Portfolio

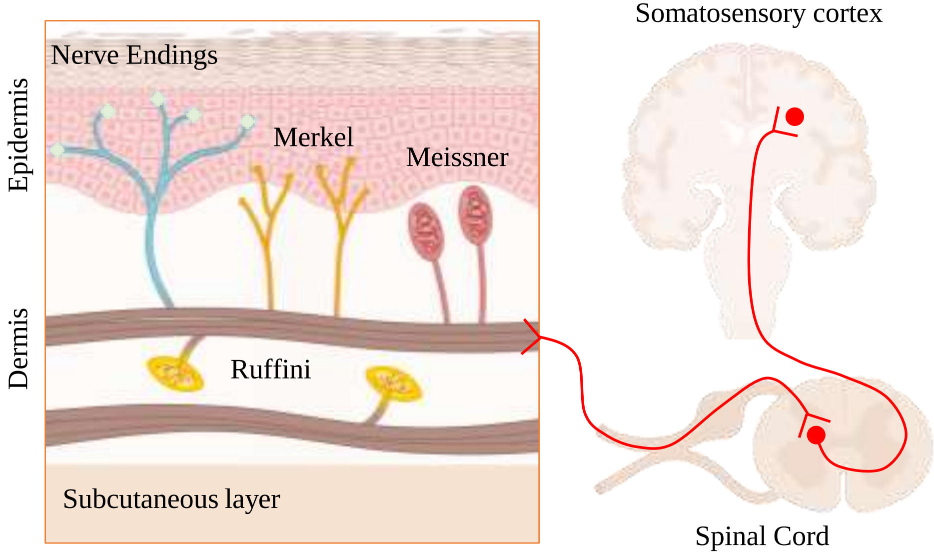
HAO WU
Projects 2020-2025
Mechanical Engineering
Personal Website: https://wuhao-me.github.io/

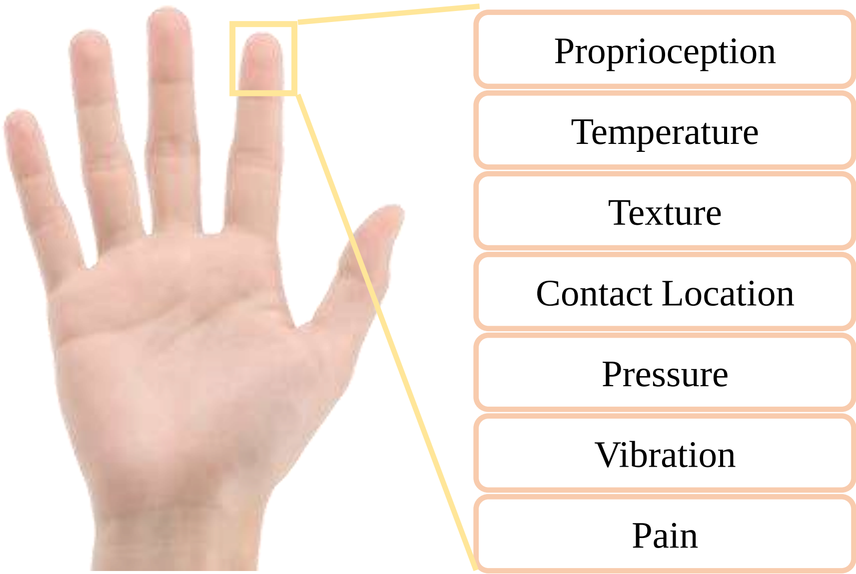
Flexible Tactile Sensing

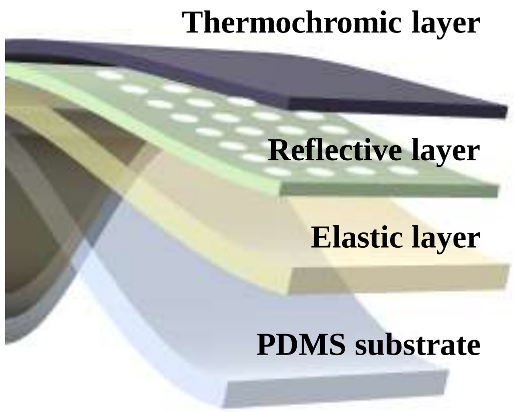
Development and Integration of Highly Compliant Optical Tactile Sensor with Grasping Manipulator

Background: Human hands process highly complex and refined sensory capabilities, playing a crucial role in how humans perceive and understand the world. This study proposes a novel soft robotic hand that replicates human tactile functions.

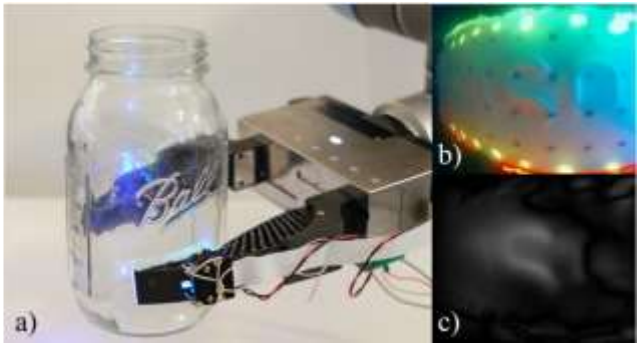
Biological motor and tactile sensory system

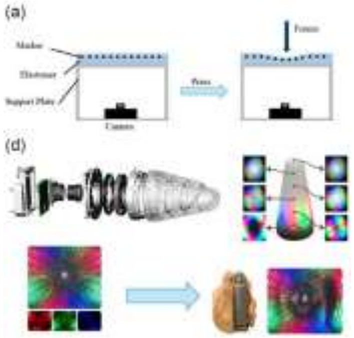


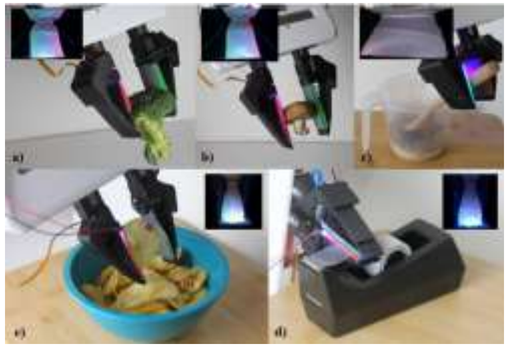




Current Research: The inherent deformations of soft interactions obstruct optical paths and restrict the camera's field of view, making it challenging to integrate visual-tactile sensing with soft grippers while maintaining compliance and coverage.

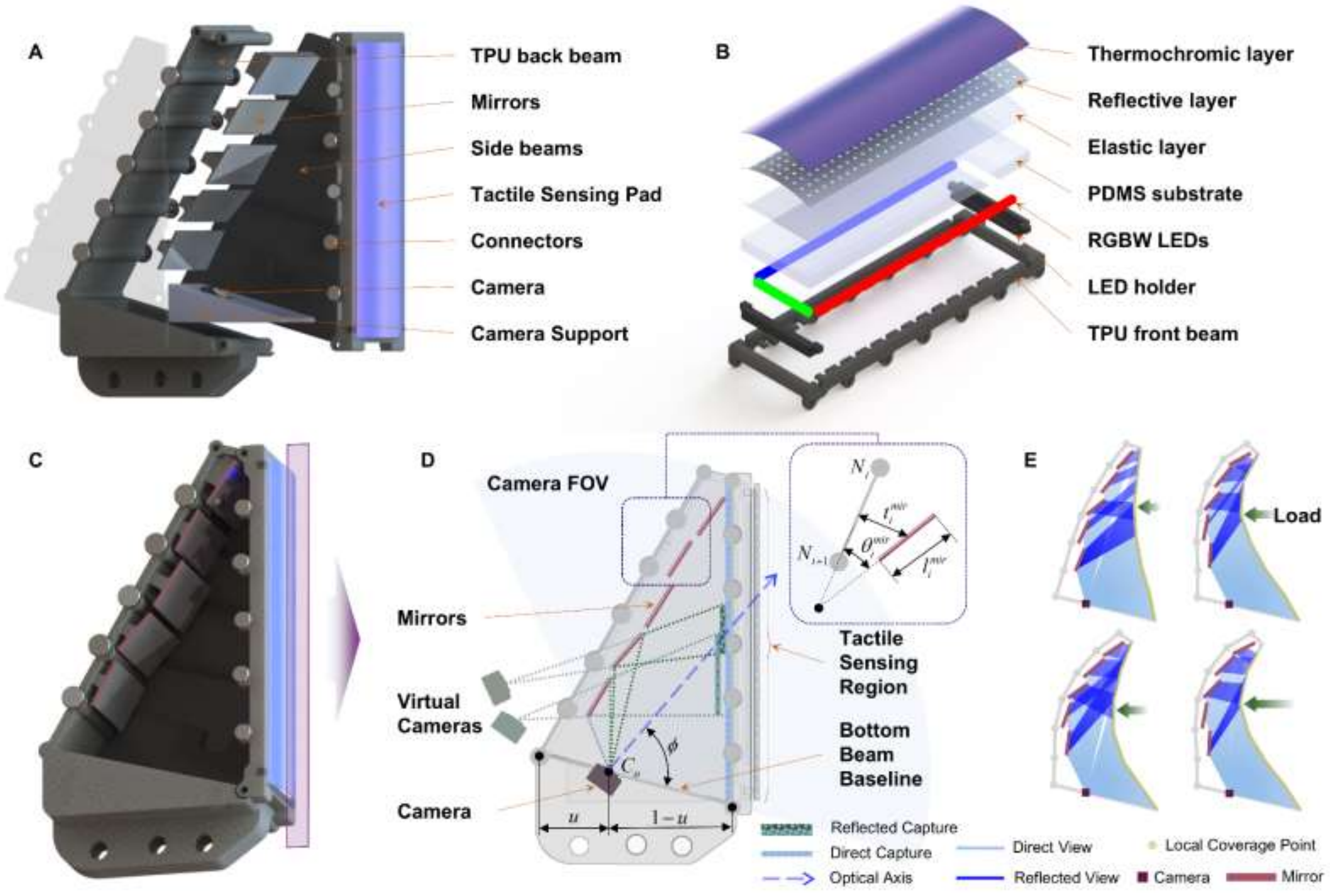


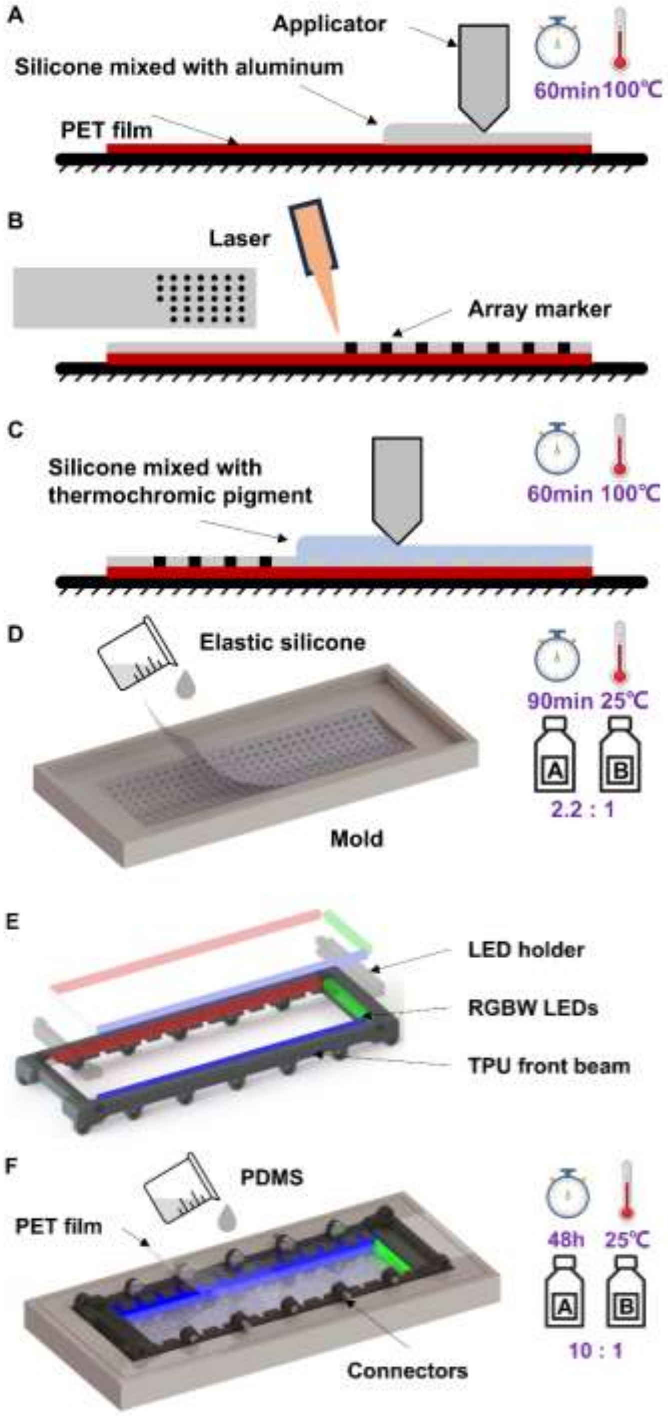




Flexible Tactile Sensing

Research: We propose Gelsight FlexiRay, a novel integrated soft manipulator that combines visual-tactile sensing with the FRE gripper. It offers low cost, large sensory coverage, high compliance, and human-like multimodal tactile capabilities.



