University of Stuttgart

Institute for Adaptive Mechanical Systems

Bachelor's thesis
Master's thesis
Term paper

Designing Versatile Robots via Stochastic Programming

Topic Areas: Optimal Control, Legged Robotics

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Prerequisites/Prior Knowledge: Optimization, Matlab

Designing energetically optimal robots that perform well across multiple tasks and environments requires careful joint optimization of hardware configuration and control algorithms. For example, efficient legged robots tend to exploit their natural dynamics in order to reduce actuator effort. These natural dynamics are largely determined by the mechanical design, yet they directly shape the achievable control strategies, highlighting the strong interconnection between morphology and control.
A classical approach to address this coupling is to jointly optimize morphology and control parameters through trajectory optimization. These optimizations typically consider idealized environments and single tasks, which often results in highly specialized and potentially fragile hardware designs. In this project, we aim to find versatile morphologies for simplified robotic models by explicitly accounting for multiple tasks and environments within the optimization problem using stochastic programming [1].
While stochastic programming applies uncertainty in the scenarios, the resulting trajectory optimization remains deterministic for a given scenario set. This allows us to use standard trajectory optimization solvers and to preserve the computational structure of the original problem, while explicitly accounting for task and environment variability.
Your task is to formulate a bi-level co-design framework in which morphology parameters are optimized at the upper level and scenario-dependent control trajectories at the lower level, using stochastic programming with randomly sampled scenarios. The resulting designs should represent a trade-off in performance across multiple tasks and environments (Fig.1)
The framework should be evaluated on up to three case studies of increasing complexity: a planar two-link manipulator, a one-legged hopper, and a bipedal robot. On the one hand, our goal is to analyze the observed differences between single and multi-task co-design and assess the framework's scalability to more complex models and scenario sets. On the other hand, we aim to study how joint compliance and damping affect the energy cost and performance of versatile robot designs.

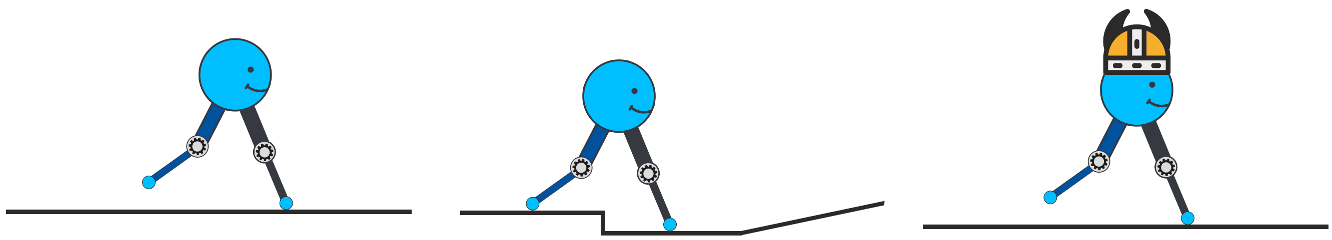

Figure 1: Illustration of an optimized bipedal morphology for versatile operation across multiple scenarios, including an ideal setup, uneven terrain, and an additional head-mounted load.

[1] Bravo-Palacios, G., et al. *One Robot for Many Tasks: Versatile Co-Design Through Stochastic Programming, IEEE ROBOTICS AND AUTOMATION LETTERS, Vol. 5, No. 2, April 2020.*