous" operation than legs. These observations have an important bearing on their effectiveness for inertial reorientation as well as the selection of actuators to drive them (Libby et al., 2016), as well as acceleration in the horizontal plane (Patel and Braae, 2013).

We have previously introduced the Jerboa robot (De and Koditschek, 2015a), a tailed bipedal robot with only four actuators (Figure 1). Partially due its high degree of underactuation, the tail is multifunctional, serving not only for inertial reorientation, but in addition for vertical energization (De and Koditschek, 2015b) and as a leg (Brill et al., 2015). These multiple functions manifest as additional constraints/objectives on the design problem. In addition, since tails typically have more inertia than legs do, they exert far greater influence on the body dynamics than massless legs, which must be accounted for at both design and control time.

In this talk, we focus on two tail functions (a) vertical energization of the COM, and (b) inertial reorientation (control of net angular momentum and internal shape). We describe our approach to both control (using parallel composition) as well as design (using analysis of an averaged "equivalent" system) of this highly coupled system.

In terms of control, we have expanded on Raibert's early work on empirical compositions, and developed a formalism which predicts composed limit cycles' location and stability (De et al., 2018). We can empirically demonstrate spatial hopping using this parallel composition strategy, and in addition numerically demonstrate the modularity benefit of compositional control: expressing the same limiting behavior (planar hopping) employing appendages and actuators in different ways (tail-energized vs. hip-energized), as shown in Figure 2.

In terms of design, we have shown for the first time in (Shamsah et al., 2018) how the 2DOF TVH template (Figure 3) can be used to analytically predict tail-energized hopping performance, and now propose that the 3DOF TVH-HIR template can be used to analytically express the competing or synergistic demands of the energization and reorientation tail functions, and the consequent implications on Jerboa's design and control.

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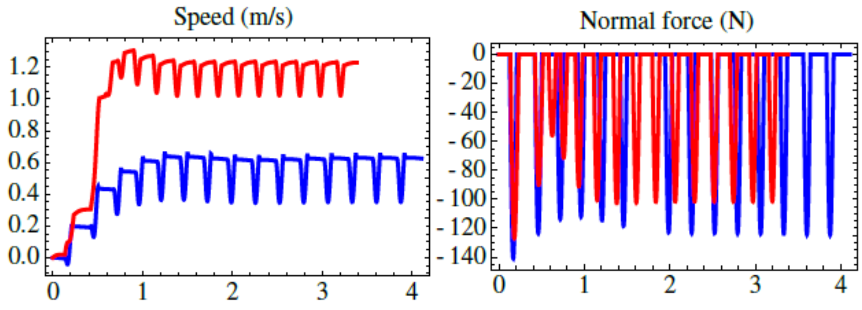
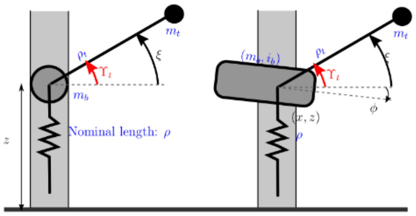


Figure 3



(a) TVH
Tailed vertical hopper

(c) TVH-HIR
TVH with Inertial Reorientation

Figure 2