

ICRA2024
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A Strong Underwater Soft Manipulator With Planarly-Bundled Actuators and Accurate Position Control

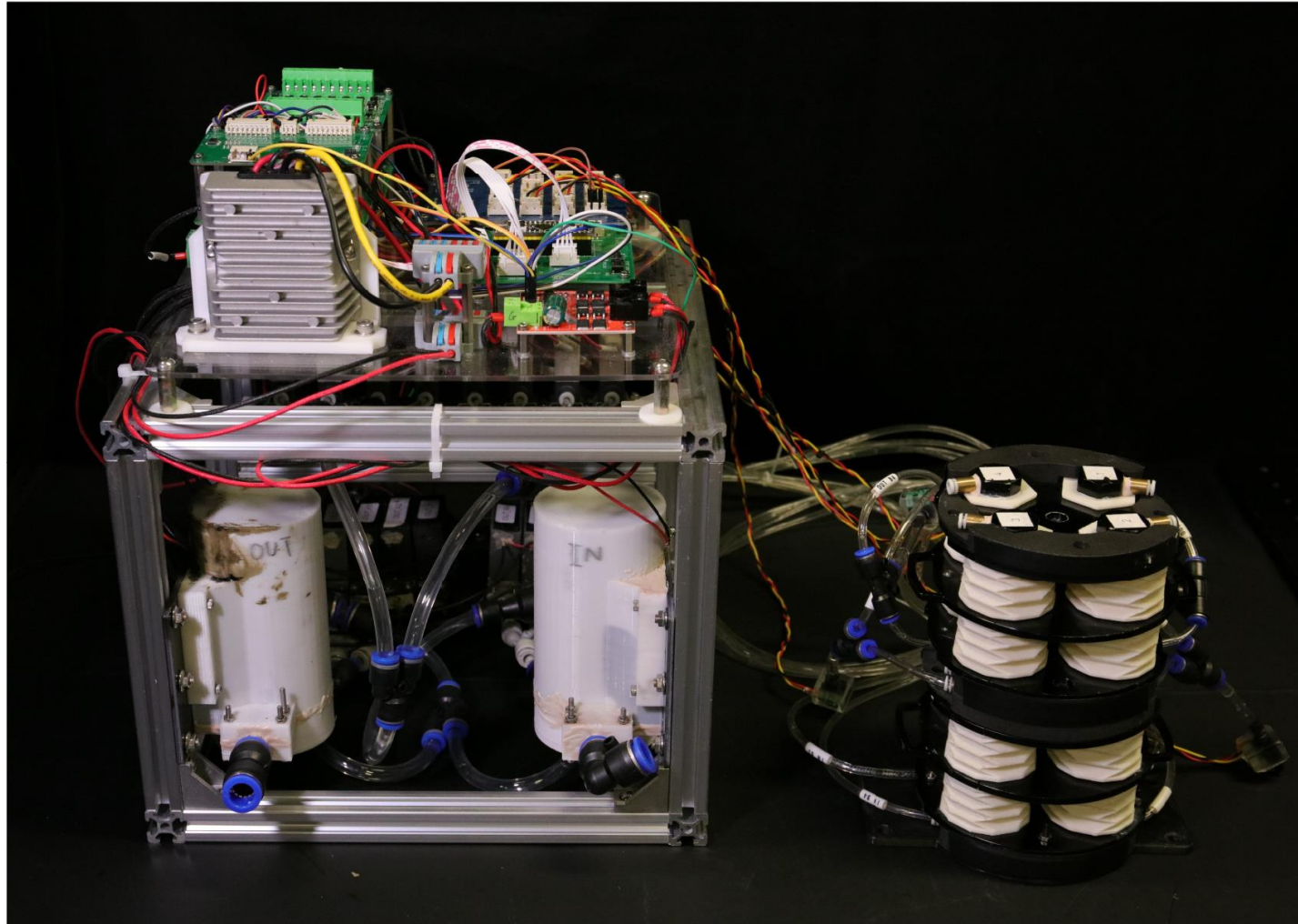
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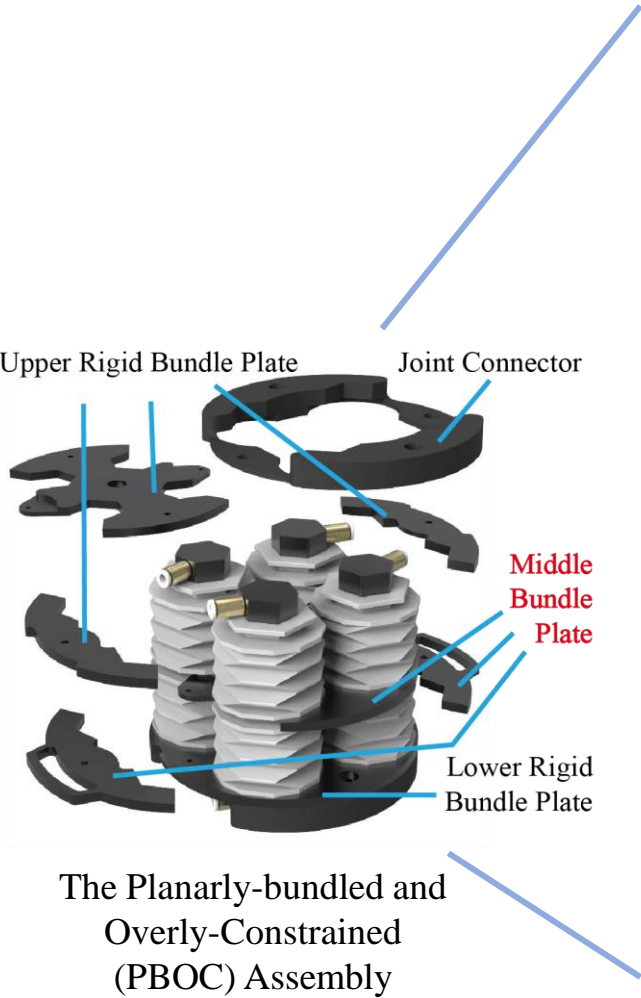
The Underwater Manipulator System Prototype



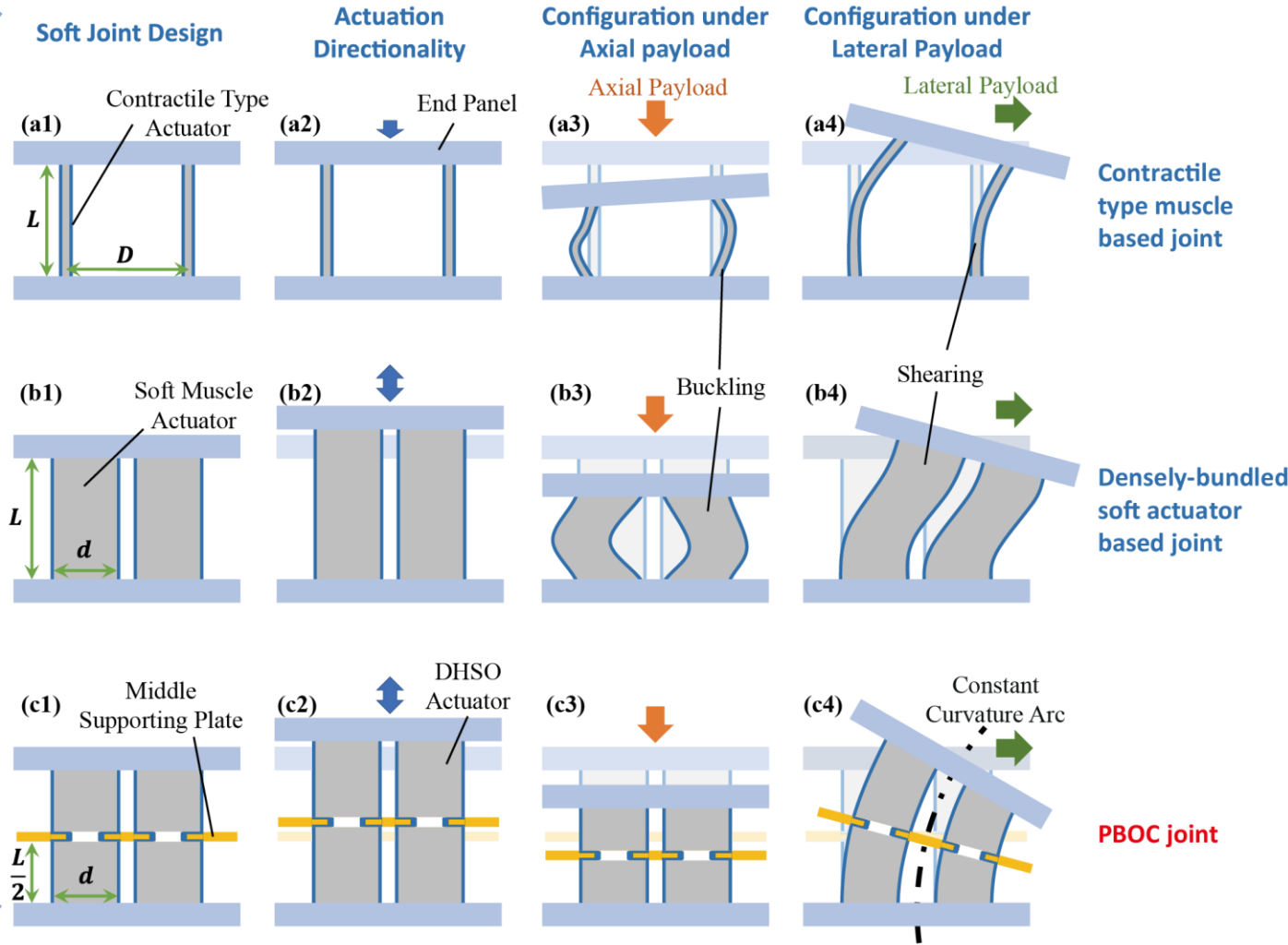
