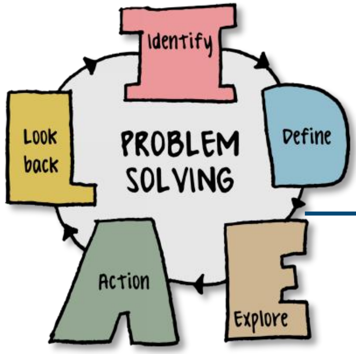
Introduction

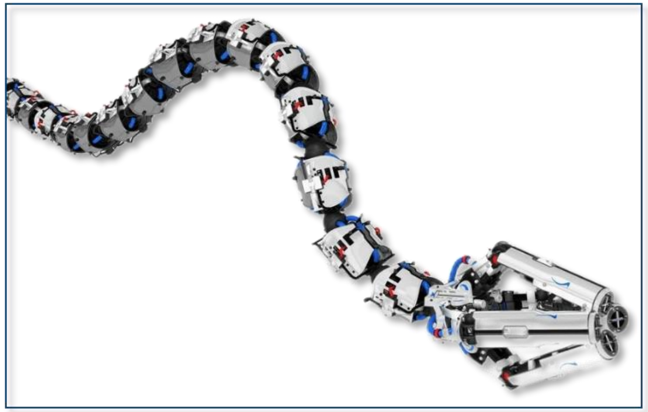
Curious thinker



Confident problem solver

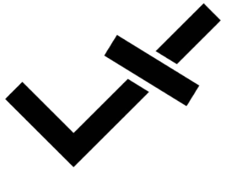
Ke Wu

Down-to-earth teacher



Enthusiastic robotics lover

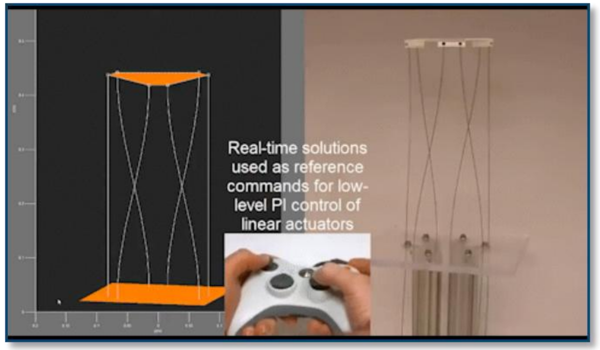
Career



Life

Research interests

Deformable robotic systems



Continuum parallel robots [University of Tennessee]

Cable-driven continuum robots [University of Toronto]

Magnetic-driven continuum robots [MIT]

Drawing from ⇨ **Classic Robotics**

Fundamentals

Modeling
- Statics/kinematics
- Dynamics

Motion planning
- Configuration
- End effector

Control
- Motion control
- Force control

Design
- Actuation design
- Sensor design

World modeling
- Dynamic environments

Perception
- Sensing
- Estimation

Advanced manipulation

- Human robot interaction
- Human robot collaboration

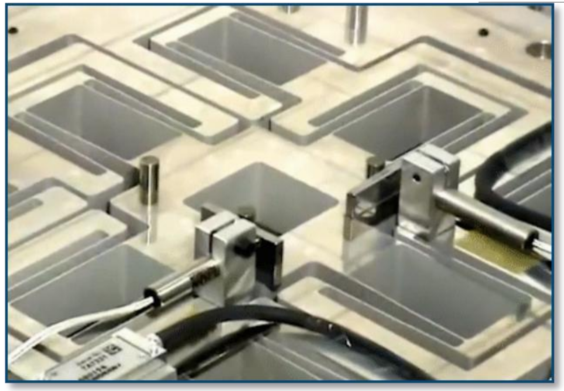
Research experience

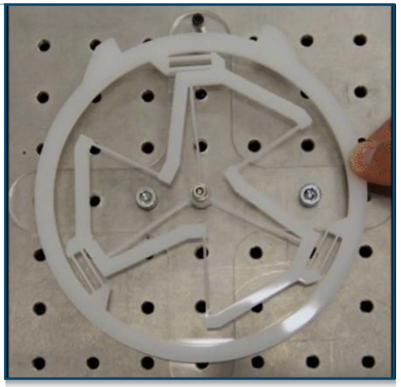
Theoretical Studies | Applied Research | Collaborations

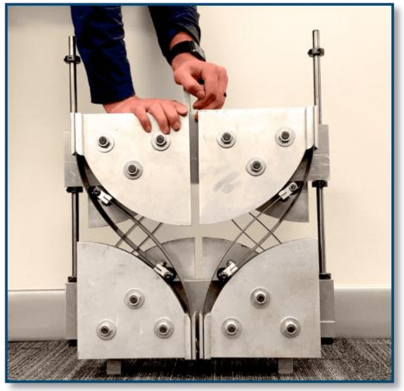
Flexible-structure-involved robotic systems

Modeling

- Statics/kinematics
- Dynamics


Compliant positioning stage [Umich]


Compliant revolute joint [EPFL]

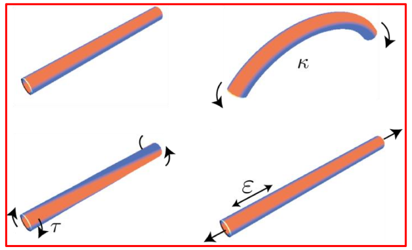

Contact-aided mechanism [BYU]


Bi-stable mechanisms [Delft University of Technology]

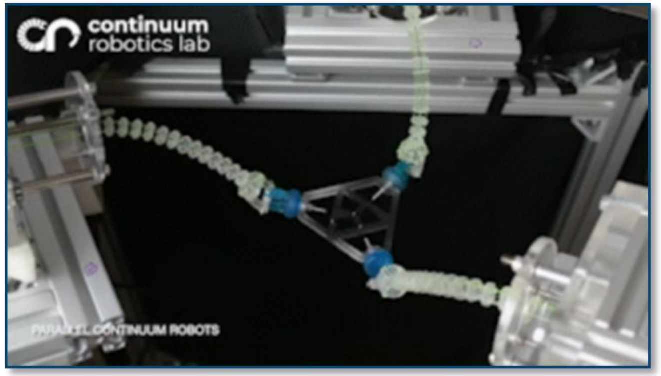

Wire-driven continumm robots [Maxon]

Slender structures

Rod, beam, plate theories




Pneumatic continuum robots [ETH]



Cable-driven continuum parallel robots [University of Toronto]

Research experience

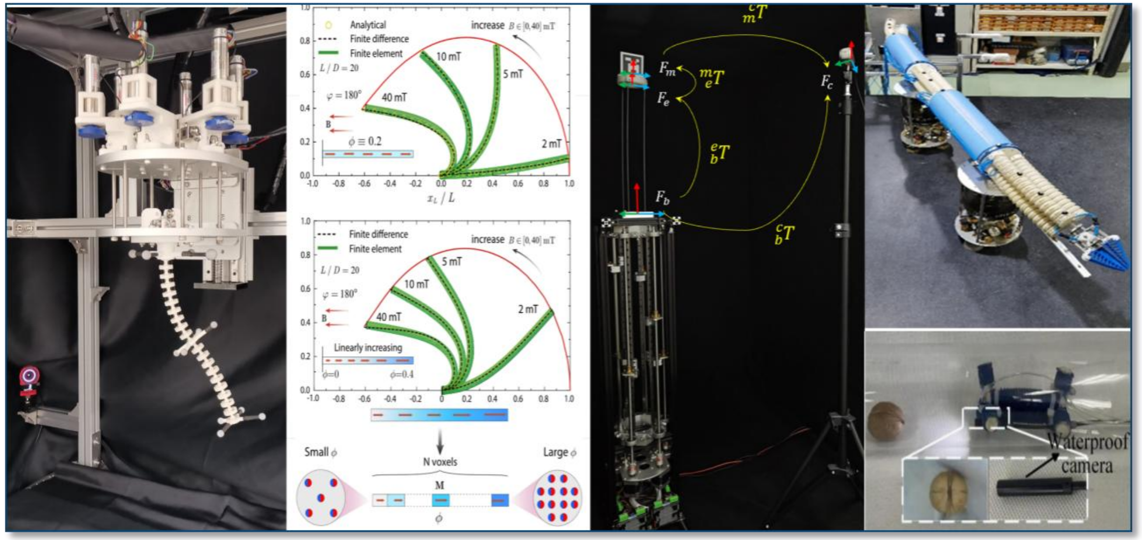
Theoretical Studies | Applied Research | Collaborations

