University of Stuttgart

Institute for Nonlinear Mechanics

Master's thesis

Data-Driven Koopman Optimal Control

Topic Areas:	Nonlinear Dynamics, Optimal control, Simulation
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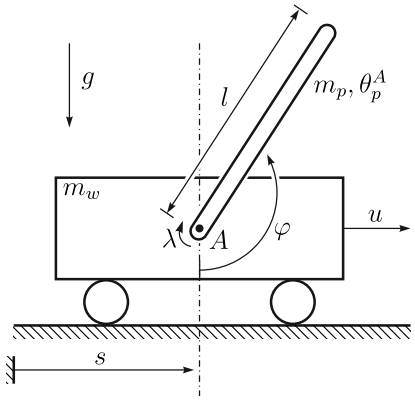
Responsible Professor:	Prof. Remco I. Leine
Prerequisites/Prior Knowledge:	Technical Mechanics III (Dynamics), Matlab, (ideally) Optimal Control, Robotics

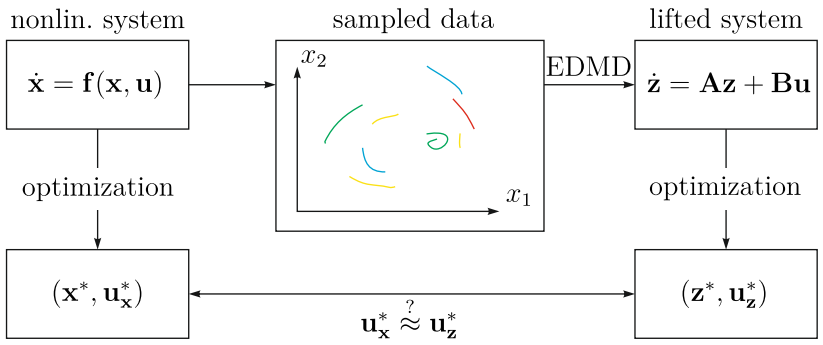
Trajectory optimization [1] is typically the tool of choice to plan and generate motions for robotic systems while minimizing a performance measure like energy consumption or operating time. Due to the nonlinear system dynamics, however, the optimization problem is in general non-convex. Hence, solving such a problem successfully is not guaranteed and potentially leads to local minima that are not globally optimal.

Recently, Extended Dynamic Mode decomposition (EDMD) based on the Koopman operator emerged as a method to obtain a higher-dimensional approximate linear system from data generated by a nonlinear system [2]. With the linear model obtained by EDMD, the optimization problem becomes convex and much easier to solve.

In your work, you will explore the opportunities and limitations of using data-generated linear models obtained through EDMD in optimal control problems. After familiarizing yourself with the theoretical foundations of the Koopman operator and EDMD, and getting an overview over the available literature, you will begin your own investigations in MATLAB for the smooth cart-pole system shown below. You will implement EDMD as well as data sampling for your system and then compare the optimization results for various optimal control tasks. When the behavior of the cart-pole system is well-understood, you will gradually extend the considered system model to include other types of nonlinearities or nonsmooth effects, bridging the gap towards more interesting systems like legged robots.



Cart-pole system:
$\mathbf{x} = (s, \varphi, \dot{s}, \dot{\varphi})^{\mathrm{T}}$



EDMD approach

[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.

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