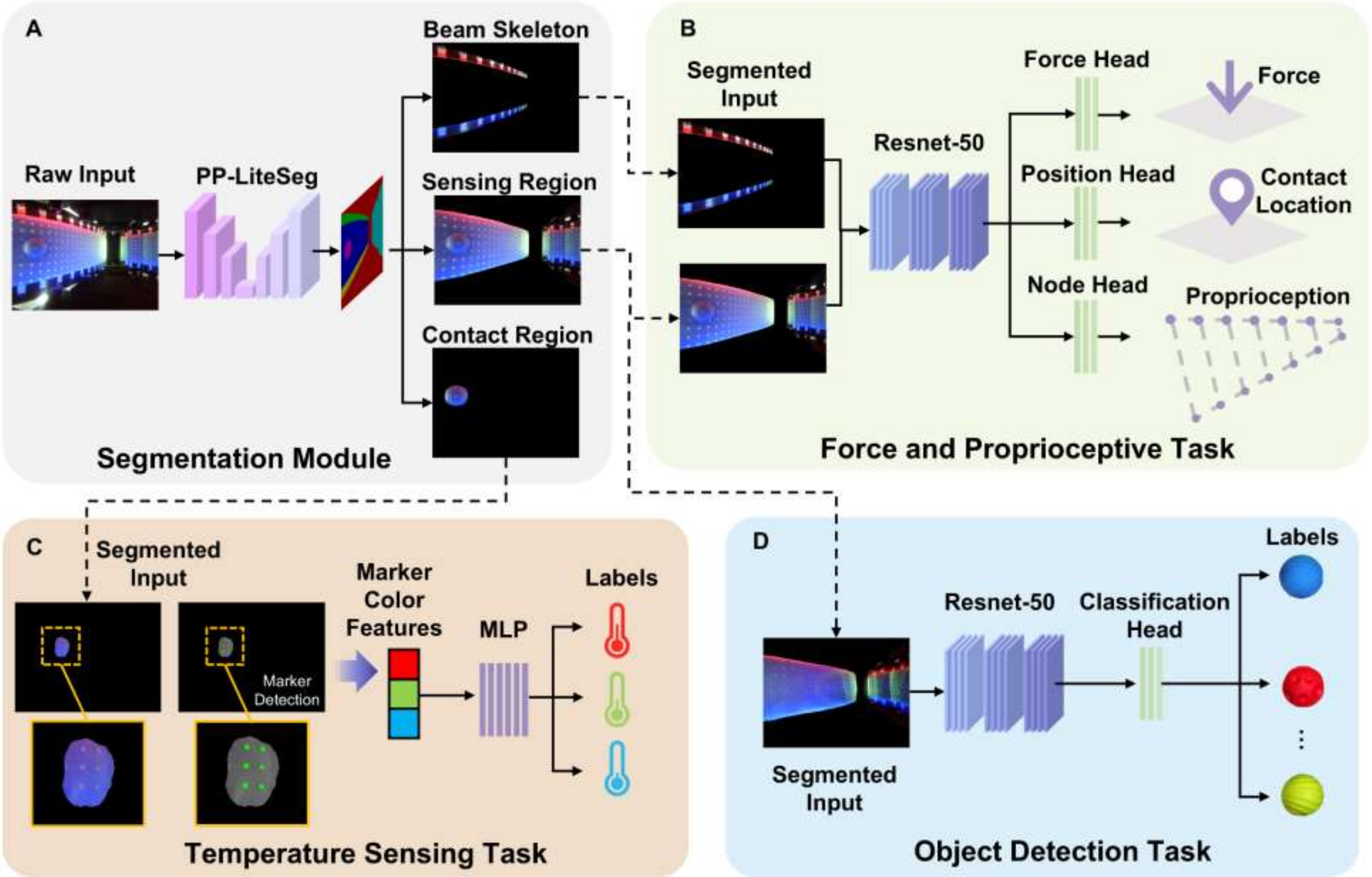


Flexible Tactile Sensing

View the article on Arxiv: https://arxiv.org/abs/2411.18979
Get more information on my website: https://wuhao-me.github.io/

Learning Methods:

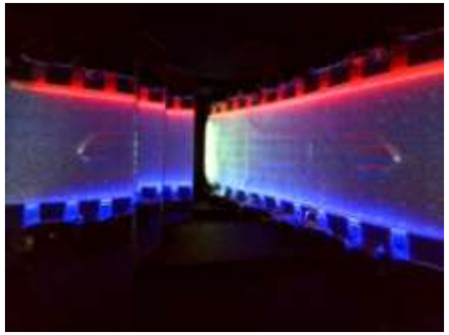
- Proprioception
- Temperature
- Texture
- Contact Location
- Pressure



Flexible Tactile Sensing

Results: The results demonstrate that Gelsight FlexiRay not only conforms to and wraps around large curved objects but also accurately captures the surface contours and geometric details of each object, even during flexible deformations.

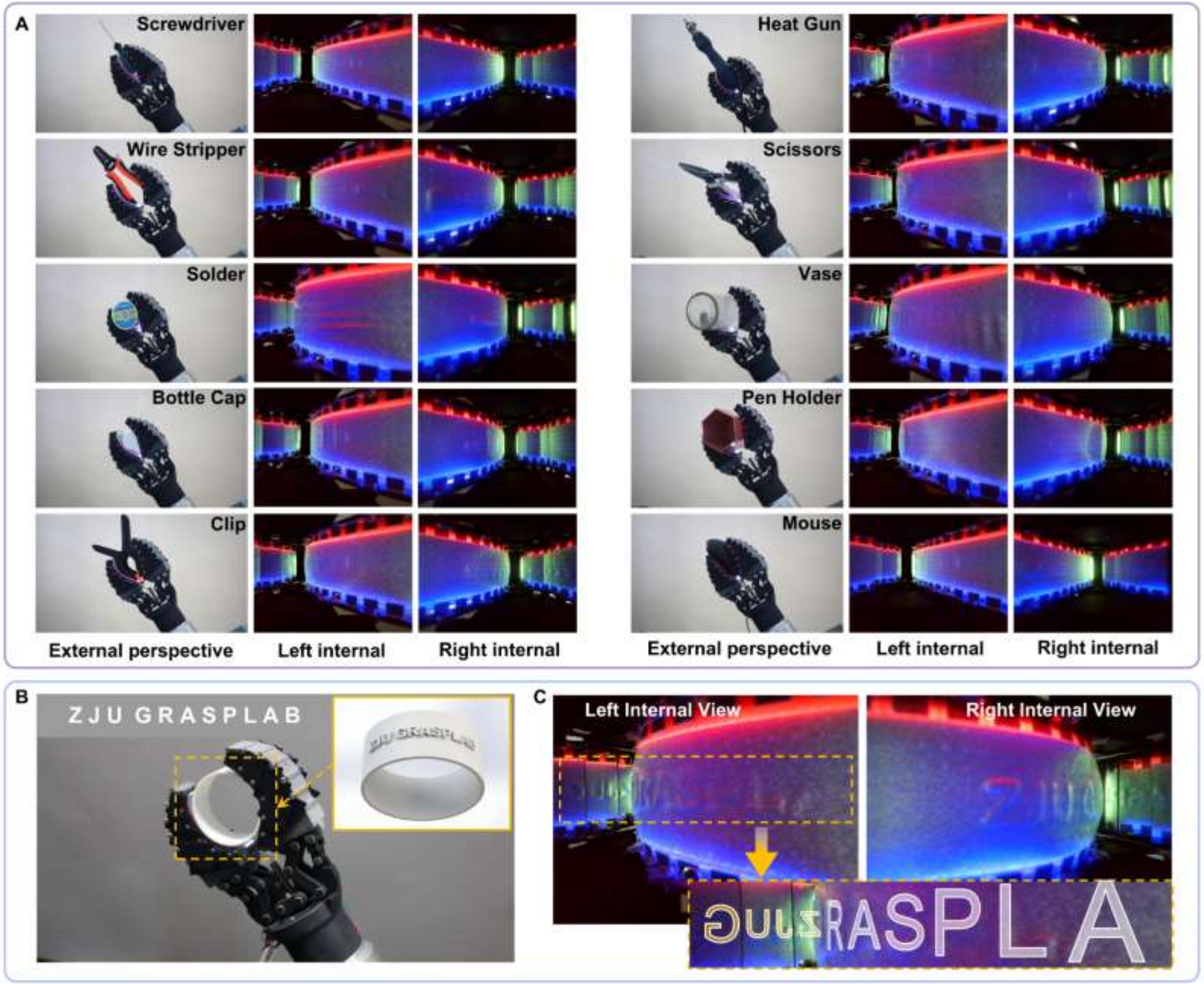
Key



Paperclip

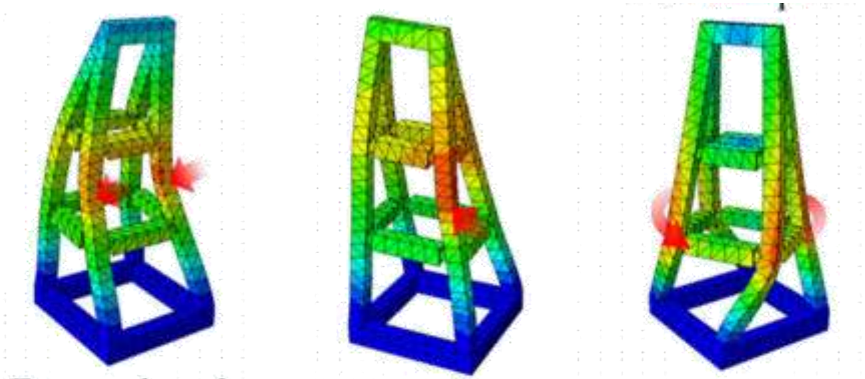
Clip

Drill bit

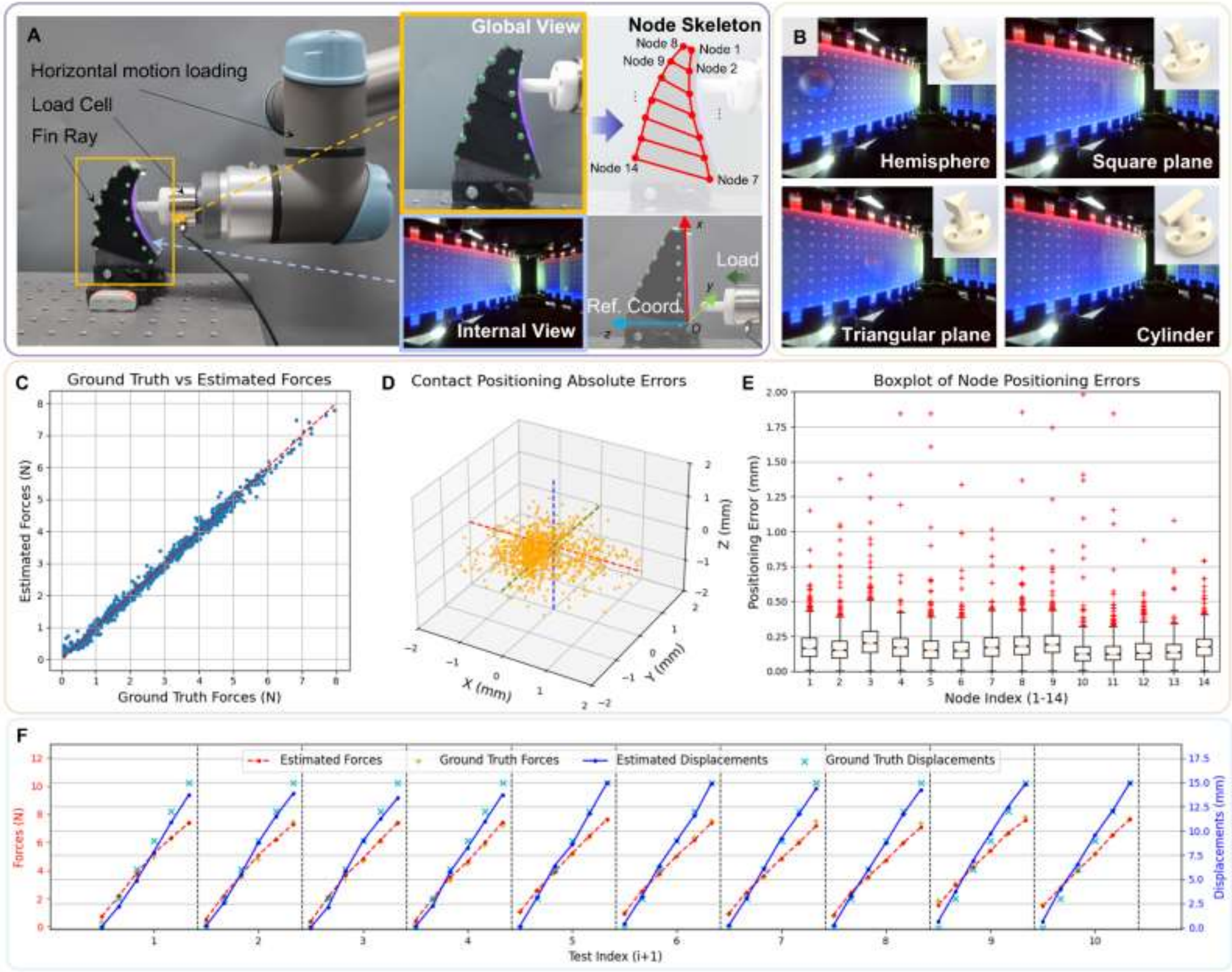


Flexible Tactile Sensing

Results: The model maintains high accuracy and stability in estimating both force and contact depth under dynamic, continuous prediction. Gelsight FlexiRay can achieve a force-sensing accuracy of 0.14 N and a proprioceptive positioning accuracy of 0.19mm.