Research interests

Research experience

Future research

Tendon-driven Magnetic-driven Rod-driven PAMs-driven

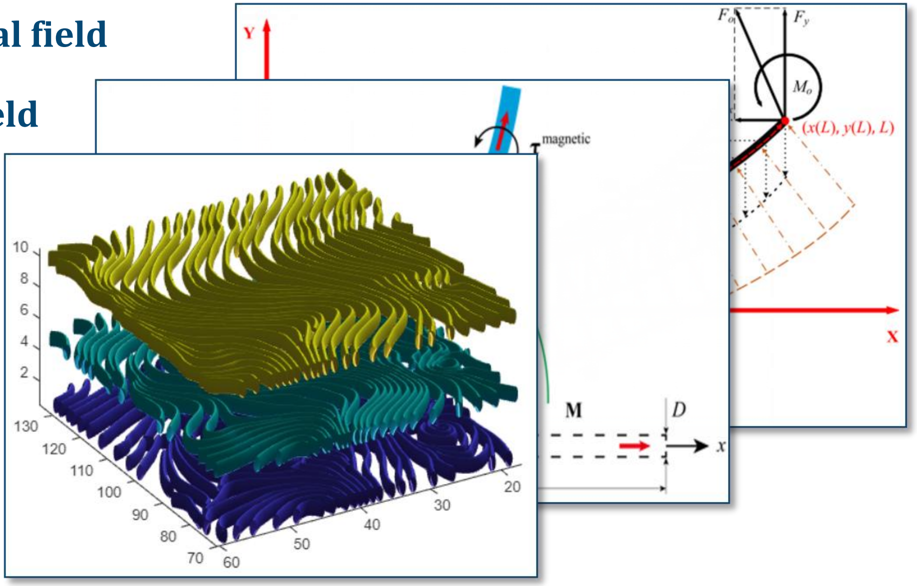


Gravitational field

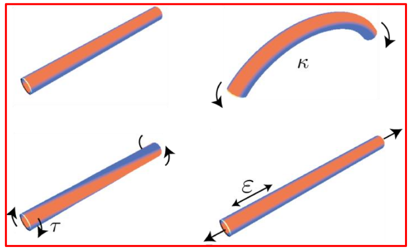
Magnetic field

Flow field

...



Rod, beam, plate theories



Cosserat rod theory

Kirchhoff rod theory

Euler-Bernoulli beam theory

...

Newtonian framework

Boundary/ initial value problem (BVP/IVP)

D.E. $\frac{d^2\theta}{ds^2} = f(\frac{d\theta}{ds}, \theta(s), \frac{dI}{ds}, I(s), \frac{dR}{ds}, R(s), F_x, F_y, M_o, q_x, q_y, q_n...)$

B.C. $\theta(0) = 0$

$\frac{d\theta}{ds}(L) = \frac{M_o}{EI(L)} + \frac{1}{R(L)}$

Lagrangian framework

Functional minimization problem (FMP)

$$\Pi = E_p - W_p$$
$$= f_{E_p}(u(s), v(s)) - f_{W_p}(F(s), \mathbf{R}(s), \mathbf{r}(s), v_o(s))$$

s.t. $\frac{\partial \mathbf{r}(s)}{\partial s} = \mathbf{v}(s)$; $\frac{\partial \mathbf{R}(s)}{\partial s} = \hat{\mathbf{u}}(s)\mathbf{R}(s)$

Wu, K., & Zheng, G. (2022). A comprehensive static modeling methodology via beam theory for compliant mechanisms. **Mechanism and Machine Theory**, 169, 104598.

Wu, K., & Zheng, G. (2022). Theoretical analysis on nonlinear buckling, post-buckling of slender beams and bi-stable mechanisms. **Journal of Mechanisms and Robotics**, 14(3), 031015.

Wu, K., Zheng, G., & Chen, G. (2023). Extending timoshenko beam theory for large deflections in compliant mechanisms. **Journal of Mechanisms and Robotics**, 15(6), 061012.

Research experience

Real-time Modeling

Newtonian framework

Boundary value problem

D.E. $\frac{\mathrm{d}^2\theta}{\mathrm{d}s^2} = f\left(\frac{\mathrm{d}\theta}{\mathrm{d}s}, \theta(s), \frac{\mathrm{d}I}{\mathrm{d}s}, I(s), \frac{\mathrm{d}R}{\mathrm{d}s}, R(s), F_x, F_y, M_o, q_x, q_y, q_n \ldots\right)$

B.C. $\theta(0) = 0$

$$\frac{\mathrm{d}\theta}{\mathrm{d}s}(L) = \frac{M_o}{EI(L)} + \frac{1}{R(L)}$$

Lagrangian framework

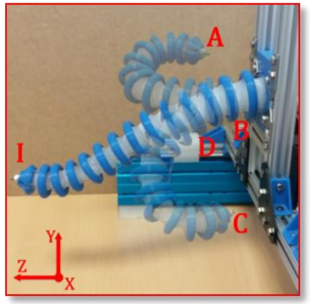
Functional minimization problem (FMP)

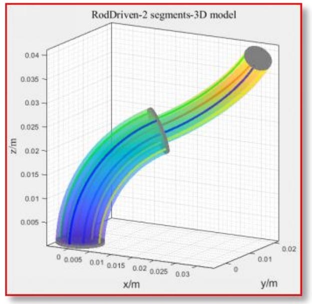
$$\Pi = E_p - W_p = f_{E_p}(u(s), v(s)) - f_{W_p}(F(s), \mathbf{R}(s), \mathbf{r}(s), v_o(s))$$

$$\text{s.t. } \frac{\partial \mathbf{r}(s)}{\partial s} = \mathbf{v}(s); \quad \frac{\partial \mathbf{R}(s)}{\partial s} = \hat{\mathbf{u}}(s)\mathbf{R}(s)$$

