University of Stuttgart

Institute for Adaptive Mechanical Systems

Term paper
Master’s thesis

Comparison of Energy-Optimal Controllers in Legged Systems

Topic Areas:	Optimal Control, Periodic Motions Legged Systems
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Prerequisites/Prior Knowledge:	Technical Mechanics III (Dynamics), Matlab, Optimal Control (ideally) Dynamcis and Control of Legged Locomotion

Optimal control is essential for generating energy-efficient trajectories for legged systems that operate on a single battery charge. Repeatable motion patterns are particularly useful because they require only a finite computation horizon and can be extended indefinitely. These patterns are often periodic, which are valuable for building a trajectory library, especially when operating a system under varying conditions such as different average forward speeds v_{avg}.

While trajectory optimization can systematically generate these motions, their stabilization offers greater design flexibility and depends heavily on the system and its environment.

In this project, you will compare different control strategies for periodically operating systems, focusing on both efficiency and robustness.

Specifically, you will implement optimal open-loop trajectories and feedback-stabilizing controllers for the three exemplary systems shown in Fig. 1. The feedback controllers will be based on virtual constraints within the hybrid zero dynamics framework [1], transversal coordinates [2], or more recent manifold stabilization approaches [3], and will be analyzed in terms of their structural similarities and differences.

Beyond robustness, a central objective in this comparison will be to evaluate the overall energy consumption of the robotic systems.

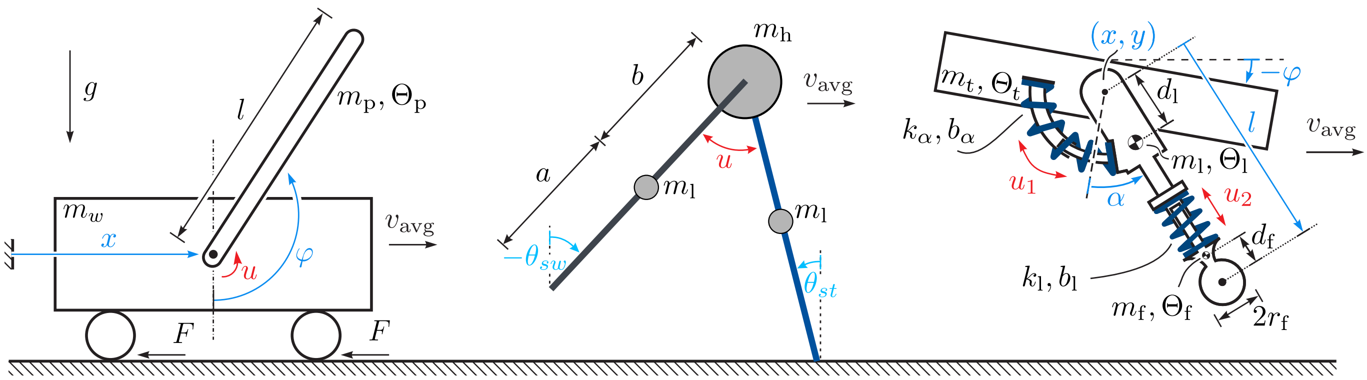

Figure 1: Three exemplary robotic systems (forward rocking cart-pendulum, compass-gait walker, and monoped with springs) using periodic motions to move forward at a fixed average speed.

[1] Westervelt, E. R., et al. *Hybrid zero dynamics of planar biped walkers.* IEEE transactions on automatic control, 2003.

[2] Manchester, I. R., et al. *Stable dynamic walking over uneven terrain.* The International Journal of Robotics Research, 2011

[3] Calzolari, D., et al. *Exciting families of passive gaits in an elastic quadruped via natural motion manifold control.* The International Journal of Robotics Research, 2024.