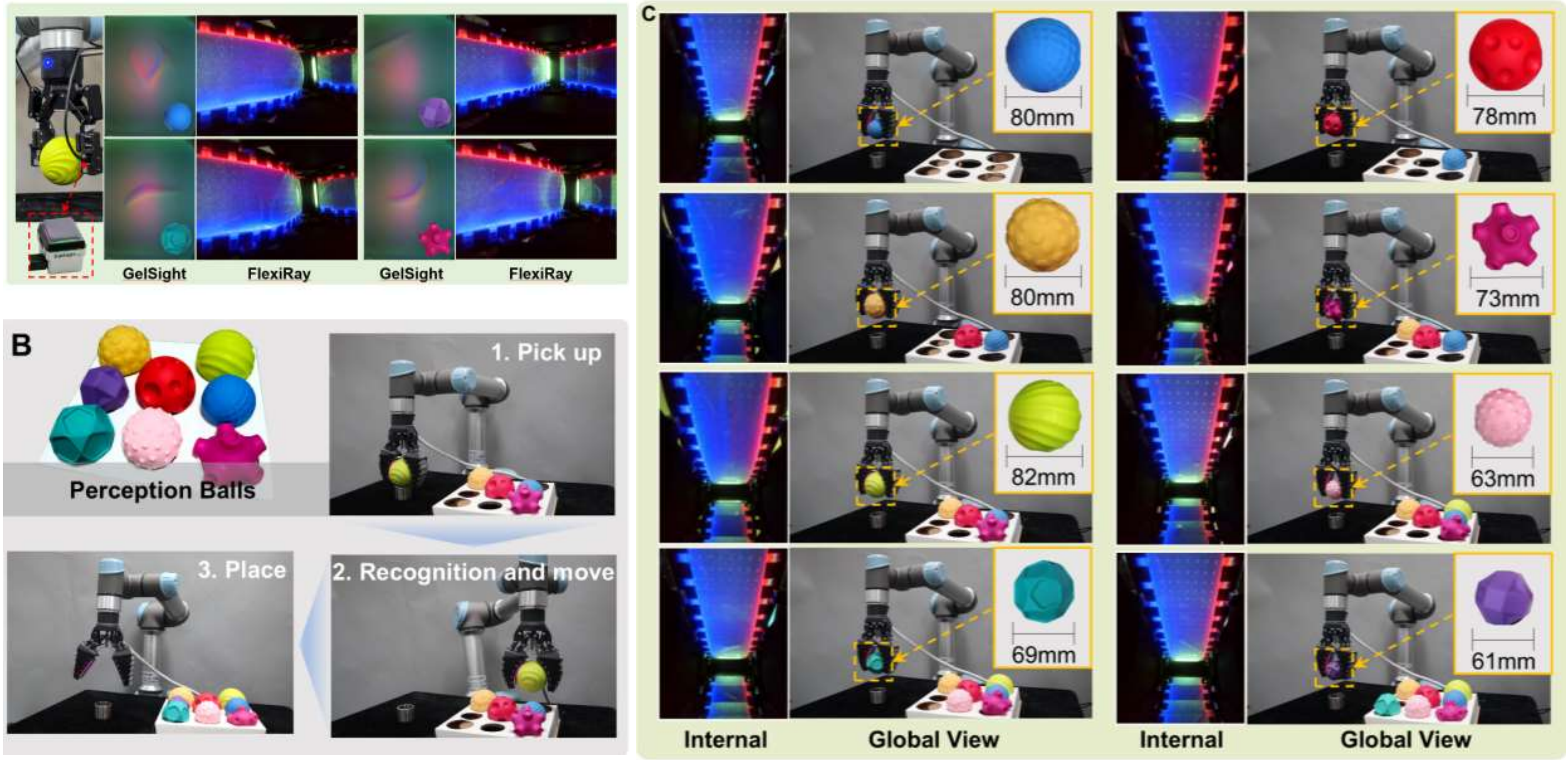


Forward push　　Oblique push　　Twist



Flexible Tactile Sensing

Results: The classification model effectively (outperform GelSight) uses tactile data to accurately identify and classify the surface textures of different balls.

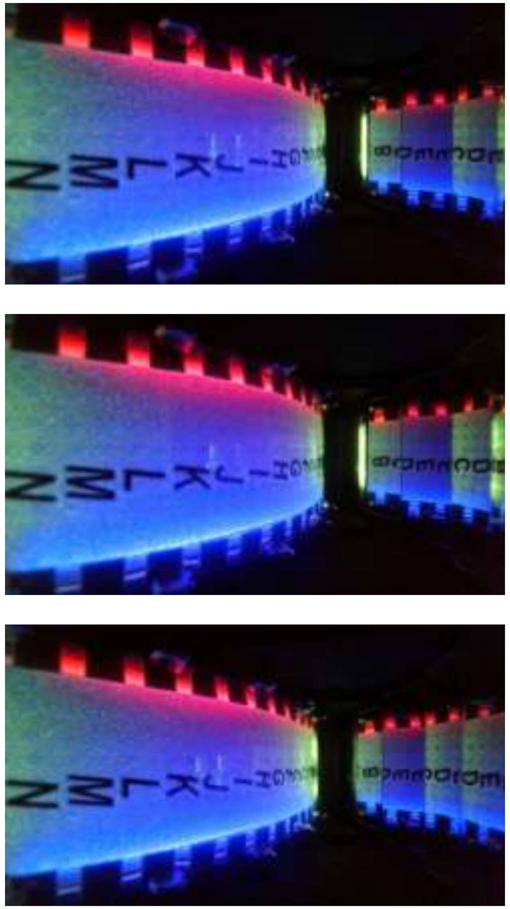


Flexible Tactile Sensing

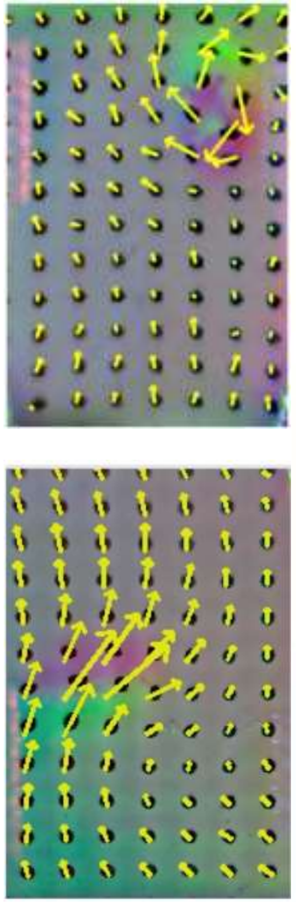
Tactile temperature sensing and sliding detection for human-robot cup interaction

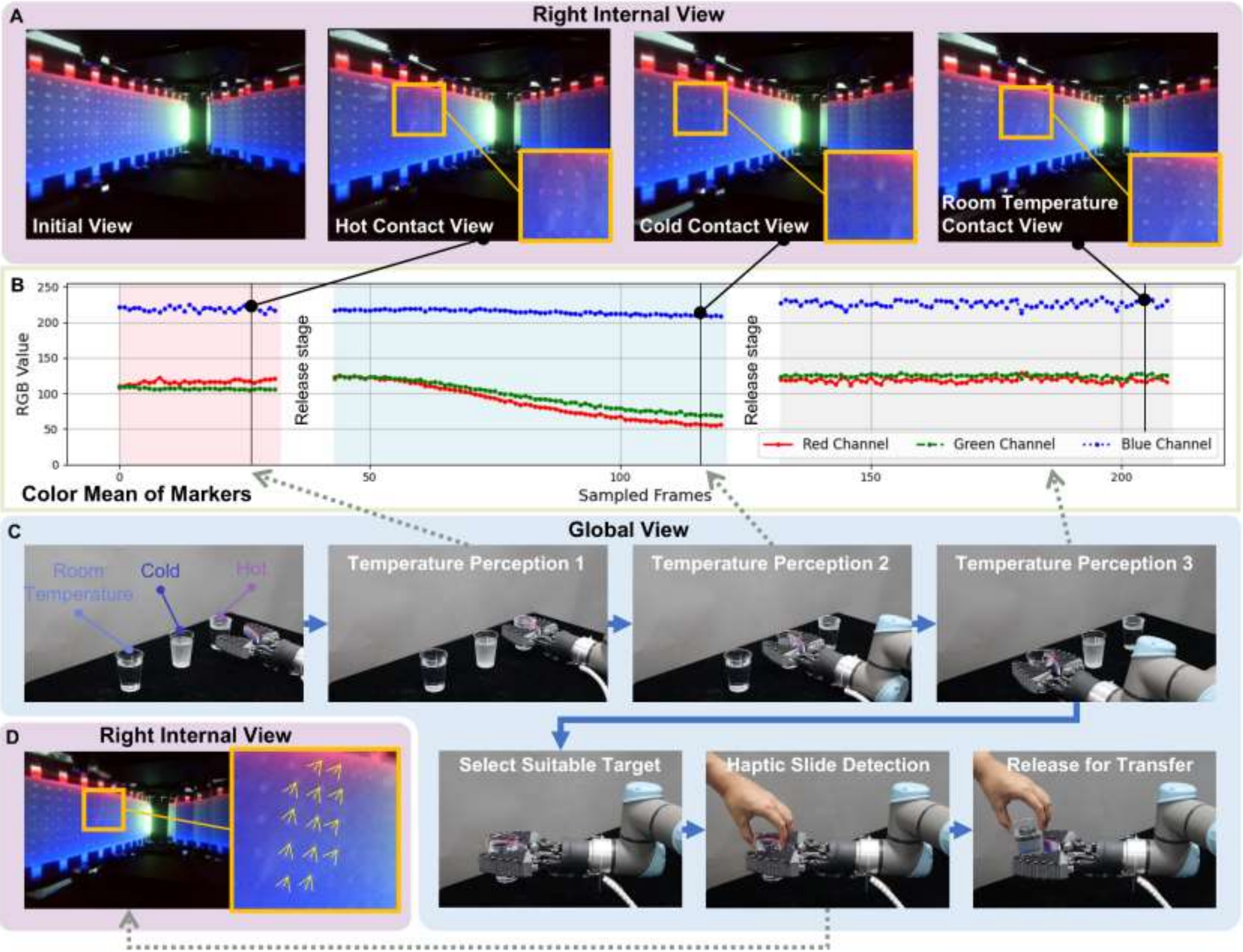
Results: The experiment illustrates the multidimensional intelligence of robots in perception, action, and human-robot interaction.

Large sensory coverage when grasping objects of different diameters



Slippage Detection in different directions



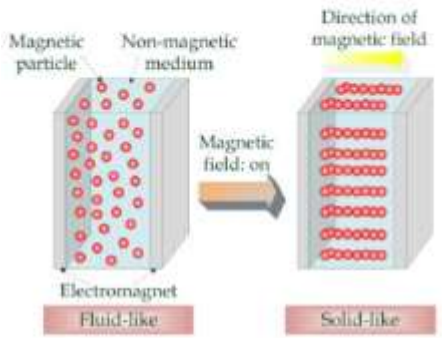


Variable Stiffness Gripper

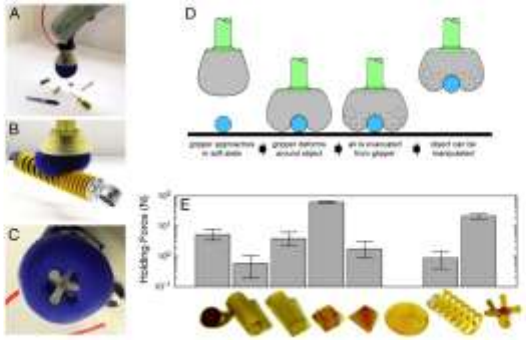
Development of A SMP-Enhanced Fin-Ray Gripper to Enable Tunable Stiffness, Adhesive Grasping, and Interaction-driven Reconfiguration

Background: Soft robotics hands have a wide range in life and industrial scenarios. The inherent adaptability and flexibility of soft materials make them a safe and versatile grasping solutions. Variable stiffness materials and principles include:

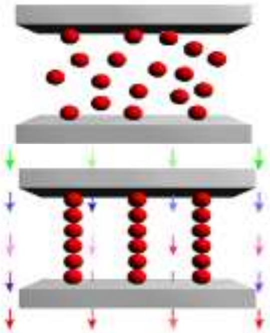
Magnetorheological Fluids



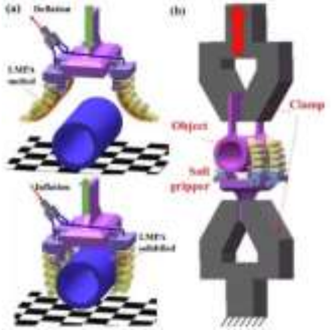
Jamming



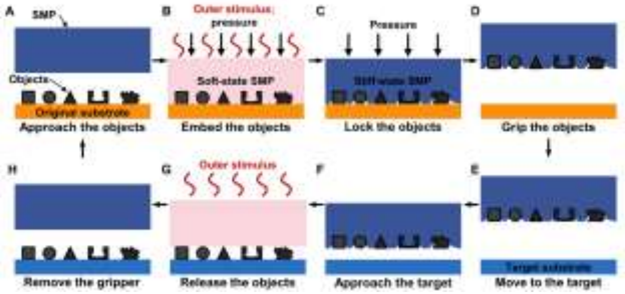
Electrorheological Fluids



Liquid Metal



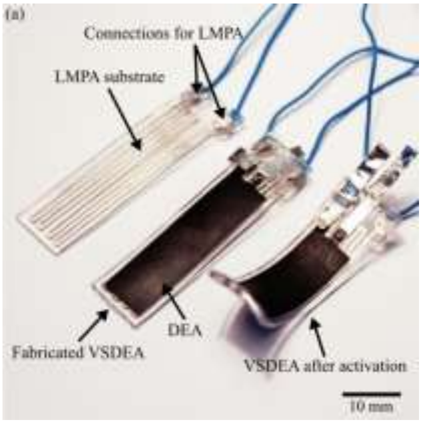
Shape Memory Polymer (SMP)



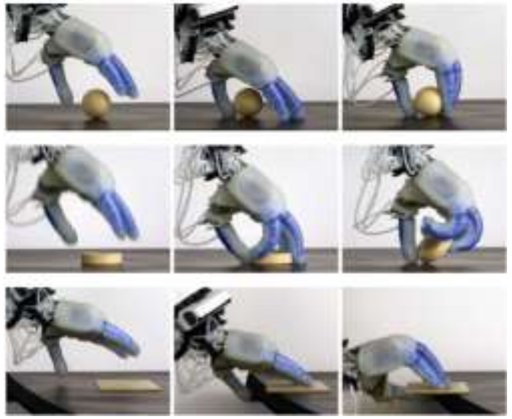
Limitations and challenges: (1) Traditional soft hands have poor load-bearing capabilities and can only adapt to a limited range of objects; (2) The enhancement of dexterity comes at the cost of complex design and actuation.

