University of Stuttgart

Institute for Adaptive Mechanical Systems

Bachelor's thesis
Master's thesis
Term paper

Towards Optimal Morphology for Bipedal Walking and Running

Topic Areas:	Optimal Control, Legged Robotics
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Prerequisites/Prior Knowledge:	Optimization, Matlab

Designing legged robots for energetically optimal locomotion requires careful optimization of both the hardware configuration and the control algorithm. In fact, key to achieving energy-economic locomotion is the exploitation of natural dynamics driven by the mechanical structure of the system. Hence, hardware properties must be jointly optimized with control strategies during motion planning for legged robots (Figure 1). Additionally, legged systems must be versatile—capable of operating under varying conditions such as changes in speed, slope, or ground characteristics.

To address the coupling between control and morphology, as well as the need for adaptability, we are currently developing a framework that simultaneously optimizes state and input trajectories alongside hardware parameters for simplified models of legged systems. This framework generates a map that shows how variations in hardware properties and operating conditions influence the cost of energetically optimal periodic trajectories for hybrid dynamical systems.

In this project, we aim to apply the framework to investigate the optimal morphology of a simplified bipedal robot equipped with parallel elastic actuators at the leg and hip joints (Figure 2). Specifically, we want to analyze how joint compliance affects energy cost across different locomotion speeds. Our goal is to understand these effects in both walking and running, and to explore transitions between the two gaits as speed increases.

Depending on the type of thesis, your task may involve further developing the numerical framework to better accommodate bipedal locomotion. This includes developing the model and implementing suitable heuristics to construct an effective warm-start strategy that guides the solver toward meaningful optimal solutions. Subsequently, you will perform a grid-based exploration to generate a map of optimal solutions, illustrating how different joint stiffness values affect energetic performance across a range of speeds. Finally, we aim to analyze the results and draw conclusions that can generalize to the design of real bipedal robots.

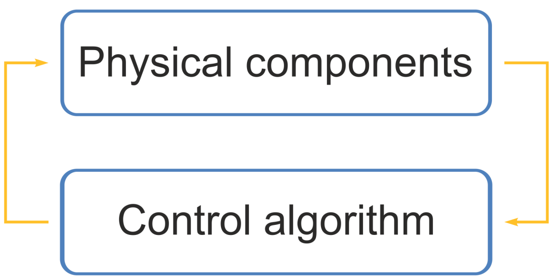

Figure 1: Schematic illustration of the coupling between optimal hardware design and control strategy.

Figure 2: Simplified bipedal model with parallel elastic actuators used in the study.