The Planarly-Bundled Over-Constraint Joint Design Concept



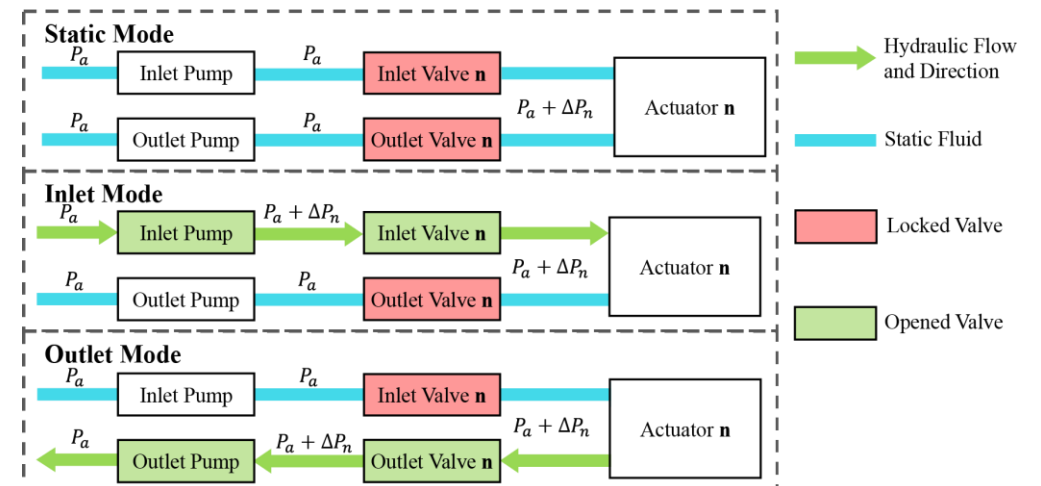
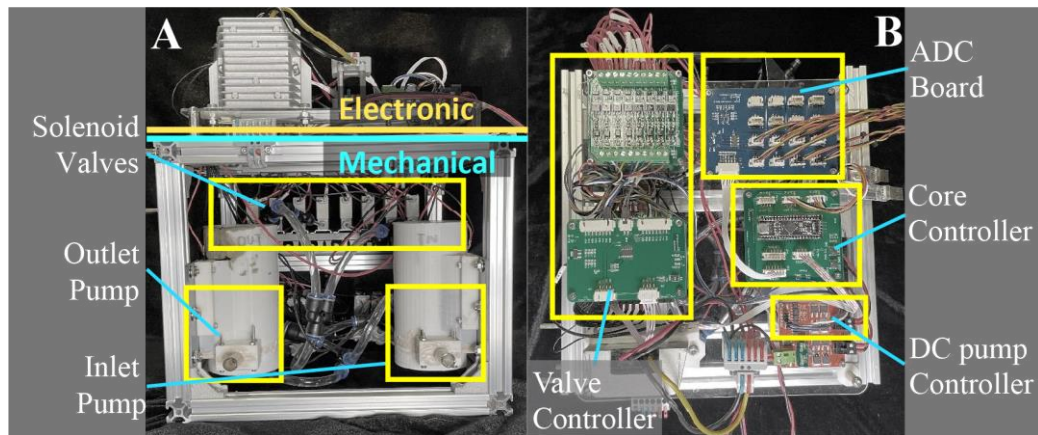