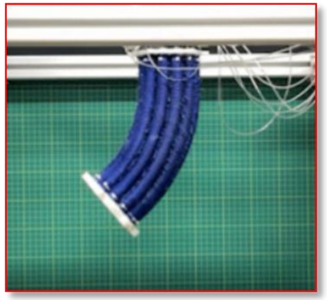
Model reduction strategies

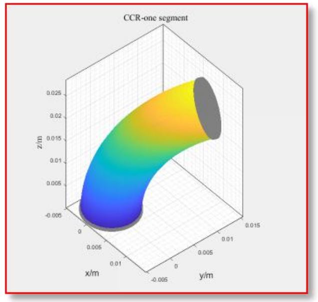
Rod/beam/plate model reduction





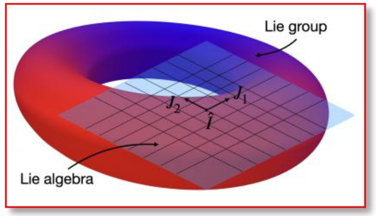
Virtual modeling

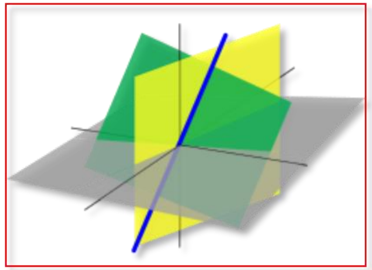




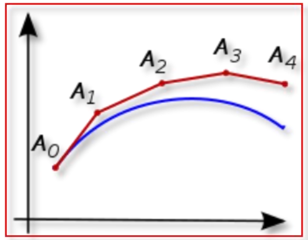
Efficient computing methods

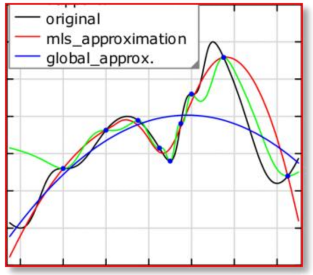
Choice of domain



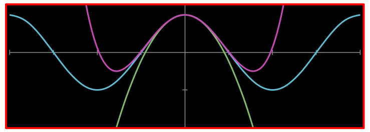


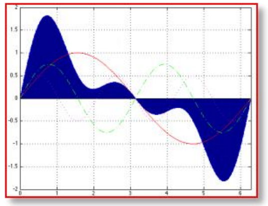
Approximation techniques

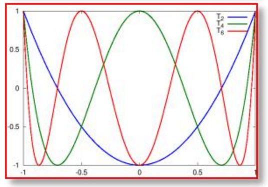




Basis functions





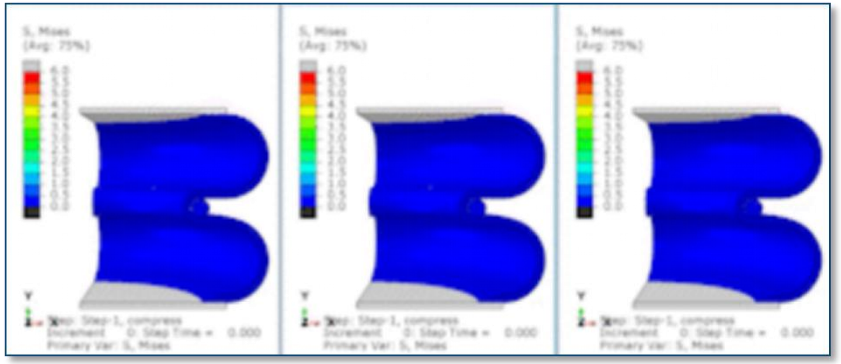


Wu, K., & Zheng, G. (2022). Solutions to large beam-deflection problems by Taylor series and Padé approximant for compliant mechanisms. **Mechanism and Machine Theory**, 177, 105033.
Wu, K., & Zheng, G. (2022). Insight into numerical solutions of static large deflection of general planar beams for compliant mechanisms. **Mechanism and Machine Theory**, 172, 104757.
Wu, K., Zheng, G., Chen, G., & Awtar, S. (2024). A Body-frame Beam Constraint Model. **Mechanism and Machine Theory**, 192, 105517.

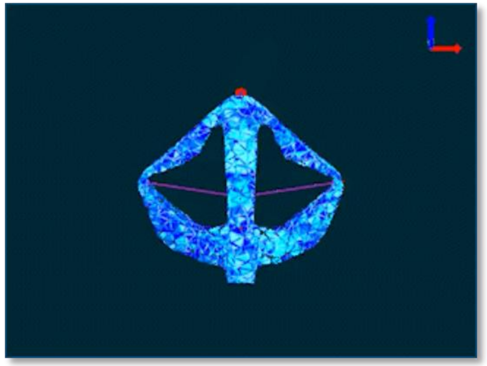
Research experience

Flexible-structure-involved robotic systems

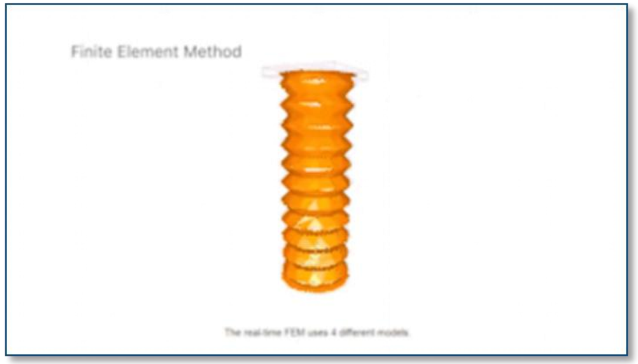
Modeling
- Statics/kinematics
- Dynamics



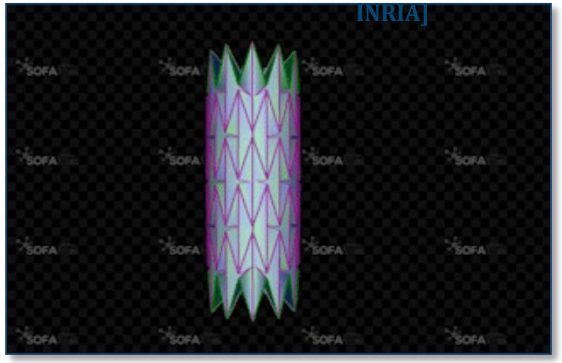
Rubber fibre reinforced air spring [Simuleo]



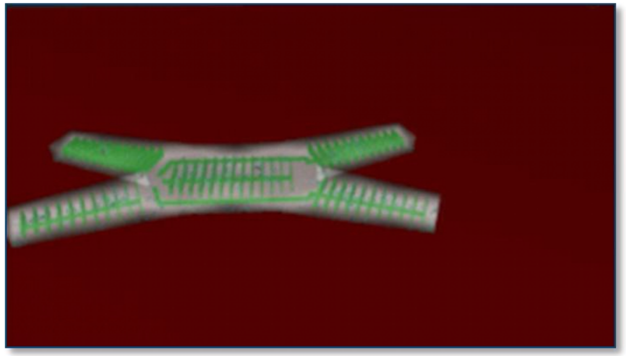
Soft diamond robot [DEFROST INRIA]



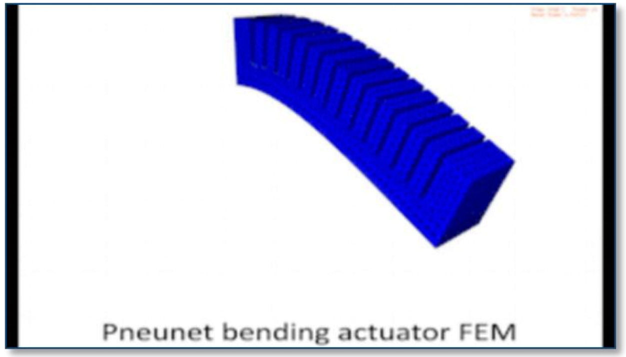
Cable&pneumatic-driven rubber robot [UPM]



Origami [DEFROST INRIA]



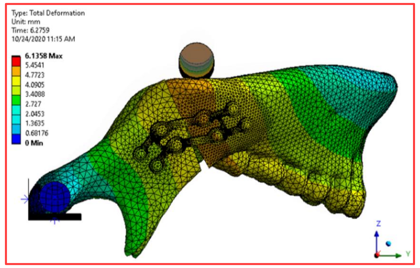
Soft multi-gait robot [Harvard&DEFROST INRIA]



Pneunet actuator [Harvard]

Complex structures

Solid mechancs



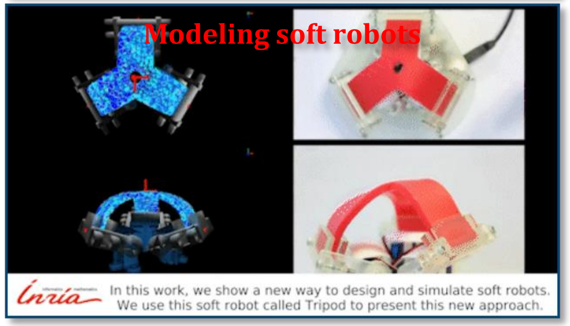
Wu, K., & Zheng, G. (2020, July). Simulation and control co-design methodology for soft robotics. In 2020 **39th Chinese Control Conference (CCC)** (pp. 3910-3914). IEEE.

