Dr. Arkal S. Shenoy Research Award Seminar

Adaptive Koopman Embedding for Control of Nonlinear Systems

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ABSTRACT

Precise control of nonlinear dynamical systems remains a critical problem across diverse scientific and engineering disciplines. Unfortunately, a unifying mathematical framework for the control of such complex systems remains elusive. The well-developed field of linear control theory offers a robust toolbox for analyzing and controlling linear systems. Consequently, there is significant appeal in synthesizing global linear representations for nonlinear systems. To this end, data-driven Koopman operator-theoretic methods have emerged as a powerful approach for identifying such linear embeddings, enabling the use of linear control strategies in inherently nonlinear systems. However, these methods often struggle to generalize beyond training data and lack robustness to changes in system dynamics caused by intrinsic or environmental factors. This study tackles these challenges by introducing an adaptive Koopman architecture designed to dynamically adapt to evolving system dynamics. We leverage the fact that the uncertainties/disturbances in system dynamics can be linearly parameterized through prelearned Koopman embeddings or sufficiently approximated through their projections onto them with sufficient accuracy. We employ an autoencoder-based neural network that utilizes input-output data from the nominal system to learn the corresponding Koopman embedding offline and subsequently augment it with an online neural learning architecture that modifies the nominal dynamics in response to any deviation between the predicted and observed lifted states, leading to improved generalization and robustness to a wide range of uncertainties and disturbances compared to contemporary methods. By integrating the adaptive Koopman framework into a Model Predictive Control approach across multiple robotic platforms, we demonstrate its robustness and superior performance against leading contemporary designs.

ABOUT THE SPEAKER

Rajpal Singh received his bachelor's degree in mechanical engineering from the National Institute of Technology, Srinagar, in 2020. He is currently pursuing a Ph.D. degree in the Indian Institute of Science, Bangalore, in the DACAS lab under the supervision of Prof. Jishnu Keshavan. His current research interests are broadly in the areas of nonlinear dynamics and control, data-driven control, continual learning, and control-oriented learning.

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