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# Data-driven Soft Robot Control using Adiabatic Spectral Submanifolds

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## Abstract

Controlling soft robots is inherently challenging due to their flexible and dexterous design, which leads to highly nonlinear dynamics described by high-dimensional governing equations. These complexities make real-time control difficult, especially for dynamic trajectory tracking tasks. Additionally, in most real-world applications, data is typically limited to a few planned experiments conducted on the soft robot. Soft robots are primarily intended for use in environments such as surgical procedures, underwater deep explorations, and space satellite maintenance. In these contexts, precise control is crucial for safely executing dynamic trajectory tracking tasks. Notably, the speeds of soft robots are generally much slower than the intrinsic decay rates of their vibration modes. This observation can be leveraged by applying recent theory of temporal spectral submanifolds (SSMs) to identify a low-dimensional adiabatic spectral submanifold (aSSM) from data. By reducing the robot's dynamics to an aSSM, we obtain a non-autonomous reduced model that accurately captures the dominant slow dynamics of the system. Further an aSSM is typically normally hyperbolic, making it robust to fast, bounded control perturbations as well. These properties make the aSSM-reduced model well-suited for model predictive control. We demonstrate that a 5-dimensional aSSM-reduced model effectively captures the dynamics of a high-dimensional soft trunk robot. This model outperforms existing nonlinear and linear control methods across various 3D closed-loop target control tasks.

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