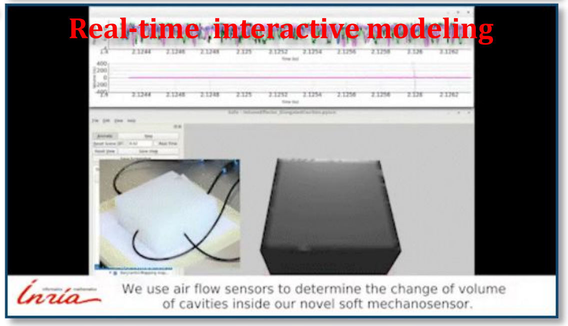
Research experience

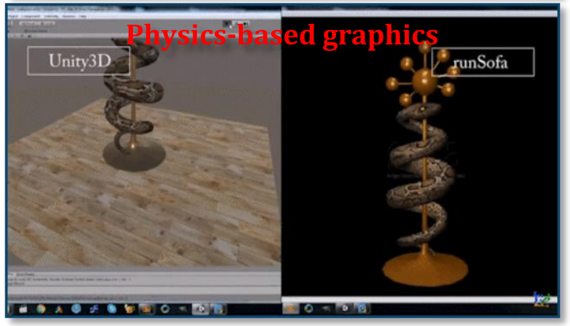
Research interests
Research experience
Future research

SOFA Simulation Open Framework Architecture

- Solid mechanics/ FEM
- Open-source
- Real-time
- Interactive simulation
- Biomechanics and soft robotics

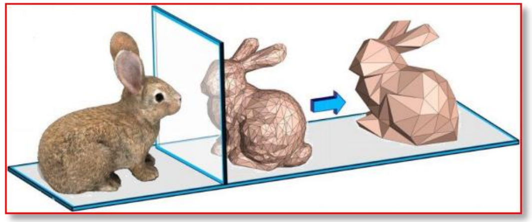






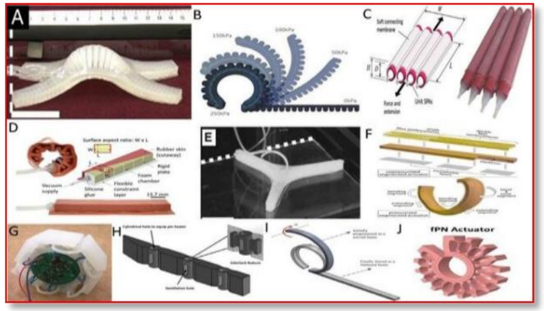
SOFA

Model reduction for real-time simulations

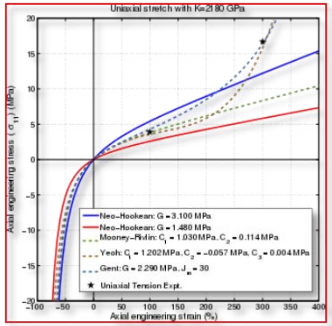


Efficient computation for FEM

Plugin development for different actuation systems in soft robots



Modeling different materials



Wu, K., & Zheng, G. (2021). Fem-based gain-scheduling control of a soft trunk robot. **IEEE Robotics and Automation Letters**, 6(2), 3081-3088.

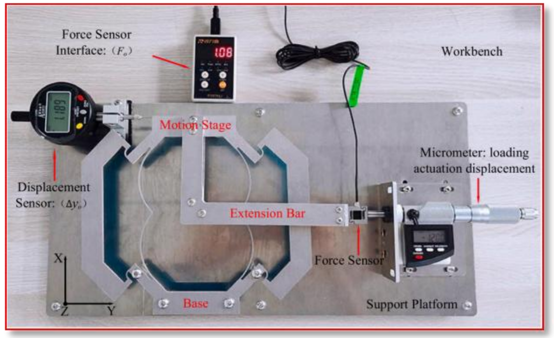
Wu K., & Zheng, G. (2022). FEM-based nonlinear controller for a soft trunk robot. **IEEE Robotics and Automation Letters**, 7(2), 5735-5740.

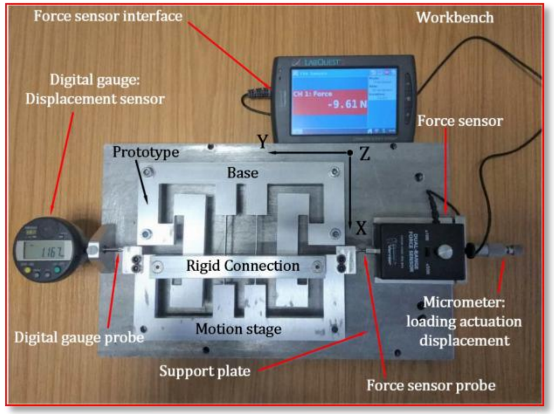
Wu K., Zheng, G., & Zhang, J. (2022). FEM-based trajectory tracking control of a soft trunk robot. **Robotics and Autonomous Systems**, 150, 103961.

Design
Structure optimization

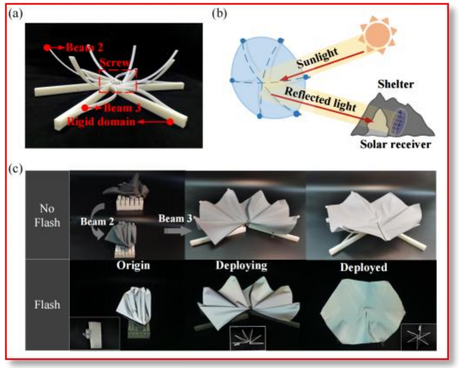
Design problem → Design Objectives / Design Constraints → Cost Function / Constraints → Optimization problem

Micro-positioning Stages

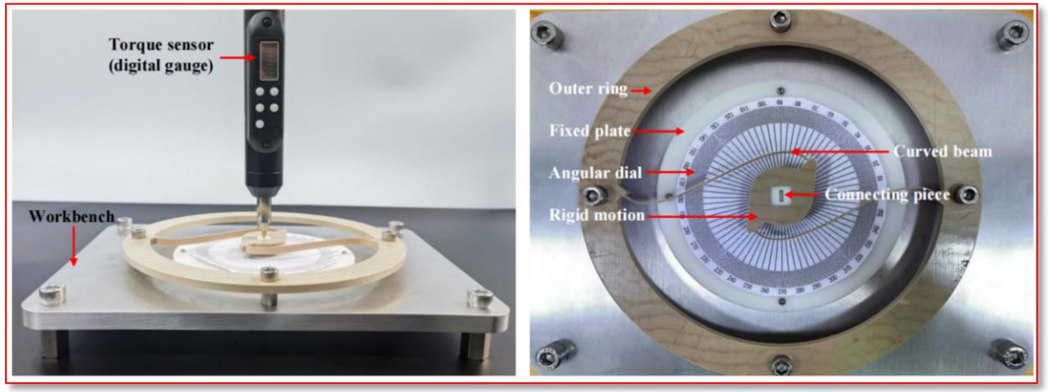




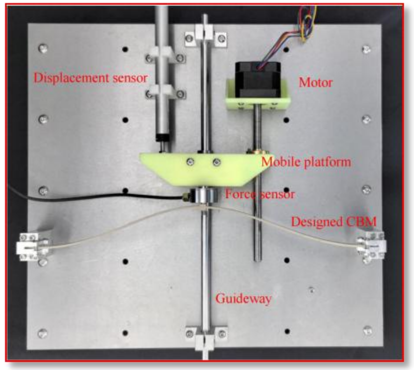
Deplyable Structures



Compliant Constant-torque Mechanisms/Sensors



Bi-stable Mechanisms



Wu, K., & Hao, G. (2020). Design and nonlinear modeling of a novel planar compliant parallelogram mechanism with general tensural-compresural beams. **Mechanism and Machine Theory**, 152, 103950.
Wu, K., Zheng, G., & Hao, G. (2021). Efficient spatial compliance analysis of general initially curved beams for mechanism synthesis and optimization. **Mechanism and Machine Theory**, 162, 104343.
Chen, R., Wang, W., **Wu, K.**, Zheng, G & Luo, J. (2023). Design and optimization of a novel compliant planar parallelogram mechanism utilizing initially curved beams. **Mechanism and Machine Theory**, 179, 105092.