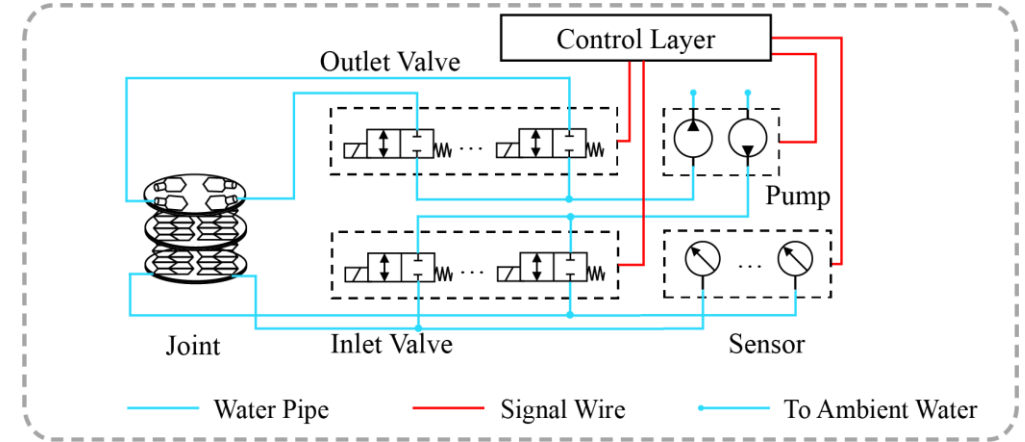
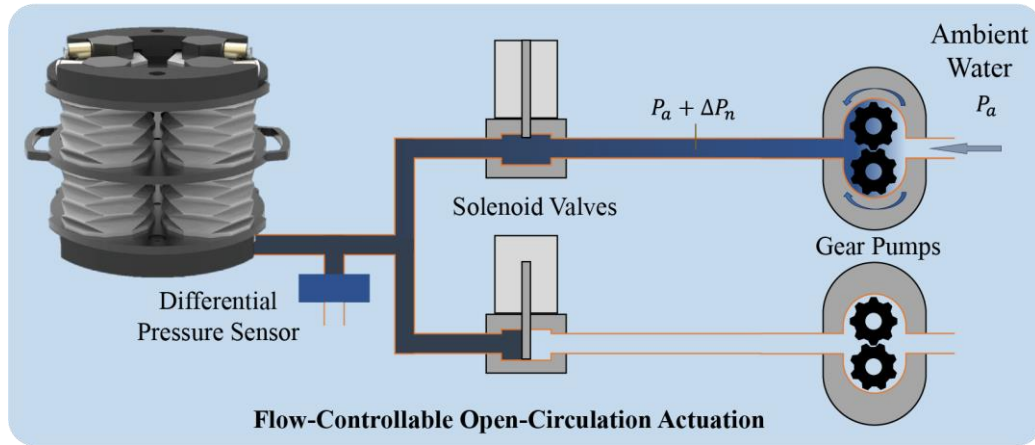
The Dual-segment Hydraulic-enhanced Origami (DSHO) Actuator Assembly



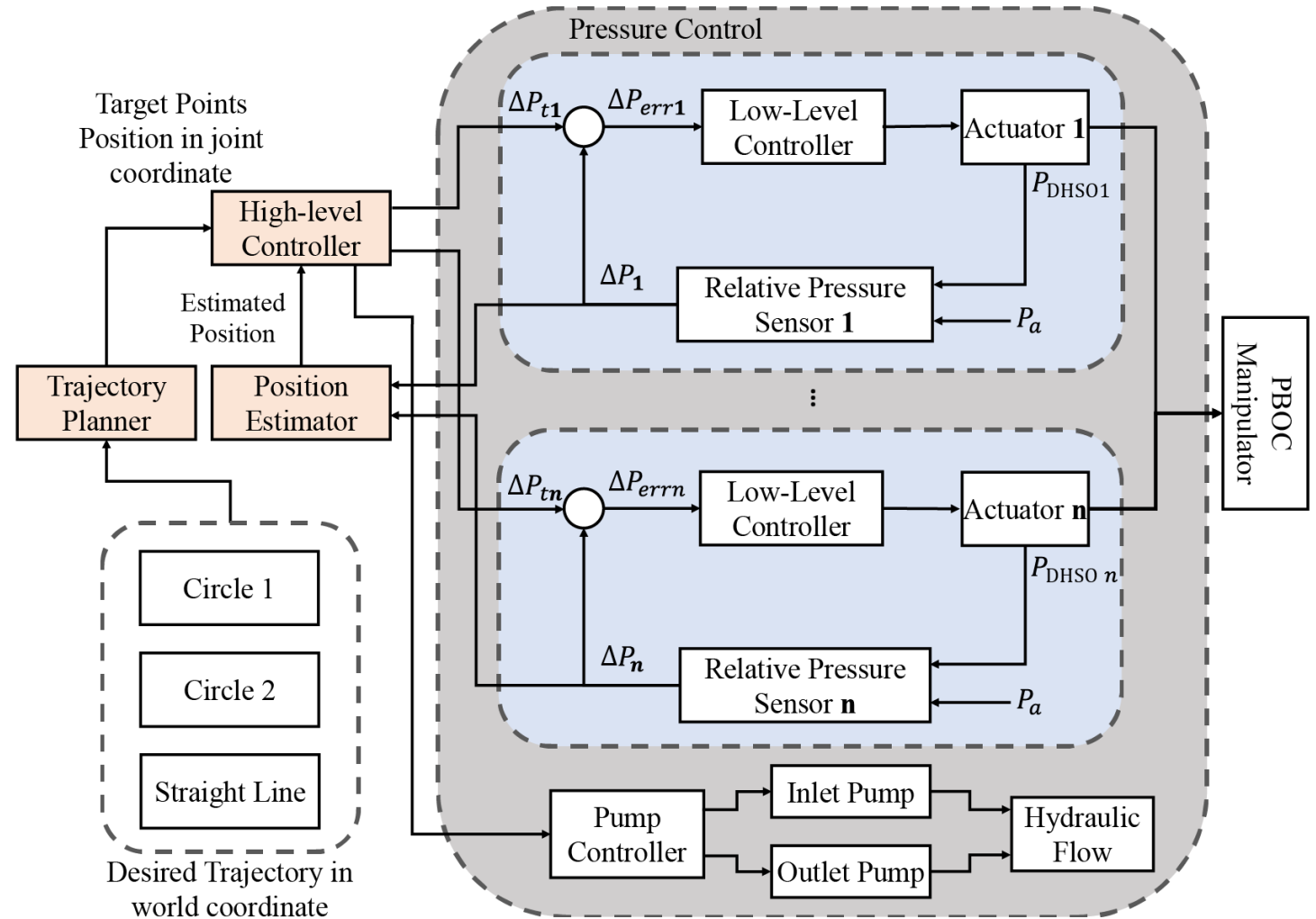
