UNIVERSITÀ DI TRENTO

Programming and Predicting Soft Pneumatic Actuators: From Metamaterial Skins to Digital Twins

Prof. Ning An
School of Aeronautics and Astronautics,
Sichuan University, China
Email: anning@scu.edu.cn
Homepage: https://www.anning.me

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Soft pneumatic actuators combine intrinsic compliance, adaptability, and safe interaction, making them promising for robotic manipulation, bio-inspired systems, and operation in unstructured environments. However, their highly nonlinear deformation presents two closely related challenges: programming their mechanical response through structural design and efficiently predicting their behavior during operation.

This seminar presents two complementary approaches to addressing these challenges. First, auxetic metamaterials are introduced as robotic skins for programming actuator bending and shape morphing. By tailoring the geometry, number, and spatial arrangement of unit cells with different Poisson's ratios, the actuator's bending curvature, radial expansion, and deformation path can be controlled. Second, a reduced-order surrogate framework is developed for constructing digital twins of soft pneumatic actuators. By integrating high-fidelity finite-element simulations, proper orthogonal decomposition, and radial-basis-function interpolation, the framework enables near-real-time prediction of full-field deformation, stress distributions, and contact forces. Both approaches are validated through experiments and numerical simulations, with demonstrations involving individual actuators and a soft robotic gripper.

Together, these studies connect programmable mechanical design with efficient computational prediction. This integration provides a pathway toward soft robotic systems that can be systematically designed, rapidly and accurately monitored, and intelligently controlled.

The seminar is organized by the Solid and Structural Mechanics Group [D. Bigoni, F. Dal Corso, L. Deseri, D. Misseroni, M.F. Pantano, A. Piccolroaz, N.Pugno, R. Springhetti]