Research experience

Theoretical Studies | **Applied Research** | Collaborations

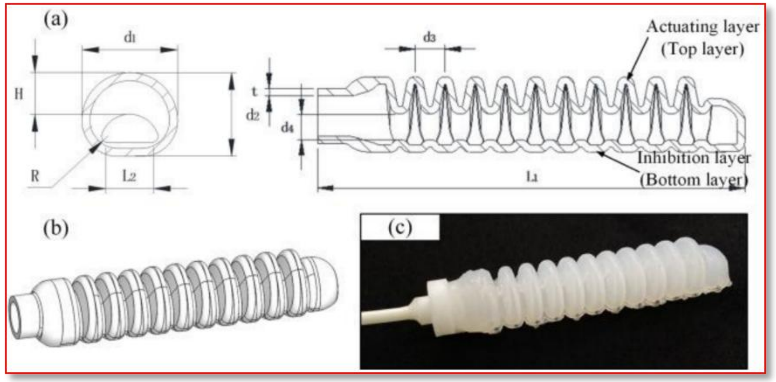
Design
Structure optimization

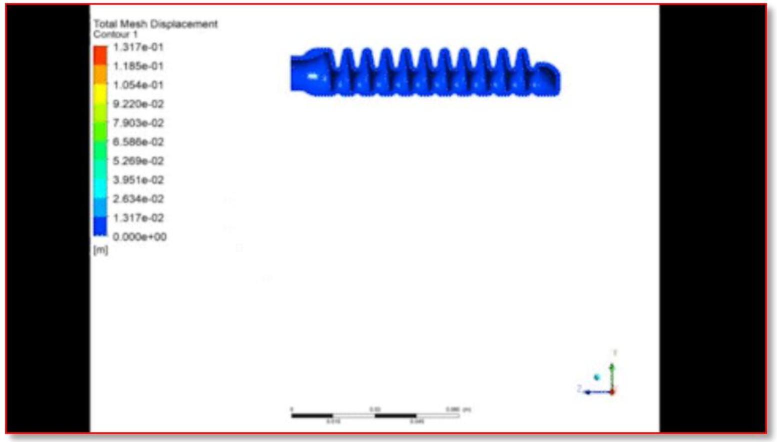
COMSOL
Ansys
SOFA

- Solid mechanics
- Fluid mechanics
- Physical contact

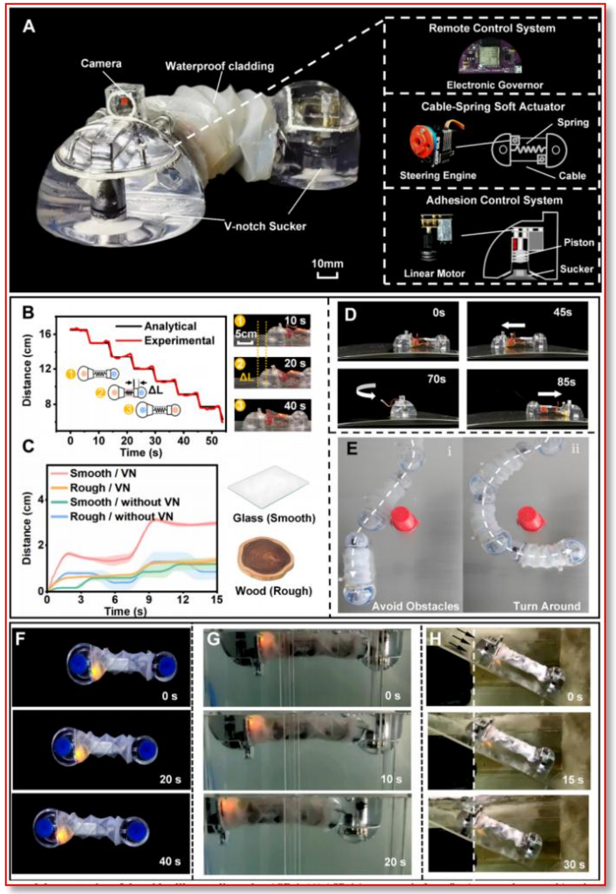
→ **Bio-inspired intuitive design**

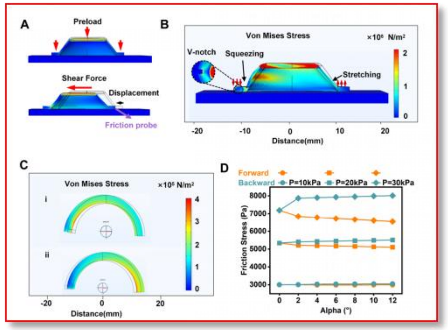
Finger-like Soft Pneumatic Actuator

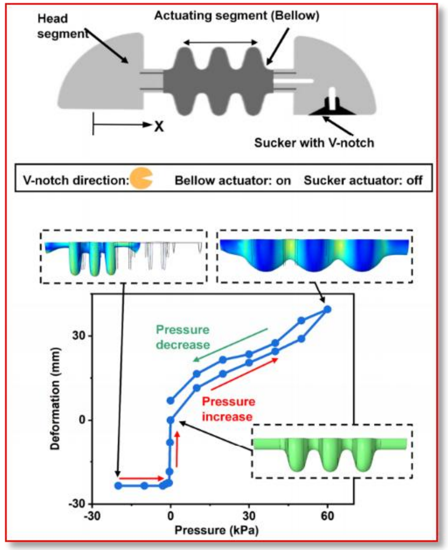




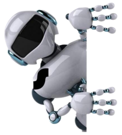
A Biomimetic Adhesive Disc



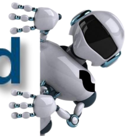




Xu, H., ...**Wu, K.**, Wang, T., Pham, N., Kovac, M., Ding, X. & Wen, Li. (2024). A biomimetic soft adhesive disc for robotic adhesion sliding inspired by the net-winged midge larva. **Soft Robotics. (Accepted)**
Lv, Z., **Wu, K.**, Zhang, Z., & He, Y. (2024). Two-way FSI simulation and experiments for finger-like soft pneumatic actuator under high-speed pressurization. **IEEE Robotics and Automation Letters.**



