University of Stuttgart

Institute for Nonlinear Mechanics

Master's thesis

Optimal Leg-Stiffness in a 2D Monoped

Topic Areas: Legged Robots, Trajectory Optimization, Numerical Continuation Methods

Advisor: Maximilian Raff, raff@inm.uni-stuttgart.de

Responsible Professor: Prof. C. David Remy

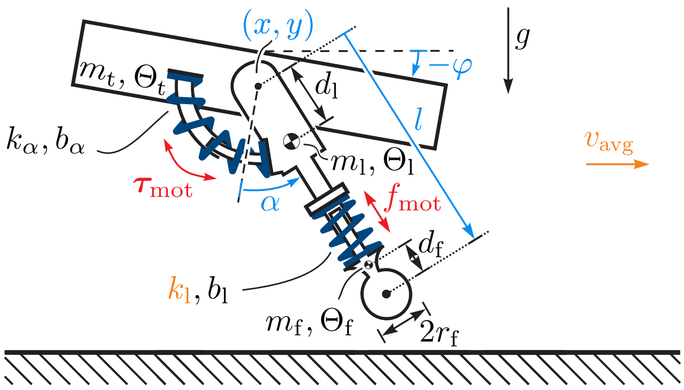
Prerequisites/Prior Knowledge: Technical Mechanics III (Dynamics), Matlab, (ideally) Optimal Control, Robotics

In the fields of robotics and bio-mechanics, the significance of elastic potentials like springs or tendons for energy-efficient locomotion is widely recognized. However, there remains an open challenge in designing a robotic leg that consistently performs well across various operating conditions, particularly different average forward speeds.

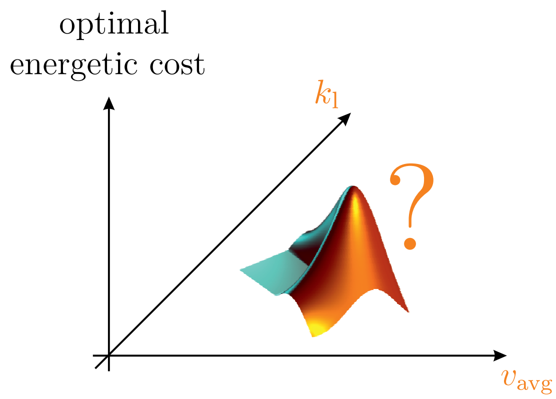
In this project, you will conduct a comprehensive parametric study using a monopedal robot (depicted below). Your main objective will be to investigate the energy efficiency of the robot by implementing a optimization problem that includes the linear spring stiffness k_l of the robot's leg. Additionally, you will explore how the optimal energetic cost varies across different k_l and average speeds v_{avg}.

To accomplish this, you will set up a (periodic) trajectory optimization problem that is parameterized by k_l and v_{avg}. To efficiently solve this optimization problem for various parameters and generate a surface of optimal points (as illustrated in the cartoon below), you will utilize numerical continuation methods for computationally efficient analyses. By visualizing and analyzing this surface, we aim to gain valuable insights into designing an efficient leg.

We hypothesize that the optimal leg stiffness, k_l, remains relatively independent of the average speed, v_{avg}. By testing and validating this hypothesis, we can pave the way for advancements in leg design for energy-efficient robotic locomotion.



Monoped with leg stiffness k_l and average speed v_{avg}



A cartoon of the desired surface plot of energetically optimal gaits

[1] Y. Yesilevskiy, Z. Gan, and C. D. Remy. *Optimal configuration of series and parallel elasticity in a 2d monoped,* International Conference on Robotics and Automation (ICRA). IEEE, 2016.

[2] J.T. Betts, *Practical methods for optimal control and estimation using nonlinear programming,* Society for Industrial and Applied Mathematics, 2010.

[3] Allgower, Eugene L., and Kurt Georg. *Numerical continuation methods: an introduction.* Vol. 13. Springer Science & Business Media, 2012.