Shape Memory Alloy

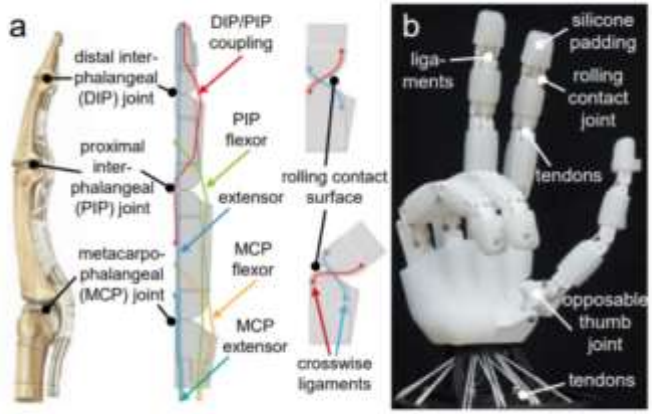
Dielectric Elastomer



Pneumatic



Tendon-Driven



Insufficient load capacity & versatility ⟷ **Structural/Control complexity**

Variable Stiffness Gripper

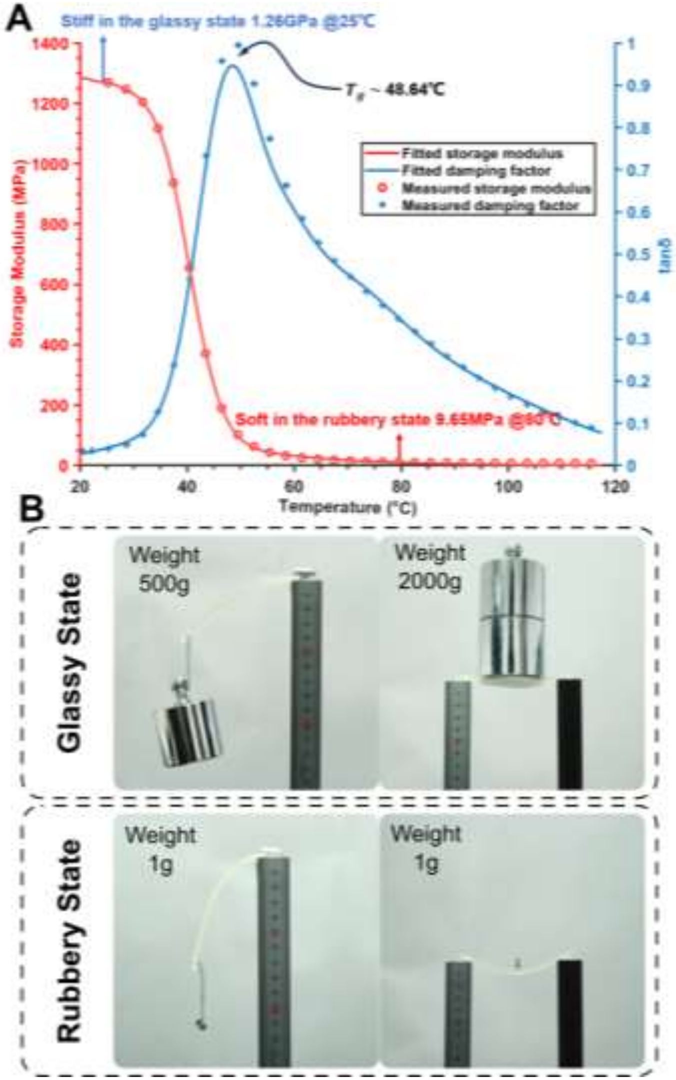
View the article: https://wuhao-me.github.io/pdf/SMP-FR_Gripper.pdf
Get more information on my website: https://wuhao-me.github.io/

Shape Memory Polymer Preparation

- Preparation: Epoxy resin monomer (E44 6101) and curing agent (JEFFAMINE D-230, Aladdin), mass ratio 81:46.
- Curing conditions: 50°C for 2 hours; 100°C for 2 hours; 130°C for 2 hours.

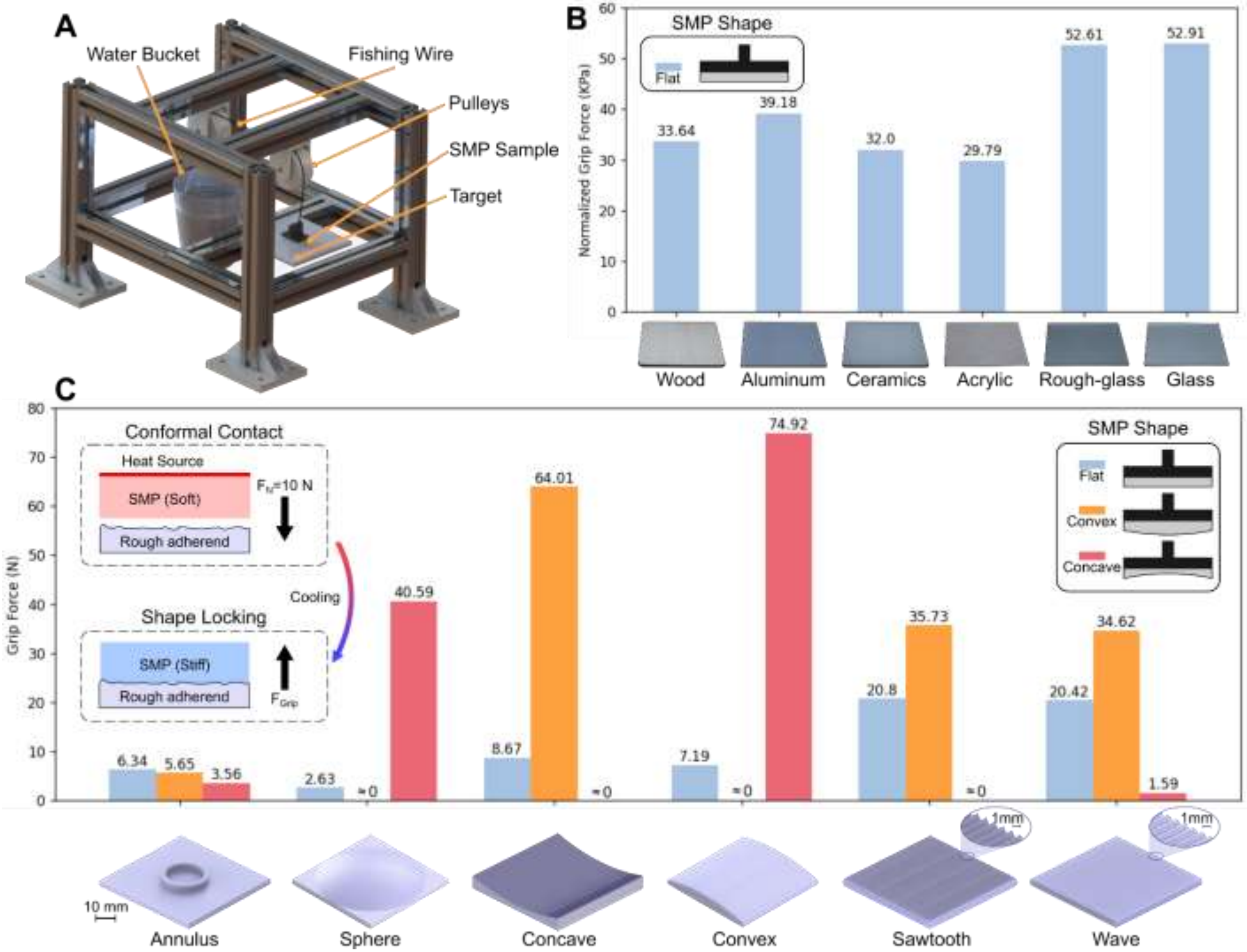
Characterization of the Material

High modulus adjustment range (~1MPa to GPa)



Adhesion Characteristics of the Material

High gripping force on varied surfaces

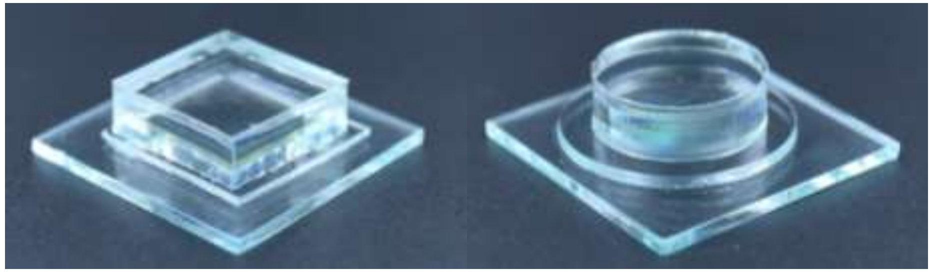


Variable Stiffness Gripper

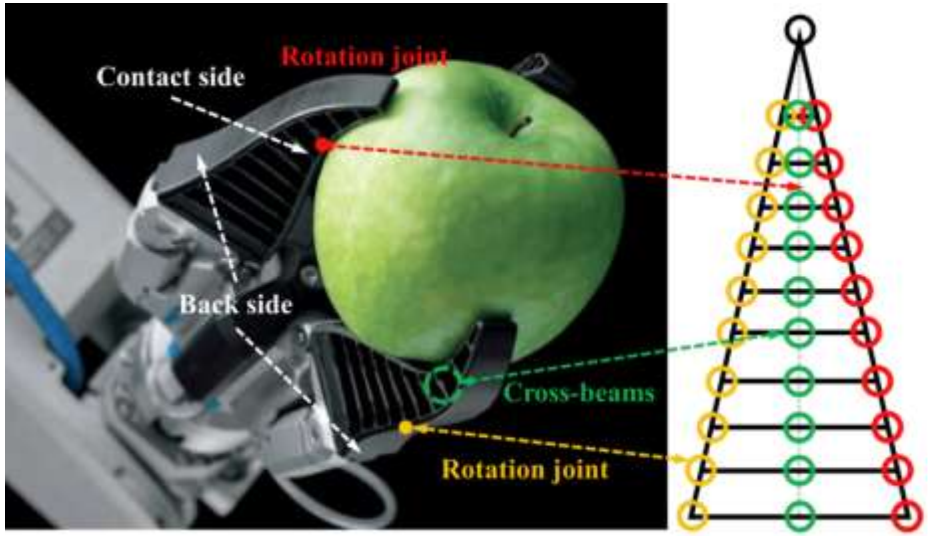
Construction of SMP-FR Gripper

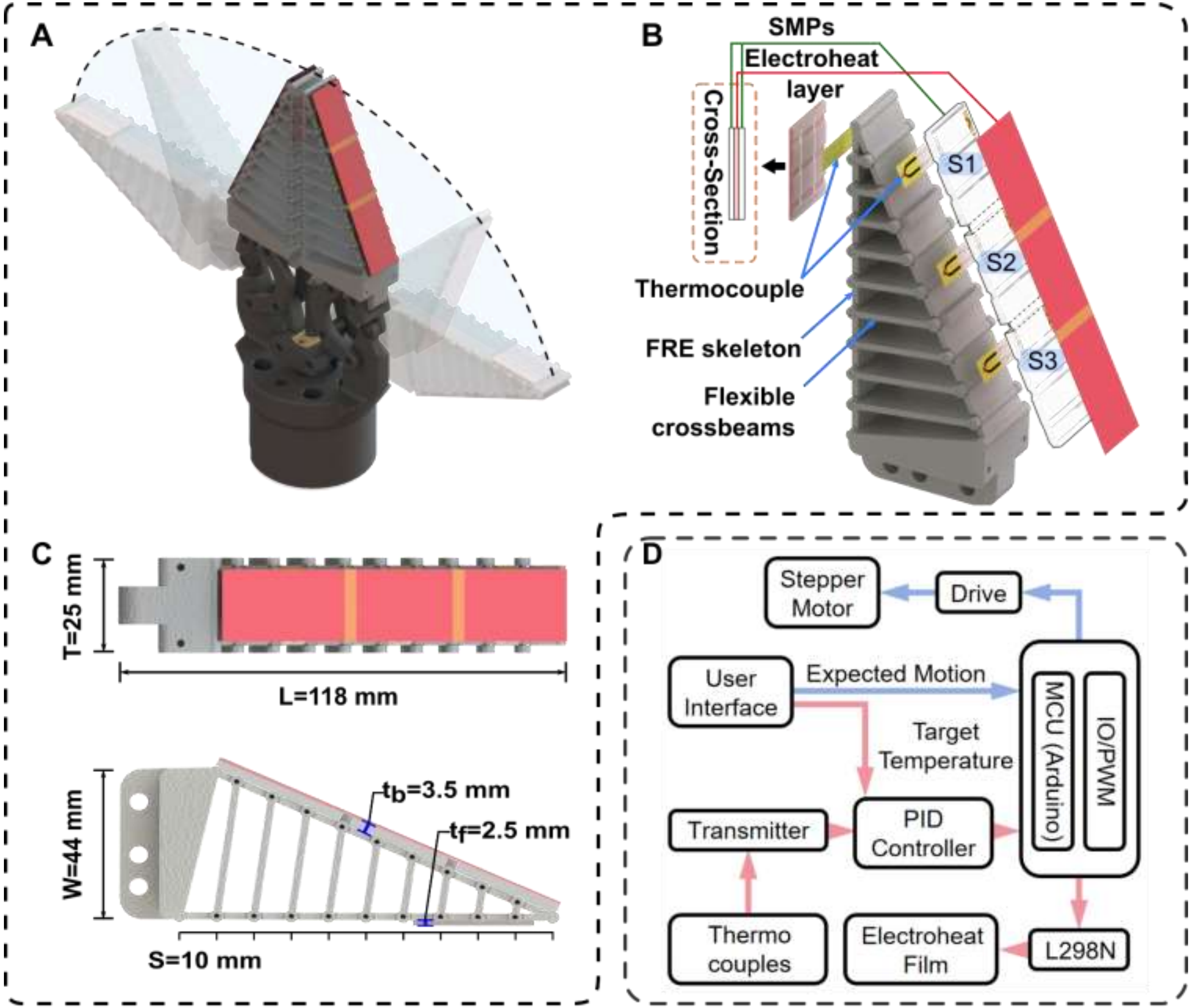
Strategically place SMP on the back contact side of the FRE structure for tunable stiffness and on the front side for adhesive grasping.

