University of Stuttgart

Institute for Nonlinear Mechanics

Bachelor's thesis

Finding Global Optimal Gaits: A Data-Driven Approach

Topic Areas:	Nonlinear Dynamics, Optimal Control, Simulation
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Prerequisites/Prior Knowledge:	Mechanical Engineering, Matlab

Finding optimally actuated periodic solutions (gaits) for dynamical systems is a difficult problem. One particular challenge arises from the problem's non-convexity and thus, the need of a good initial guess that converges to a global minimum.
One approach to address this challenge is the Extended Dynamic Mode Decomposition (EDMD), a data-driven method that aims to render the problem convex by approximating the Koopman operator. This technique involves lifting the dynamics into a higher-dimensional, yet linear system.

In this endeavor, your task is to explore various strategies for constructing such a surrogate model. This exploration encompasses efficient sampling methodologies and the identification of suitable lifting functions (observables).

To start this quest, you will first implement and analyze an actuated harmonic oscillator (see Fig. 1) using Matlab. This entails discretizing the problem in time and employing Matlab's fmincon solver to tackle the resulting nonlinear program. Furthermore, this solver will be instrumental in validating the optimal EDMD solutions. Subsequently, you will advance to hybrid dynamical systems, encompassing multiple nonlinear dynamics, including nonlinear algebraic equations. As an example system, you will study a planar monoped with 5 degrees of freedom (Fig. 2(a)), which reduces to 2 degrees of freedom when constrained to vertical motions (Fig. 2(b)). Notably, the algebraic equations in the latter scenario are linear, enabling a seamless transition from the harmonic oscillator framework.

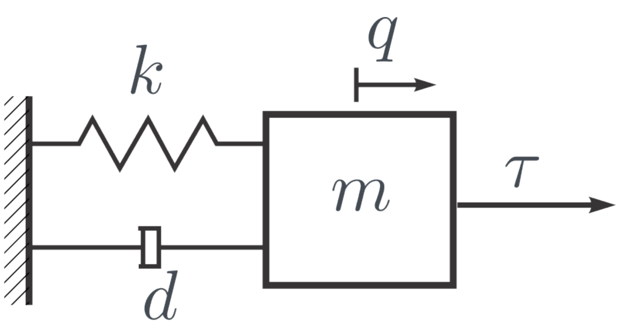

Figure 1: 1D actuated mass-spring-damper

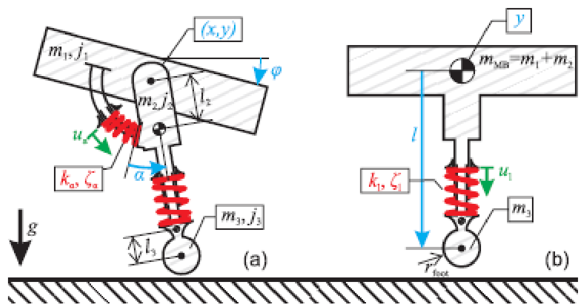

Figure 2: Monoped in 2D (a) and 1D (b)

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

[2] A. Mauroy, I. Mezić, and Y. Susuki, *The Koopman operator in systems and control. Concepts, methodologies and applications*, Lecture Notes in Control and Information Sciences, Springer, 2014.