ME Seminar

Geometric Mechanics of Hybrid Soft-Rigid Robots: A Unified, Differentiable Approach

Anup Teejo Matthew, Research Scientist, Center for Autonomous Robotic Systems, Khalifa University, Abu Dhabi, United Arab Emirates

ABSTRACT

Hybrid soft-rigid robots combine the adaptability and physical intelligence of compliant bodies with the precision and controllability of rigid mechanisms. However, their distributed deformation, high-dimensional configuration spaces, and strongly nonlinear dynamics make them challenging to model and control efficiently. This talk presents the Geometric Variable Strain (GVS) approach, a unified framework for modeling rigid, soft, and hybrid robotic systems using Cosserat-rod theory and Lie-group mechanics. By parameterizing the distributed strain field using a finite set of generalized coordinates, the approach provides geometrically exact yet computationally efficient models compatible with established rigid-body algorithms.

The talk will describe the basic principles of the GVS model, the development of analytical derivatives of governing equations, and their implementation in the open-source SoRoSim toolbox. Selected applications involving continuum manipulators, underwater soft robots, hybrid parallel mechanisms, and proprioceptive sensing will illustrate the framework's generality. The talk will conclude with a research vision for extending this foundation toward high-performance differentiable simulation, contact-rich robotics, optimization, and mechanics-informed robot intelligence.

ABOUT THE SPEAKER

Anup Teejo Mathew received the B.Tech. degree with honors in Mechanical Engineering from the Indian Institute of Technology Hyderabad, India, in 2015, and the Ph.D. degree in Mechanical Engineering from the National University of Singapore, Singapore, in 2019. He is currently a Research Scientist with the Department of Mechanical and Nuclear Engineering and the Khalifa University Center for Autonomous Robotic Systems, Khalifa University, Abu Dhabi, United Arab Emirates.

His research focuses on geometric mechanics, differentiable physics, robot dynamics, contact mechanics, and the modeling and control of soft, rigid, and hybrid robotic systems. He has contributed to the development of the Geometric Variable Strain framework and is a principal developer of SoRoSim, an open-source MATLAB toolbox for modeling, analyzing, and simulating hybrid soft-rigid robots. His work spans theoretical and computational modeling, analytical derivatives of robot dynamics, reduced-order modeling, differentiable collision detection, and mechanics-based optimization. These methods have been applied to continuum manipulators, underwater soft robots, hybrid parallel mechanisms, proprioceptive sensing, robot design, and motion planning.

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