Modeling complex-structured robots



Virtual model based on Cosserat rod theory

Material Identification

Actuation Modes

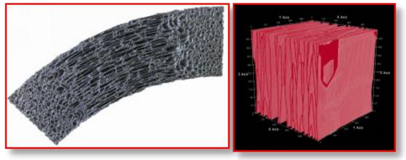
External forces

Modeling

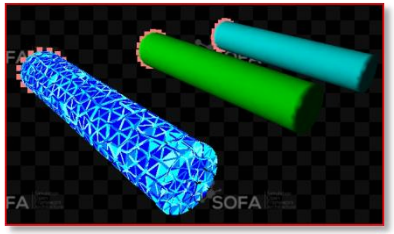
Model reduction

Efficient computation

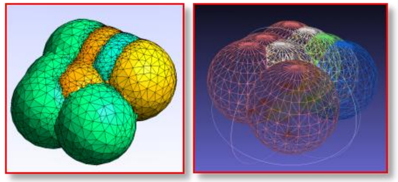
Material Identification



Anisotropic Material

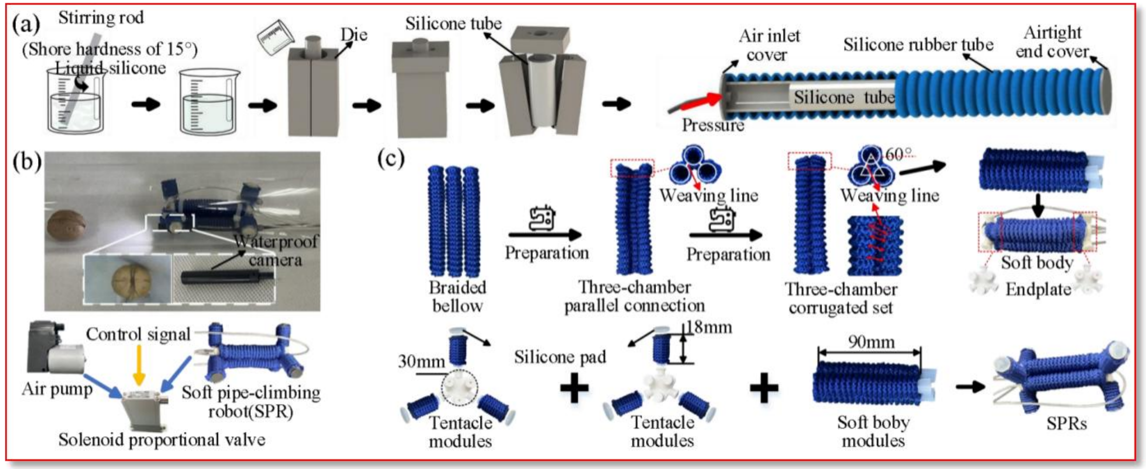


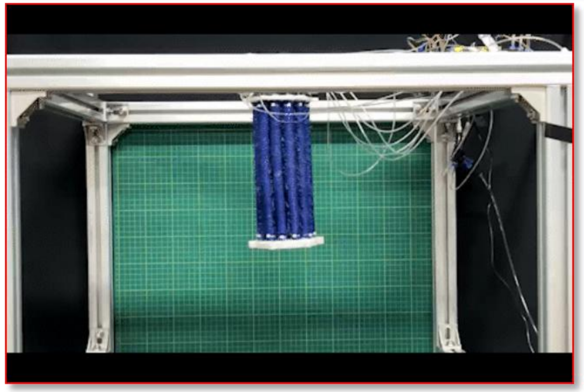
Hyperelastic Material

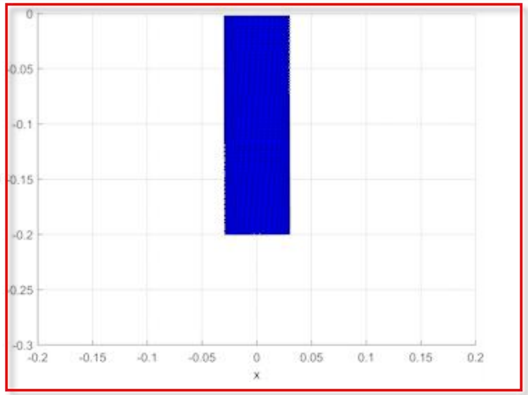


Complex Material

Pneumatic Continuum Robots







Wang, W., Wang, X., Zheng, G., Chen, R., Yuan, Z., **Wu K*** & Bao, G*. (2024). A Modular Soft Pipe-Climbing Robot With High Maneuverability. **IEEE/ASME Transactions on Mechatronics**.

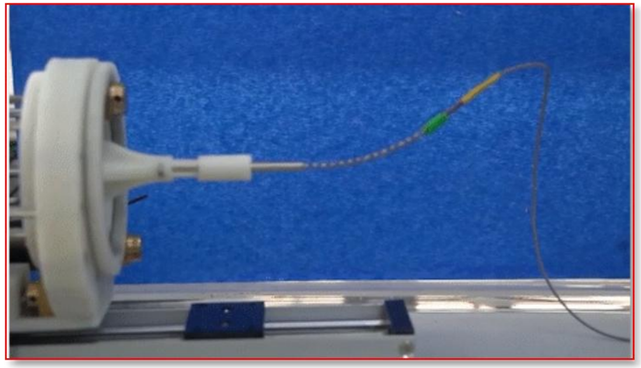
Research experience

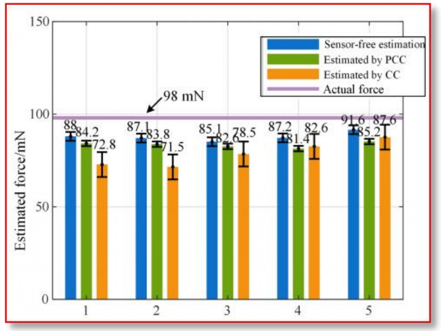
Theoretical Studies | **Applied Research** | Collaborations

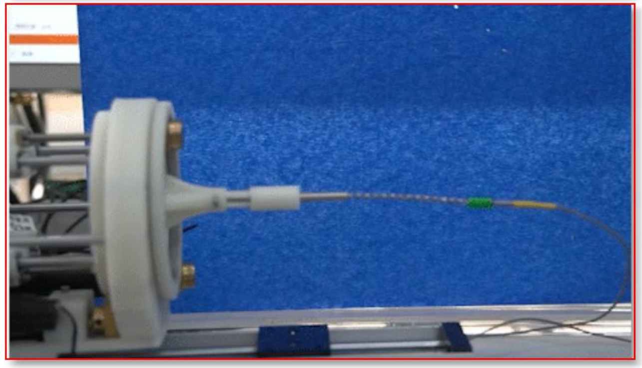
Controller
Model-based/free

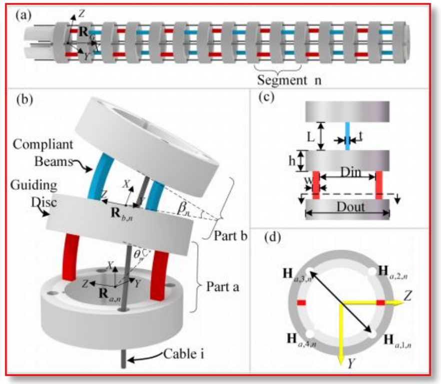
Cosserat rod theory → [Actuation Modes / External forces → Modeling → Model reduction / Efficient computation] → Controller design

Cable-driven Continuum Robots for Surgical Operation

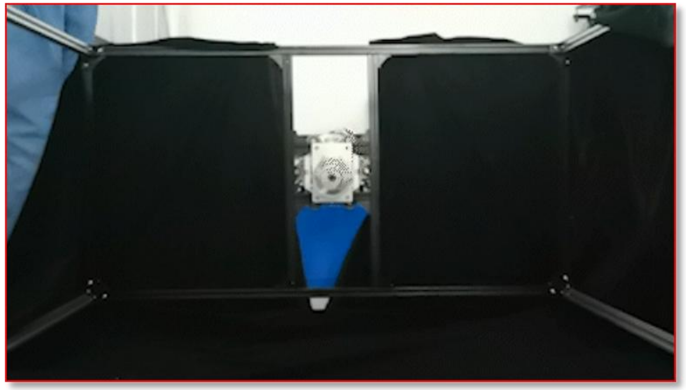


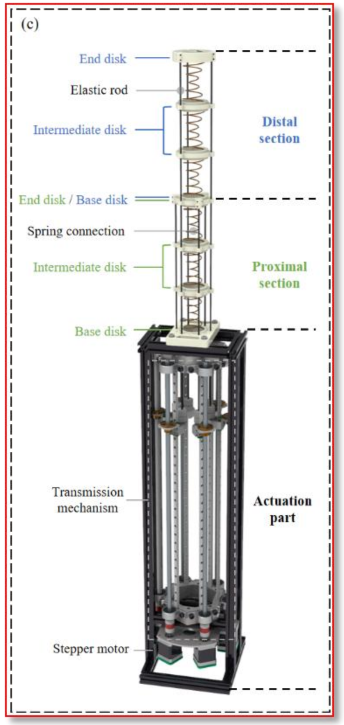






Rod-drven Continuum Robots





Li X., Wang Y., **Wu K.**,... Li T. Song R., Design and Modeling of a Multi-backbone Continuum Robot with a Large Extension Ratio. **International Journal of Mechanical Sciences. (under review)**