Shape Memory Polymer



Fin Ray Effect Soft Gripper





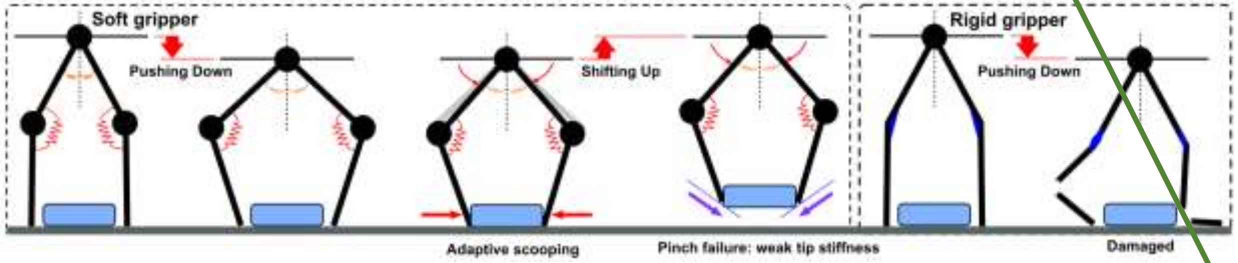
Variable Stiffness Gripper

Shape Fixation and Recovery Assessment

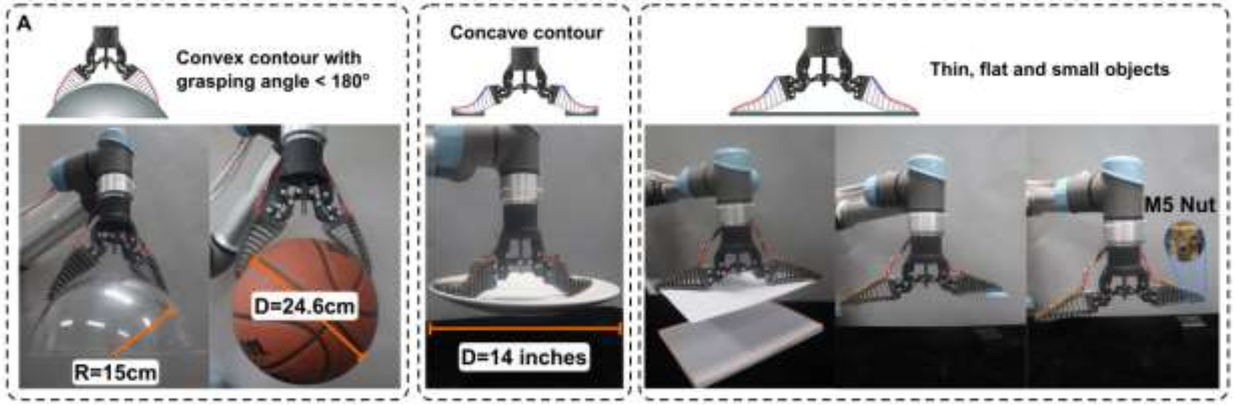
Shape Fixation Ratio: $\mathbf{SFR} = \frac{1}{N}\sum_{i=1}^{N}\frac{\|p_i^{loc}-p_i^{ini}\|}{\|p_i^{con}-p_i^{ini}\|}$

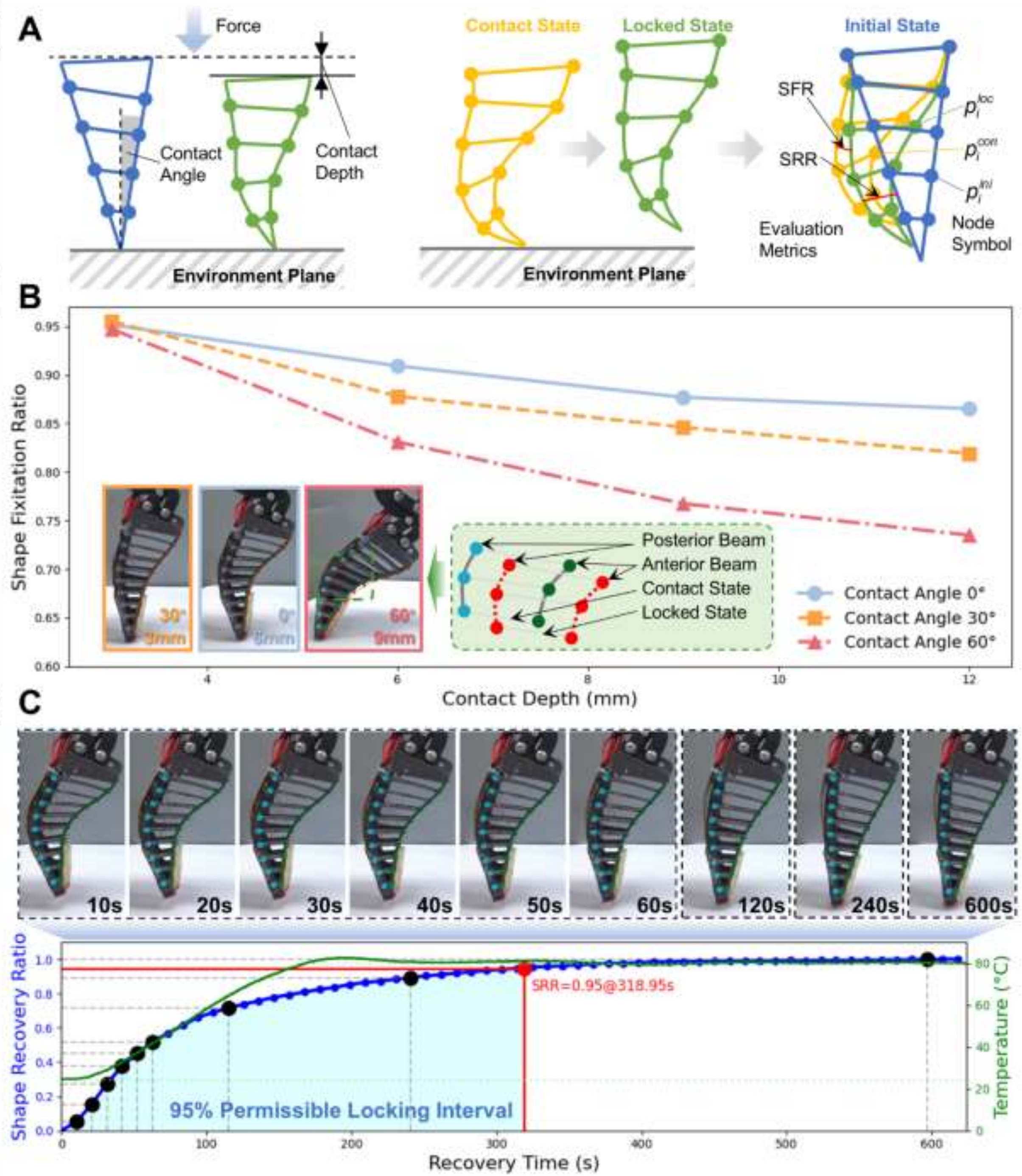
Shape Recovery Ratio: $\mathbf{SRR} = \frac{1}{N}\sum_{i=1}^{N}\frac{\|p_i^{rec}-p_i^{ini}\|}{\|p_i^{loc}-p_i^{ini}\|}$

In constrained environments, the grasping ability and stability of current soft/rigid robots are often limited.



SMP can achieve the adhesive grasping of large-diameter objects as well as small/thin objects.



