ME – MTech(Res) Thesis Colloquium

MECHANICAL ENGINEERING
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Learning-based Koopman structures for model-based control

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ABSTRACT

Mathematically modeling the dynamics of a complex system accurately from first principles is challenging and often infeasible. Simplifying assumptions commonly made in modeling such systems often restrict their scope and accuracy, diminishing their effectiveness for model-based control. Utilizing data-driven learning methods offers an effective substitute, as they learn models from observed data, thereby improving modeling, prediction, and control accuracy by capturing underlying dynamics faithfully. Lately, neural networks have frequently been employed as data-driven tools for learning system dynamics. Nonetheless, the resulting highly nonlinear models can lead to computationally demanding and less efficient control implementation. This study focuses on Koopman-based learning using the Koopman operator to derive linear models for complex nonlinear systems. We propose a combined Koopman-ZNN (Zeroing Neural Network) architecture for real-time control of redundant manipulators with input constraints. An autoencoder-based neural architecture learns the bilinear Koopman model for manipulator dynamics in joint space. This architecture is subsequently integrated with a feedforward neural network that maps the joint coordinates to end-effector Cartesian coordinates. This approach yields precise models with fewer observable states than prior research. Coupled with a ZNN controller, it provides a computationally efficient alternative to Nonlinear Model Predictive Control (NMPC), which is crucial for real-time control feasibility. Simulation and experimental studies, including performance comparisons, validate the efficacy of this approach. One of the significant limitations of conventional Koopman-based learning is that it lacks adaptability and excels only when data precisely reflects system dynamics. Furthermore, changes in the dynamics of the original system degrade model performance, limiting its practicality for real-world applications. In addition, poor and inadequate sampling of data and suboptimal choice of parameters might render the learned model inaccurate. To mitigate these challenges, we propose an adaptive Koopman algorithm that uses online data for continuous model adjustment. This method delivers robust, accurate, and efficient models, significantly outperforming traditional Koopman approaches.

ABOUT THE SPEAKER

Chandan Kumar Sah received his bachelor's degree in Mechanical Engineering from the Institute of Engineering, Pulchowk Campus, Kathmandu, in 2018. He is currently pursuing an M.Tech. (Research) degree in Indian Institute of Sciences, Bangalore, in DACAS lab under the supervision of Prof. Jishnu Keshavan. His current research interests are broadly in the areas of dynamics and control, data-driven control, Machine learning, and control-oriented learning.