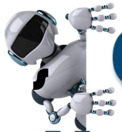
Zhang G., Du F., Zhang X., **Wu K.**, Zheng G., Li Y., Song R., Continuum Robots: a Real-time Model-based Data-driven Nonlinear Controller. **IEEE Transactions on Industrial Electronics.**

Du F., Zhang X., Zhang G., **Wu K.**, Zheng G., Li Y., Song R., Design and Modeling of Continuum Robot for Endoscopic Submucosal Dissection Surgery with Lifting Force Estimation. **The International Journal of Medical Robotics and Computer Assisted Surgery**

Research experience

Theoretical Studies | **Applied Research** | Collaborations

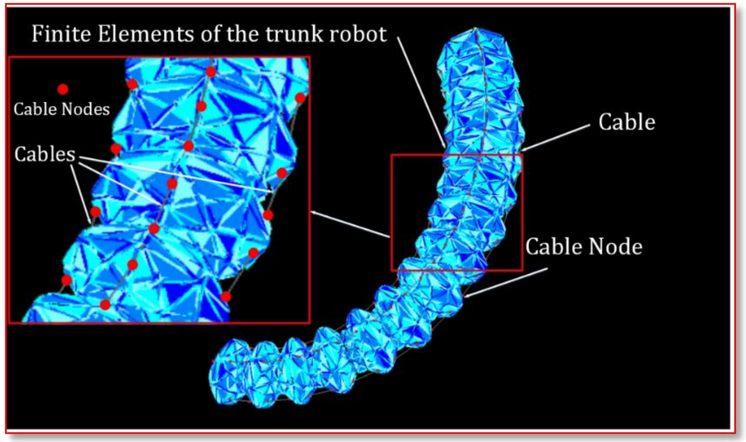
- Research interests
- **Research experience**
- Future research



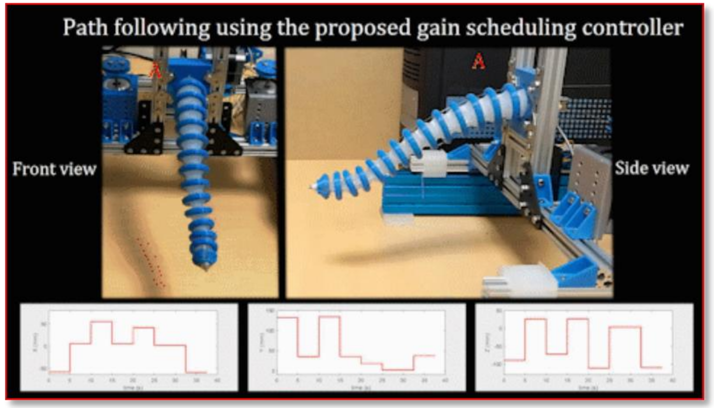
Controller
Model-based/free

Solid mechanics/FEM → [Actuation Modes | External forces] Modeling (SOFA) [Model reduction | Efficient computation] → Controller design

Silicone-based Soft Trunk Robots



Gain-schedualing controller

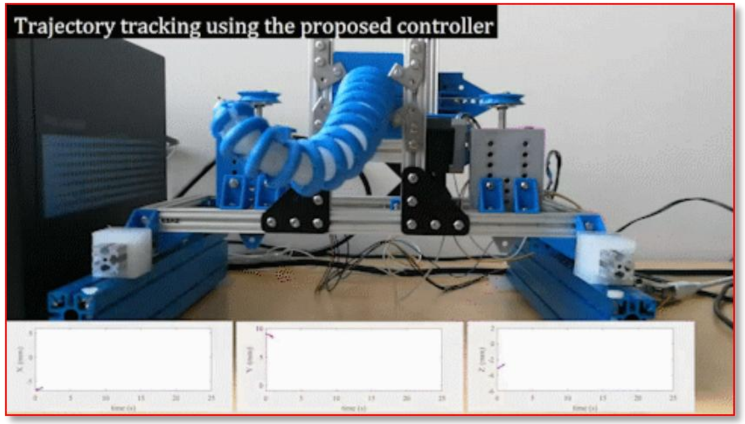


Wu, K., & Zheng, G. (2021). Fem-based gain-scheduling control of a soft trunk robot. **IEEE Robotics and Automation Letters**, 6(2), 3081-3088.

Nonlinear adpative controller

Wu K., & Zheng, G. (2022). FEM-based nonlinear controller for a soft trunk robot. **IEEE Robotics and Automation Letters**, 7(2), 5735-5740.

Trajectory tracking based on MPC



Wu K., Zheng, G., & Zhang, J. (2022). FEM-based trajectory tracking control of a soft trunk robot. **Robotics and Autonomous Systems**, 150, 103961.