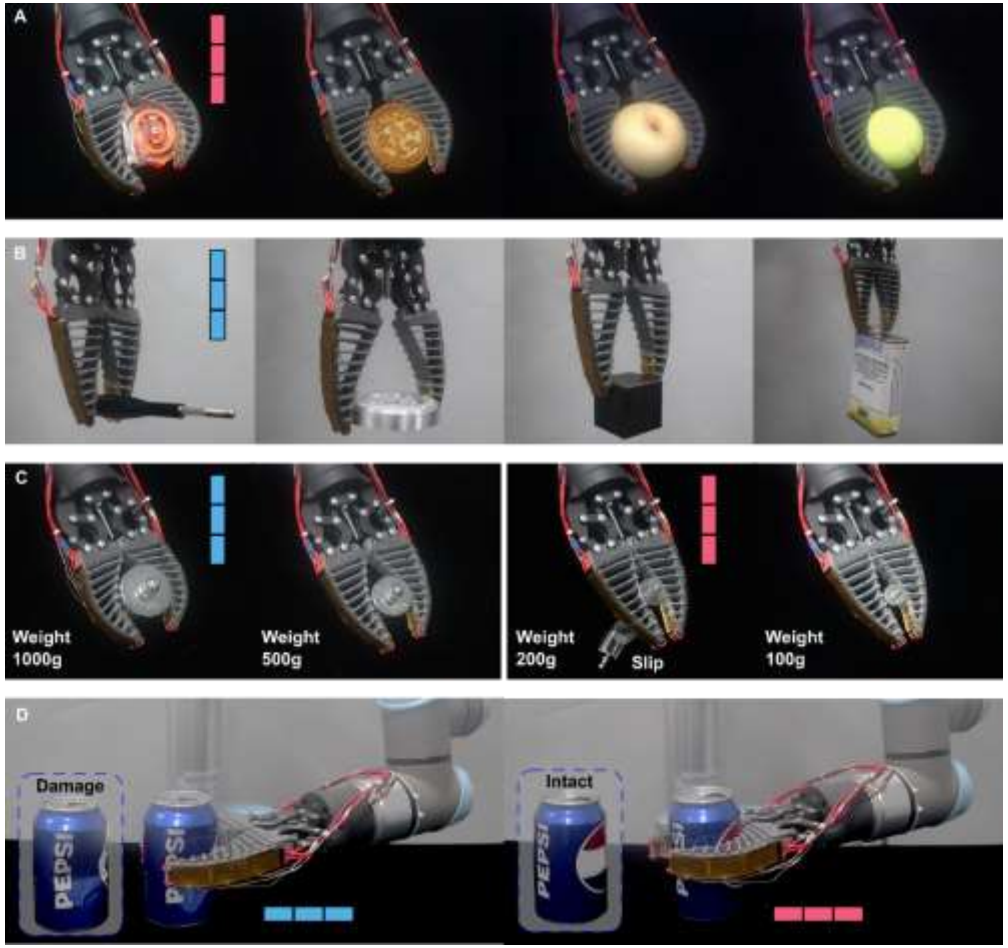


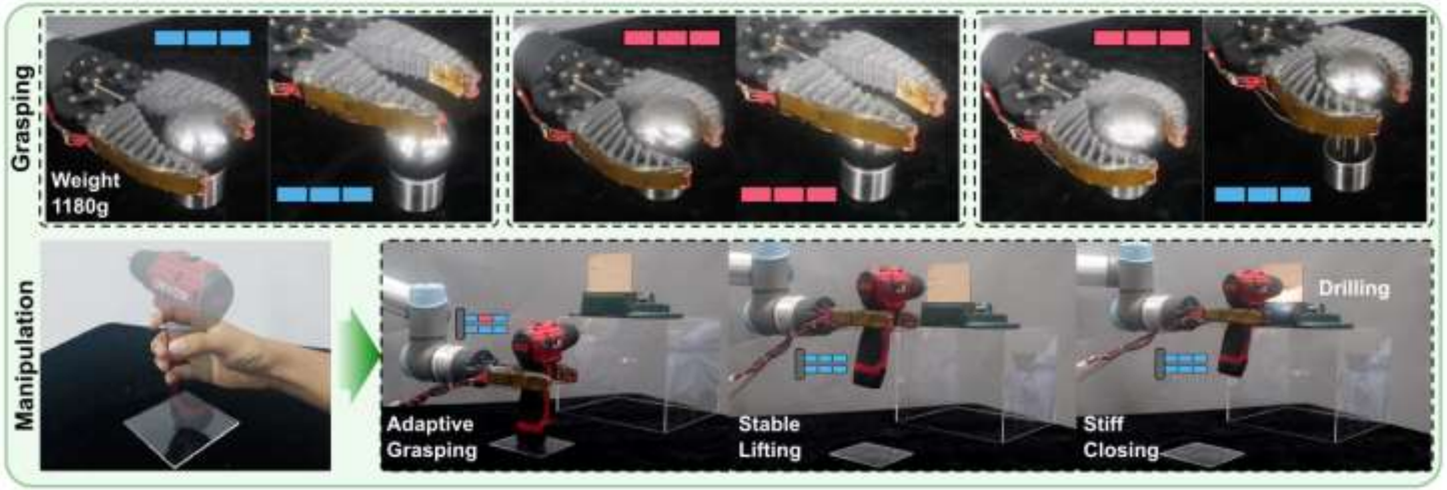
Variable Stiffness Gripper

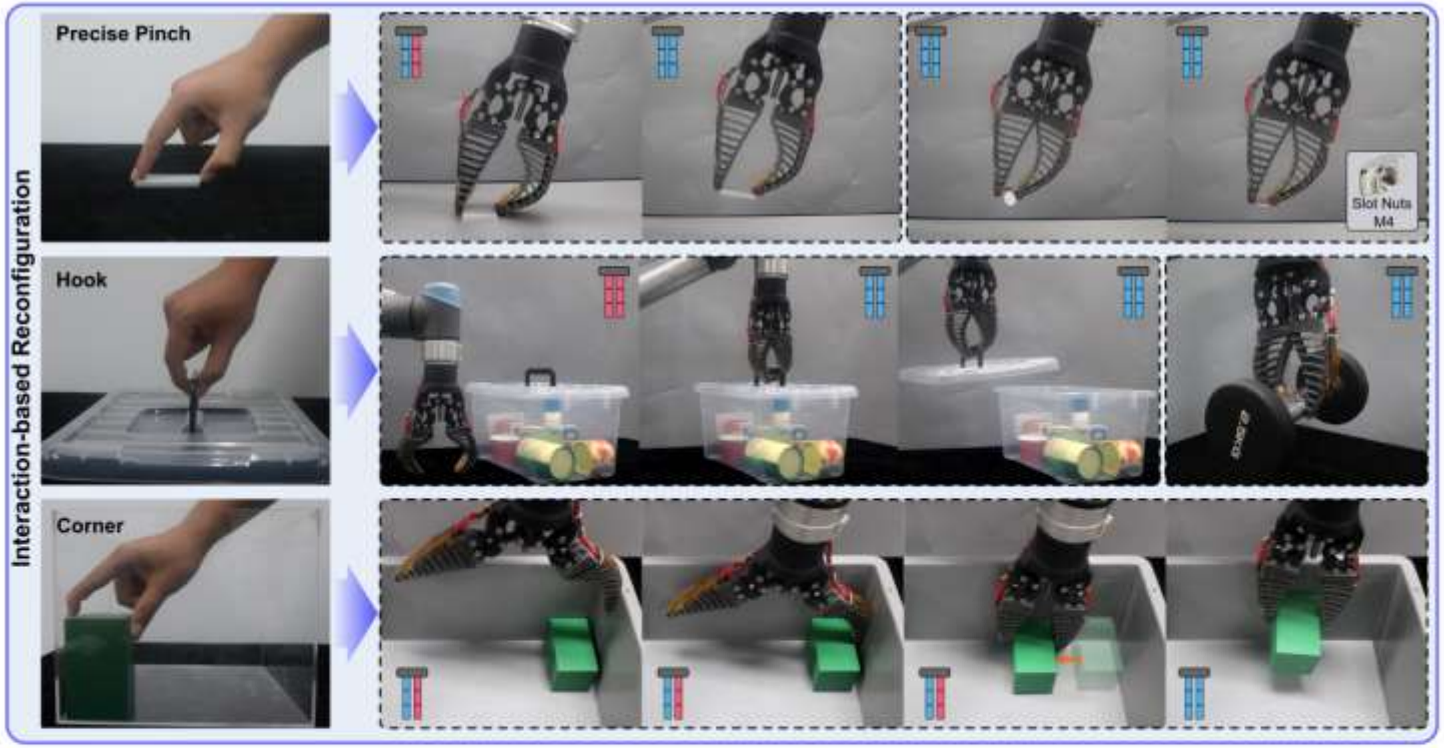
Implement human-inspired interaction strategies for dexterous grasping and manipulation in various constrained scenarios.

Grasp and Manipulation Assessment

The proposed SMP-FR soft hand can achieve variable structural stiffness, enabling stable grasping of objects across a range of grasping forces.



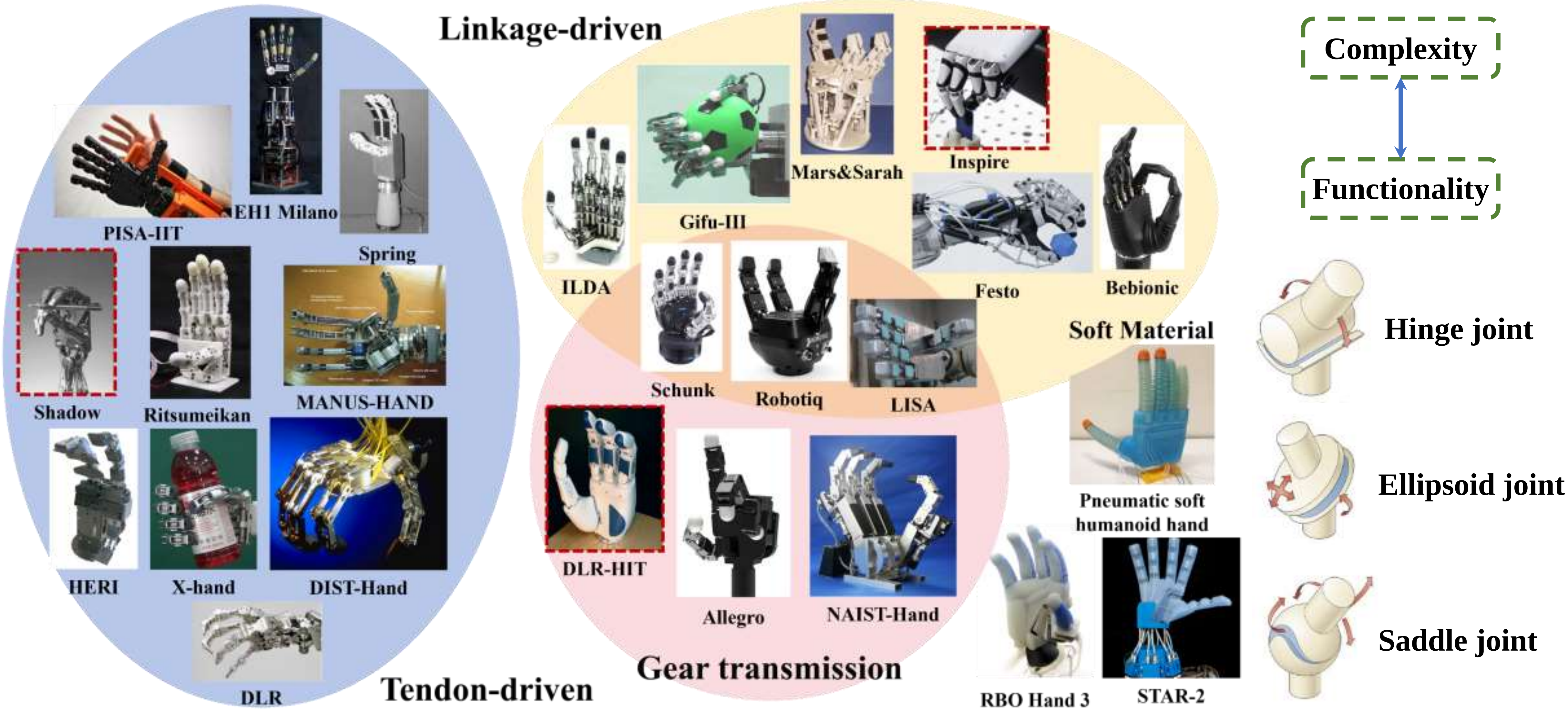




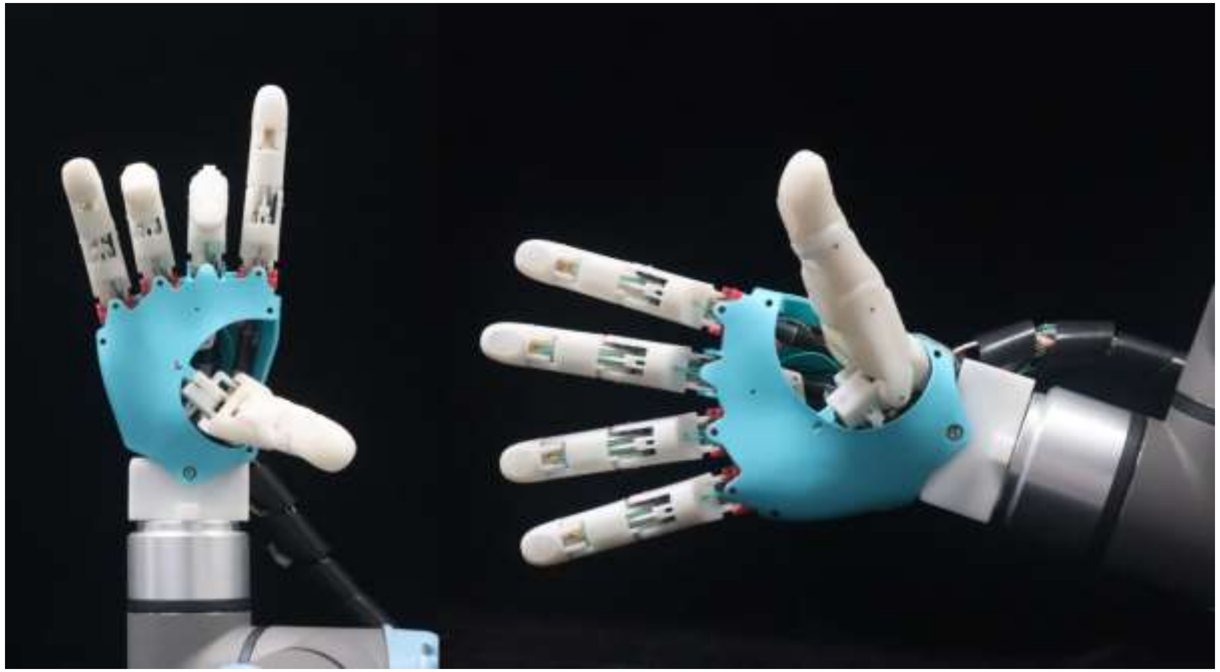
Dexterous Robotic Hand

Development of highly integrated, linkage-driven anthropomorphic hand with novel mechanisms and 19 DOFs.

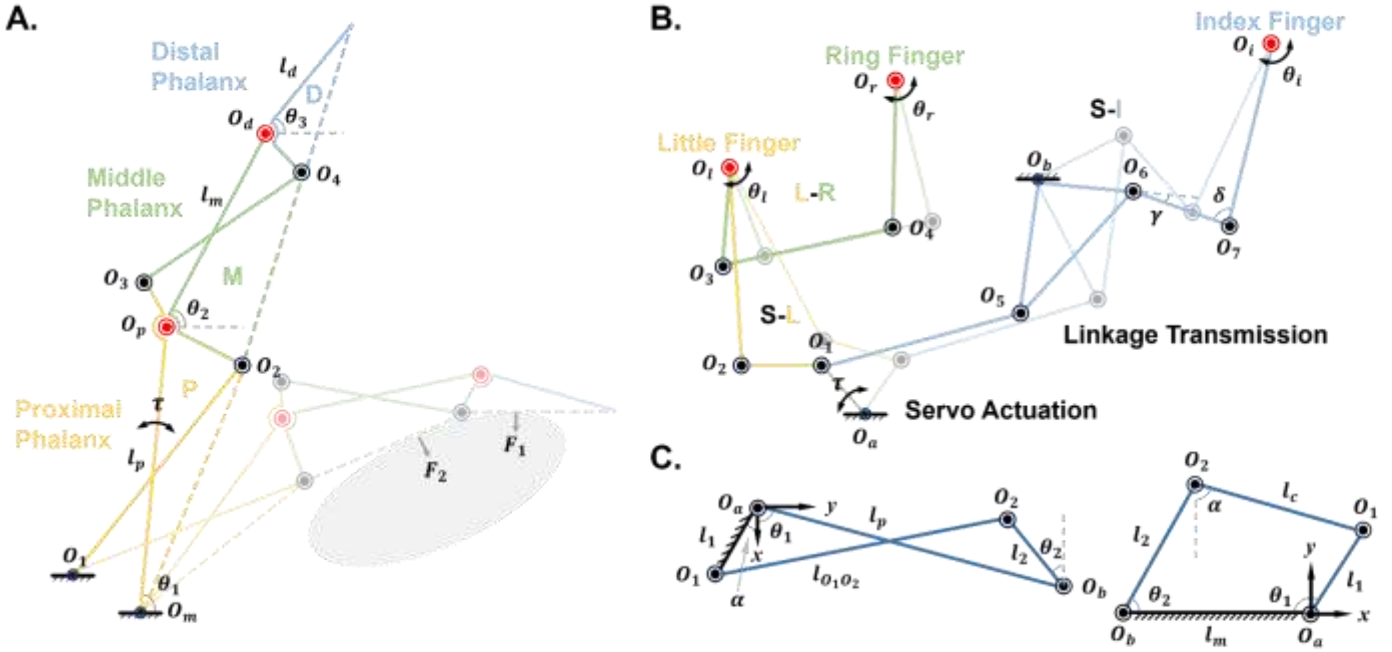
Background: It is challenging to replicate the full functions, appearance, and structures given the high degree of freedom and the intricate, compact nature of the human hand. Reasonable trade-offs need to be made between complexity and functionality.



