Towards Energy Optimal Design and Control of Tailed Legged Robot Locomotion

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***Abstract*—This work employs design and trajectory optimization to explore energy optimal morphologies and control policies for tailed quadrupedal bounding. Energy optimal control policies appear to offload the work done by the leg actuators without fighting the passive dynamics of the tail. For the tested system, decreasing the tail mass decreases energy consumption, although if the tail mass is transferred from the body of the robot, the optimal design is to increase tail mass.**

Keywords- energetics, inertial actuation, legged locomotion, trajectory optimization

I. INTRODUCTION

Tails and tail-like appendages show promise in expanding the dynamic performance of legged robots. Much of the current research on these devices aims to increase the robustness of these systems [1] or achieve more dynamic behaviors such as agile cornering or rapid acceleration and braking, [2], [3]. Less is known about the energetic effects of these devices, although it has been shown that a reaction wheel enabled on a robot biped is more efficient than a deactivated reaction wheel on the same system [4]. This work explores the energy loss mitigation capability of tails to distinguish what control objectives and design decisions are energy optimal for periodic locomotion.

II. METHODS

A hybrid trajectory optimization is posed as a series of nonlinear programming problems (NLPs) and solved in IPOPT to generate energy optimal steady state bounding gaits for a quadrupedal robot. Kinematic and dynamic feasibility are enforced via Hermite-Simpson direct collocation constraints, and the cost function is total energy expended per unit distance. To assess the relative effect of different tail masses on system efficiency, the NLPs are solved for different tail masses inside a larger optimization that searches for the optimal tail mass. Tail mass is added 1) directly to the tail without changing any other robot parameters, and 2) added to the tail with equal mass subtracted directly from the body, corresponding to transferring payload from the body to the tail.

III. RESULTS AND DISCUSSION

The energy optimal gait found by the optimization holds the tail in an upright position, applying small torques to help balance the body of the robot without fighting the passive dynamics of the tail. Fig. 1 shows the energy expenditure of the system as a function of tail mass. When the tail mass is added directly to the system, increasing the tail mass leads to an increase in energy expenditure. If that mass is instead transferred from the body of the robot, the energy expenditure decreases, eventually surpassing the original un-tailed system. This suggests that if a robot has a large payload, it would be more efficient to place that mass at the end of a tail to isolate it from the dynamic bounding motion.

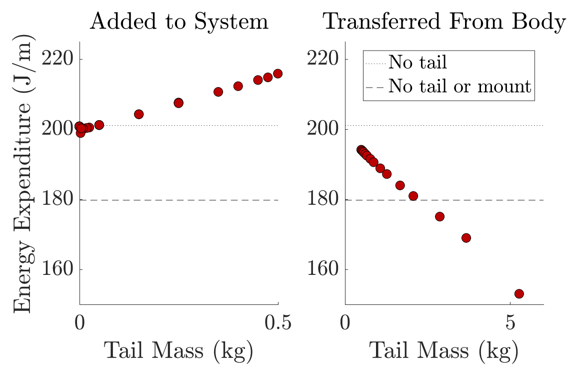

Figure 1. Energy optimal tail mass trends.

IV. CONCLUSION AND FUTURE WORK

Tails and tail-like appendages offer an array of utility in dynamic maneuverability and stability, and can also be used to mitigate to some degree the energy cost increase incurred by their inclusion. This mitigation occurs when the tail is controlled in union with the passive dynamics of the system, and is aided by a tail design that borrows mass from the body of the robot rather than adding mass from an external source. This analysis yields intuitive conclusions regarding energy optimal design and control objectives, yet so far is restricted to one robot morphology. Further work will test generality on other systems, as well as experimental validation.

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