Euler Bernoulli beam theory

Learning from demonstration

Modeling

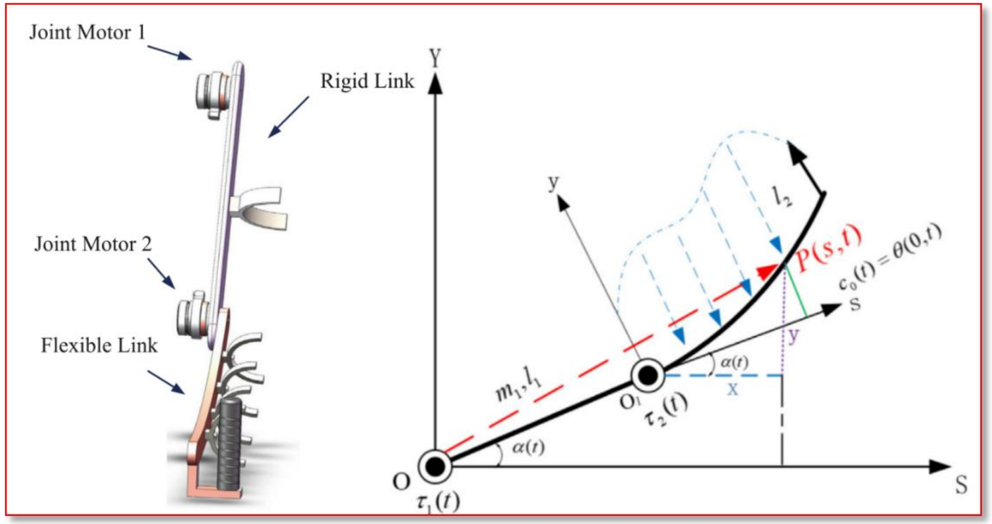
Actuation Modes

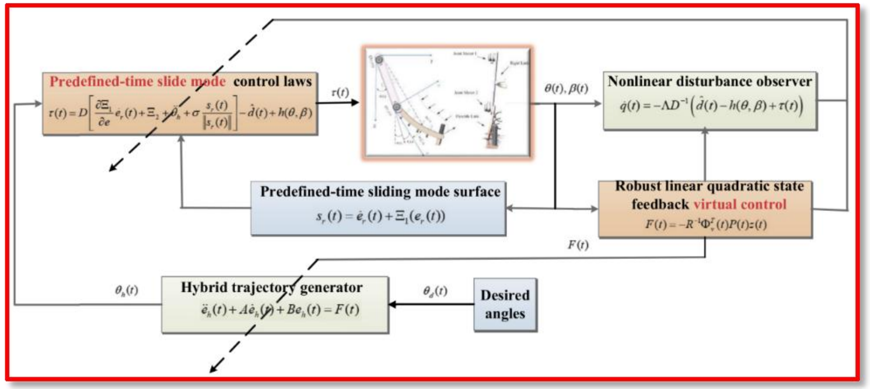
External forces

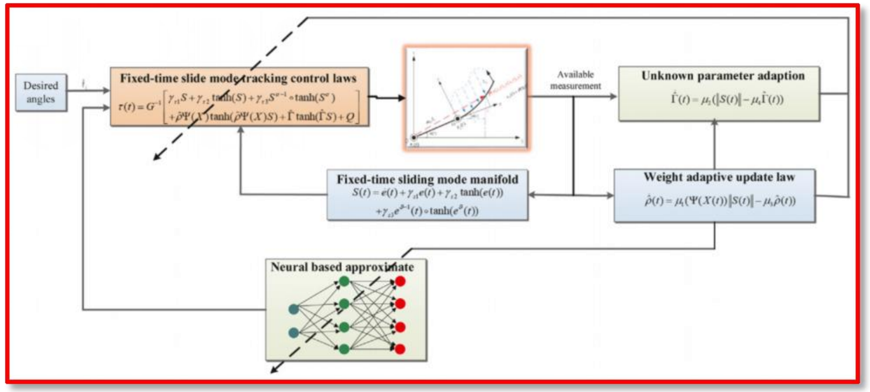
Training the model-free controller

Real-time hybrid controller design

Rigid-flexible Coupled Robotic Mechanisms





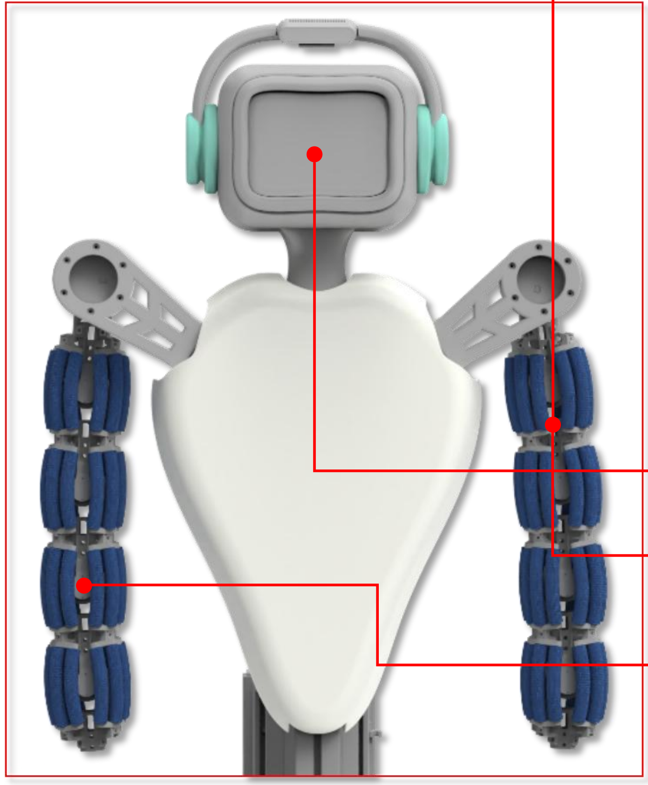


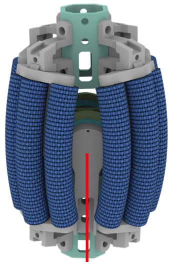
Zhou, X., Wang, H., **Wu, K.**, & Zheng, G. (2023). Fixed-time neural network trajectory tracking control for the rigid-flexible coupled robotic mechanisms with large beam-deflections. **Applied Mathematical Modelling**, 118, 665-691.

Zhou, X., Wang, H., **Wu, K.**, Tian, Y., & Zheng, G. (2023). Nonlinear disturbance observer-based robust predefined time tracking and vibration suppression control for the rigid-flexible coupled robotic mechanisms with large beam-deformations. **Computers & Mathematics with Applications**, 148, 1-25.

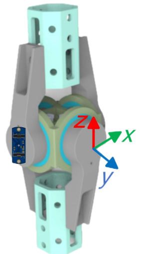
Advanced manipulation Human robot interaction

Pneumatic Humanoid Robots



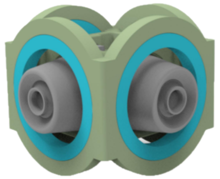


Driven by PAMs



Passive kinematic joint

Angle sensor

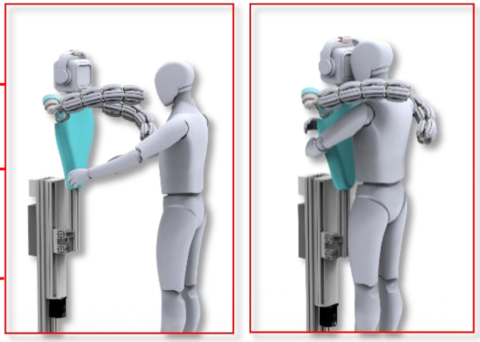


Self-adjustable stiffness

Low-level Controller design for Single soft-rigid robotic arms

Static/dynamic modeling → Motion planning → Motion control

High-level Controller design for human robot interaction



Intent recognition

Motion planning

Demo

Research experience

Theoretical Studies | Applied Research | **Collaborations**

Research interests

Research experience

Future research

NUS National University of Singapore

重庆大学 CHONGQING UNIVERSITY

香港中文大學 The Chinese University of Hong Kong

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

Inria inventors for the digital world

UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

Tyndall National Institute Institiúid Náisiúnta

XI'AN JIAOTONG UNIVERSITY 1896

ZHEJIANG UNIVERSITY OF TECHNOLOGY 1953

WUHAN UNIVERSITY 1893 武漢大學

SHANDONG UNIVERSITY 1901

SICHUAN UNIVERSITY 1896

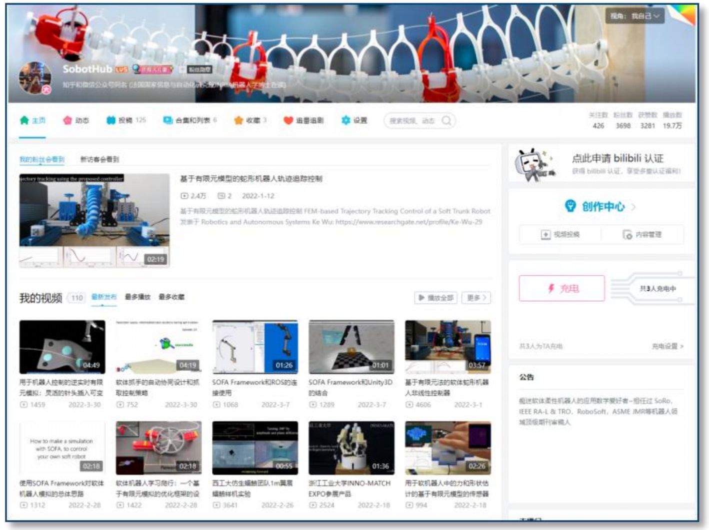
ZHEJIANG UNIVERSITY 1897

BEIHANG UNIVERSITY 1952

UCD DUBLIN

UNIVERSITY OF MICHIGAN

Sharing basic knowledge about my research areas on Chinese social media platforms with over 6000 followers

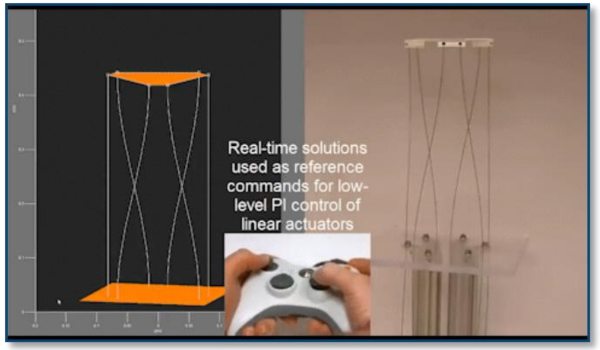


Students and young researchers come to me for advice

Building formal academic collaborations

Future research

Deformable robotic systems



Continuum parallel robots [University of Tennessee]

Cable-driven continuum robots [University of Toronto]

Magnetic-driven continuum robots [MIT]

Learning from → Classic Robotics

Fundamentals

Modeling
- Statics/kinematics
- Dynamics

Motion planning
- Configuration
- End effector

Control
- Motion control
- Force control

Design
- Actuation design
- Sensor design

World modeling
- Dynamic environments

Perception
- Sensing
- Estimation

Advanced manipulation

- Human robot interaction
- Human robot collaboration