Dexterous Robotic Hand



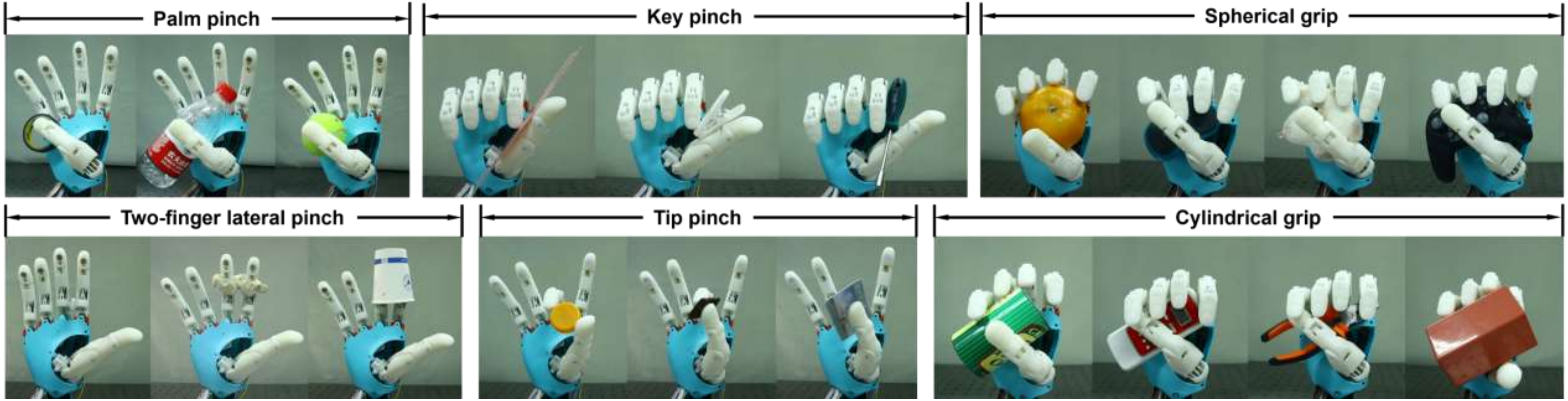
Biomimetic Analysis and Design: This design conducts biomechanical analysis of human hand synergistic movements to provide reasonable simplifications for the design of dexterous hands. Novel linkage mechanisms were proposed with optimized geometric parameters to achieve dexterous movements and resemble natural human gestures.



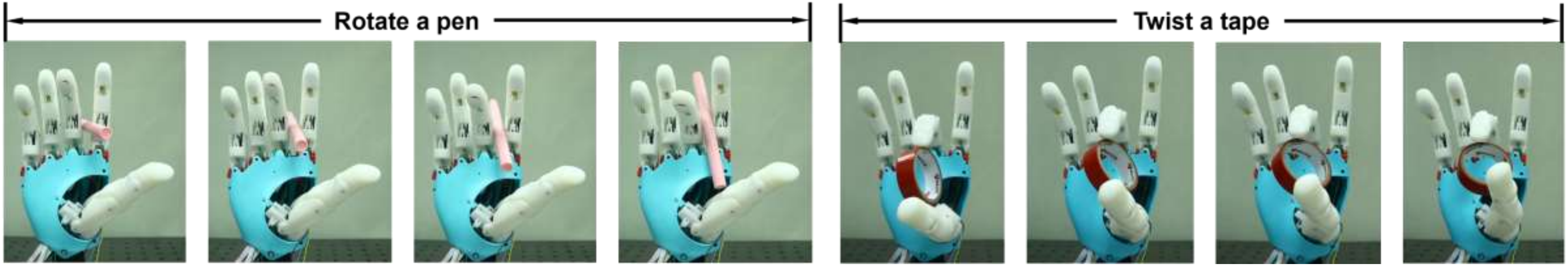
Dexterous Robotic Hand

View the video: https://wuhao-me.github.io/Videos/Dexterous_Hand.mp4
Get more information on my website: https://wuhao-me.github.io/

Grasping and Manipulation Experiments: The dexterous hand is capable of grasping daily objects with different modes and effectively repositioning objects in hand to the desired locations.

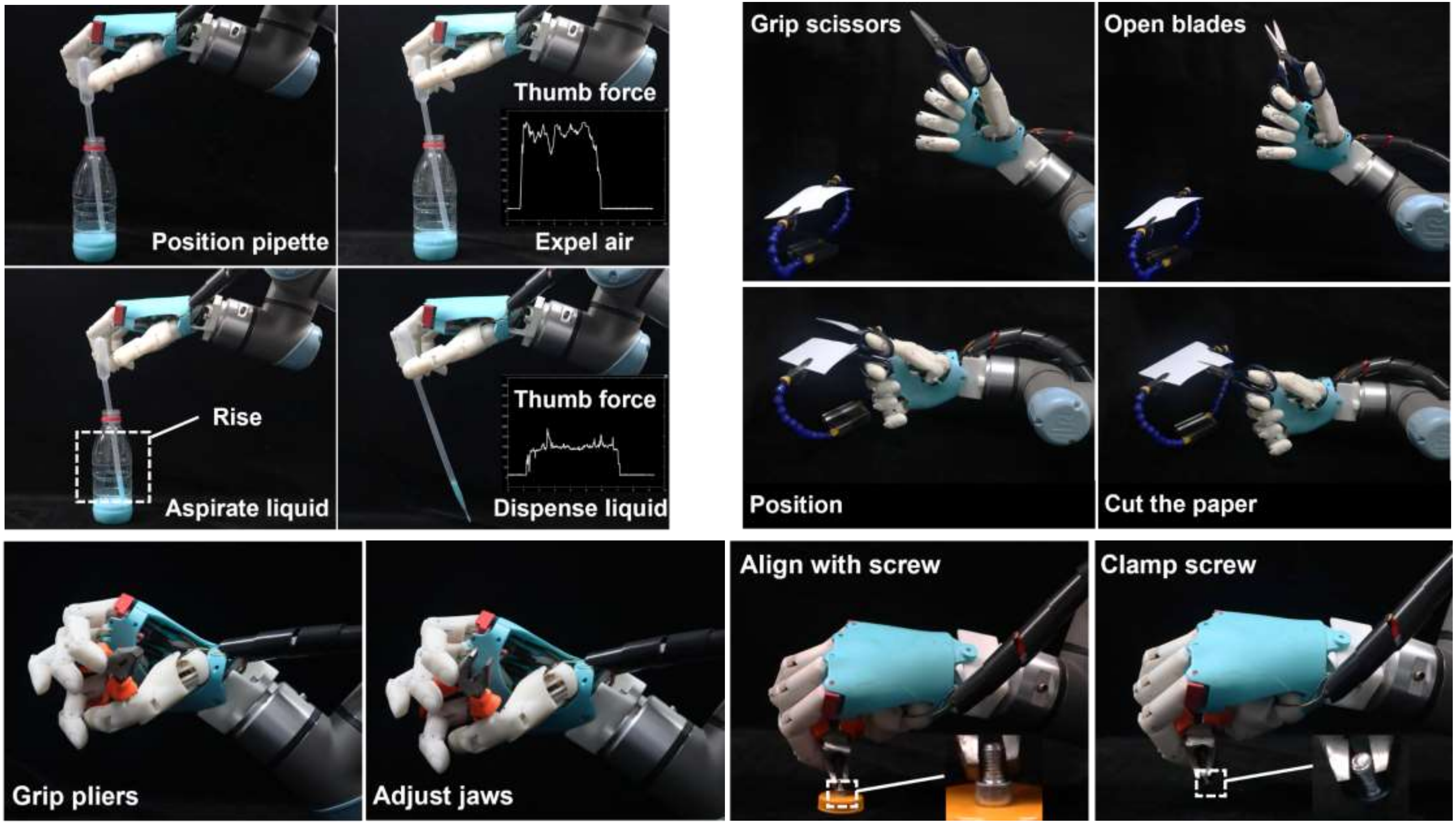


In-hand Manipulation



Dexterous Robotic Hand

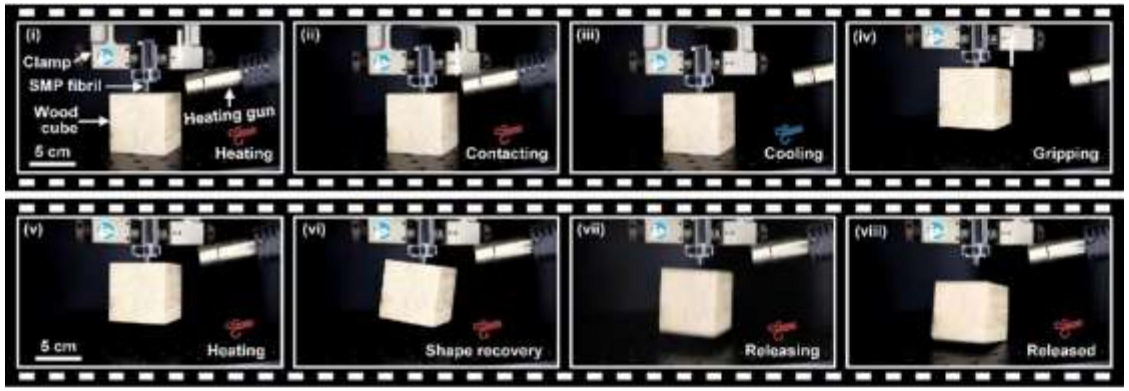
Tool Operation: The results highlight the hand's rich motion capabilities in complex in-hand manipulations and grasping force modulation.

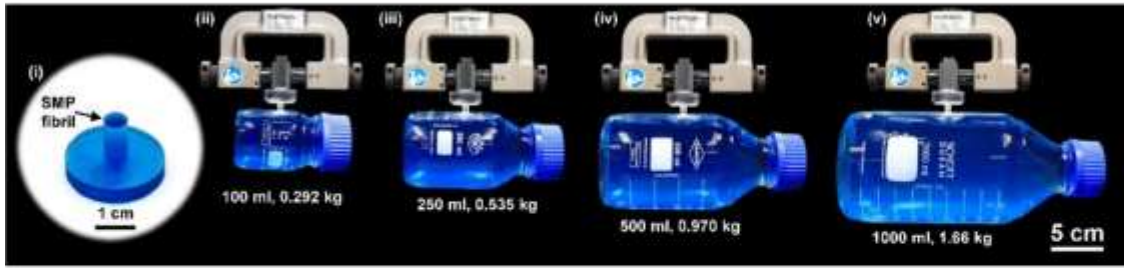


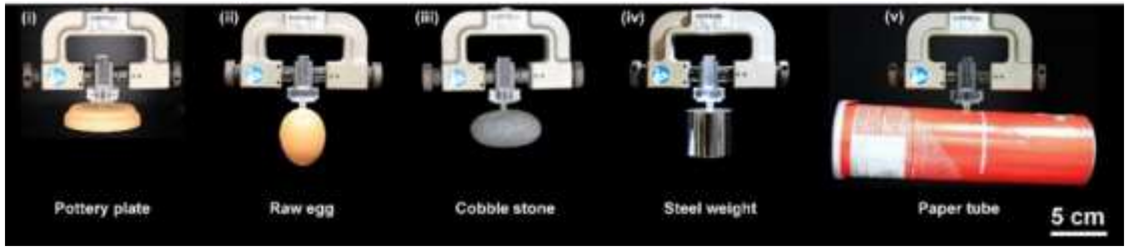
Ongoing Projects

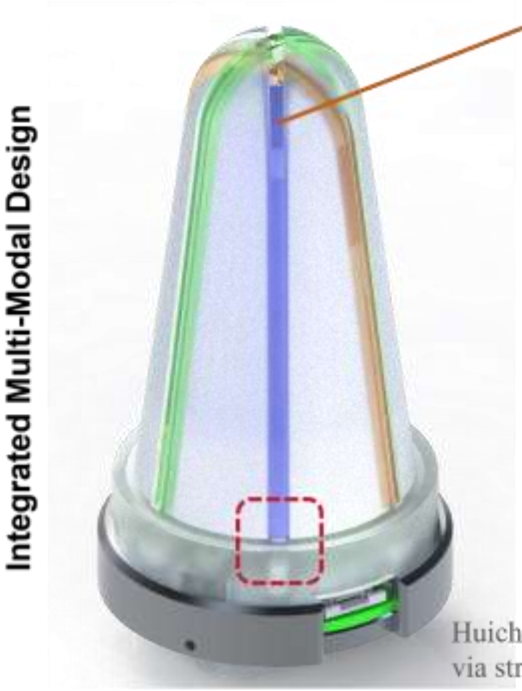
Research projects in progress. See more at https://wuhao-me.github.io/

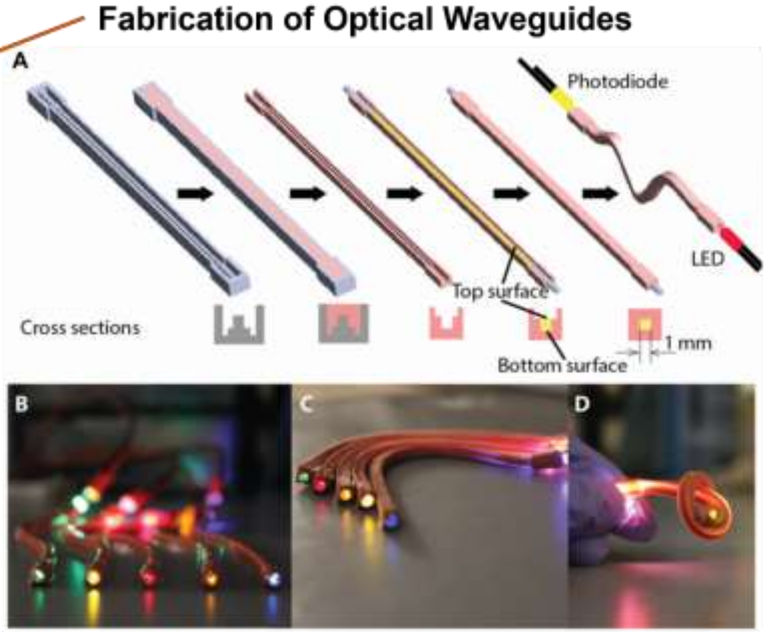
- Design a smart adhesive device with SMP and validate its performance in gripping various objects.
- Construct a vision-based tactile sensor with omnidirectional multimodal perception capability.



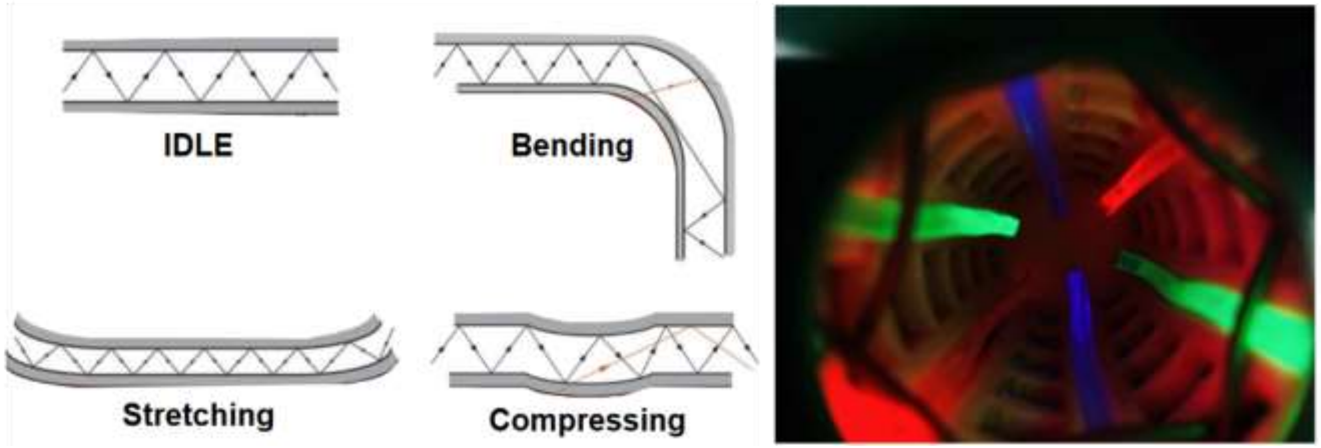






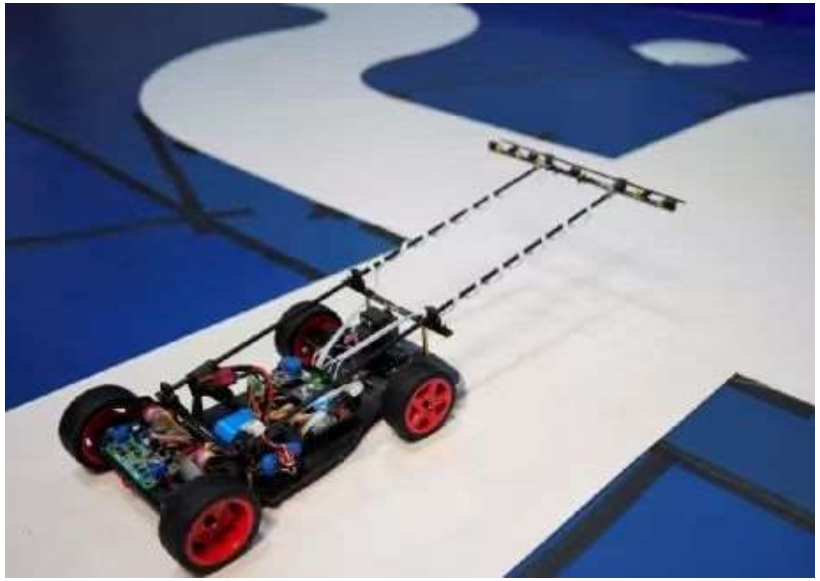


Huichan Zhao et al. , Optoelectronically innervated soft prosthetic hand via stretchable optical waveguides.*Sci. Robot.*1,eaai7529(2016).

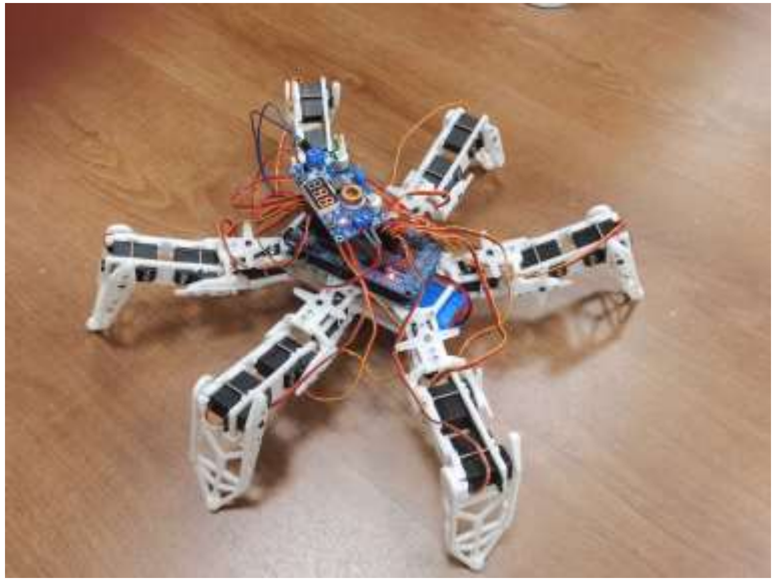


Contest/Academic Projects

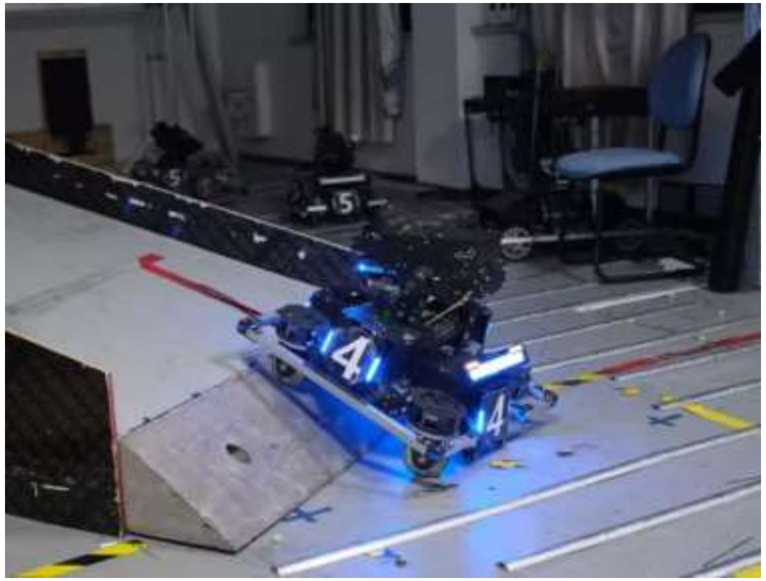
The engineering practices (Leader) in the design and construction of diverse robotic systems. See more at https://wuhao-me.github.io/



Electromagnetic Racing Car

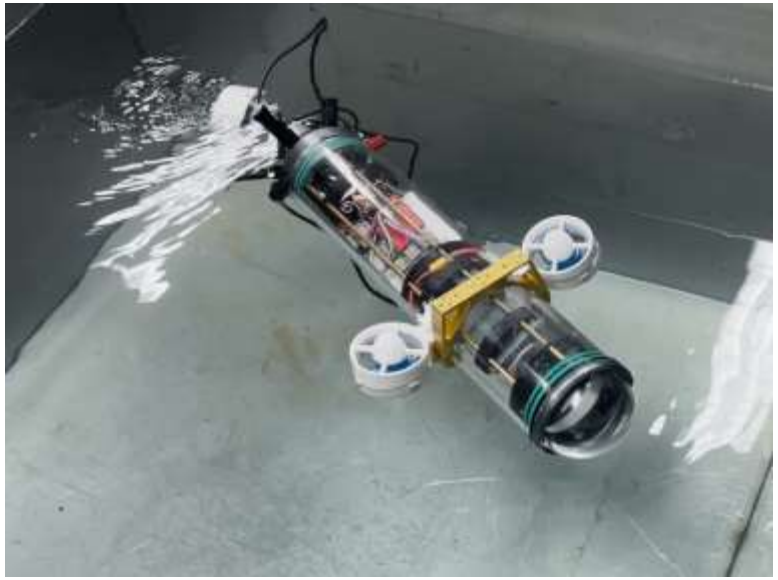


Underwater Vehicle

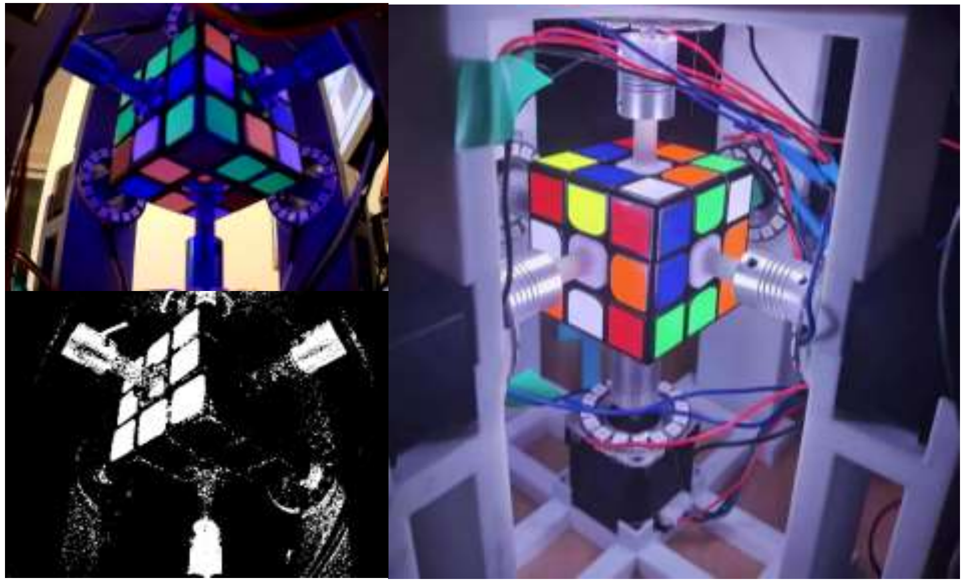


RoboMaster University Championship

Bipedal Robot



Underwater Vehicle

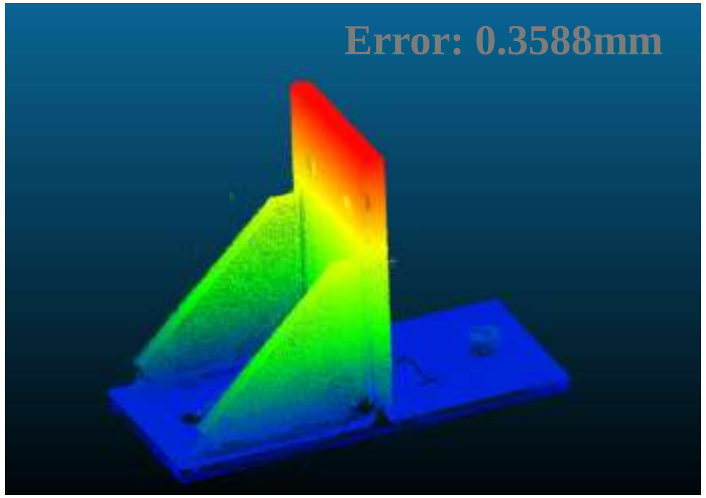


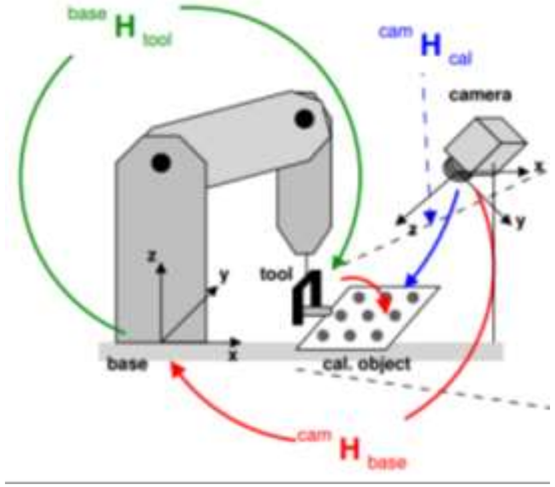
Rubik's Cube Robot

Contest/Academic Projects

Design controllers for the dynamic control of the robotic arm, including force-position, gravity compensation PD, and inverse kinematics controllers.

- Utilize a camera and a rotary stage to reconstruct the three-dimensional point cloud data of workpieces.
- Achieve high-precision eye-to-hand calibration of the robotic system.





Force-position Hybrid Controller

Control law: $\tau = J^T f = J^T\{M_\chi(\vartheta) * S * \ddot{\chi} * [K_p e - K_d \dot{\chi}] + S' * f_d + V_\chi(\vartheta, \dot{\vartheta}) + G_\chi(\vartheta)\}$

$K_d = 2\sqrt{K_p}$, $e = \chi_d - \chi$

Interactive feedback with the environment: $\tau = J^T[-(z(\vartheta) - z_w)K_e - \dot{z}(\vartheta) * K_f]$