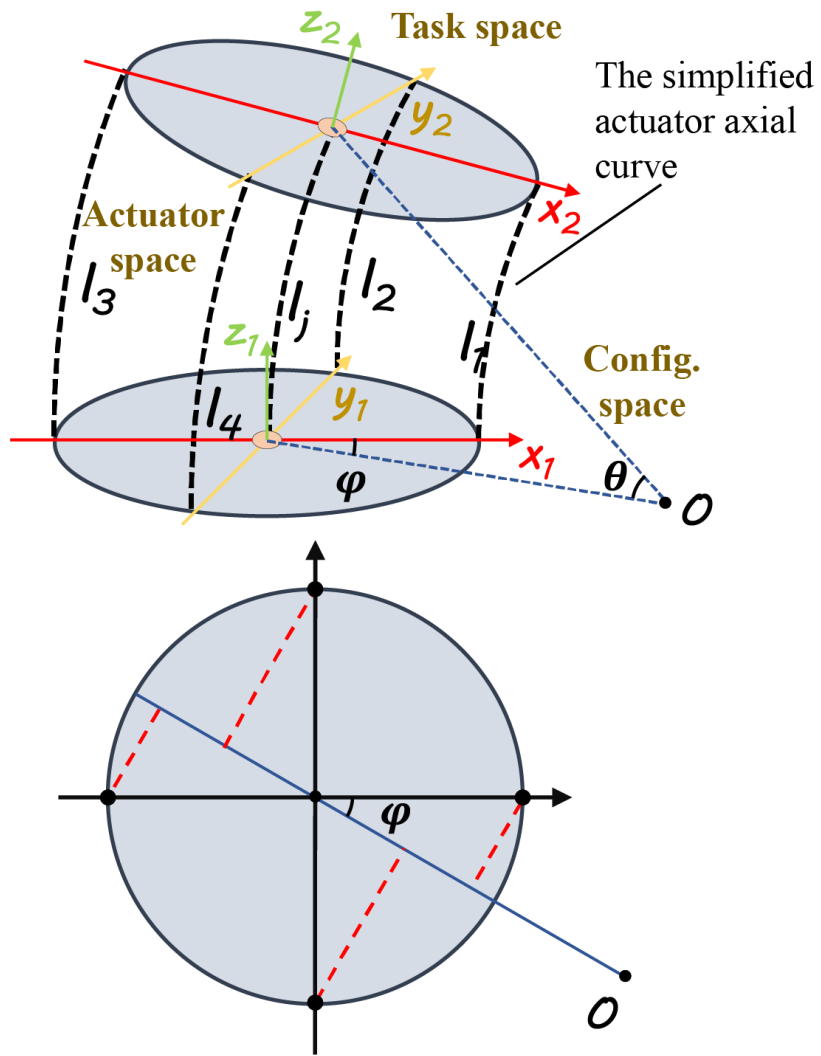
The Planarly-bundled and Overly-Constrained (PBOC) Assembly



The Flow-Controllable Open-Circulation (FOC) Actuation



Modeling of the PBOC Joint and the Control Method



Basic Performance of the DSHO Actuator and the PBOC Joint

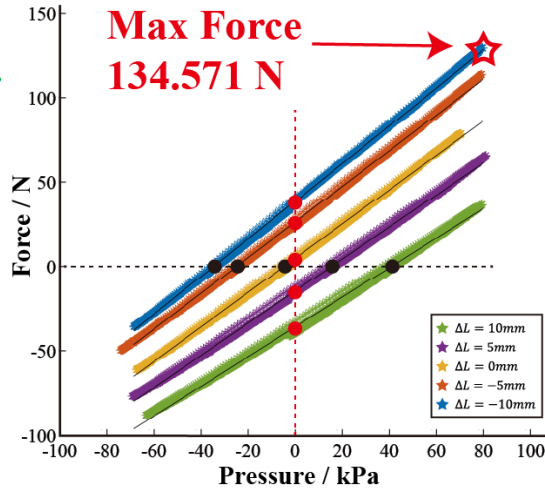
DSHO Actuator

$$\frac{\text{Load}}{\text{Weight}} = 216$$

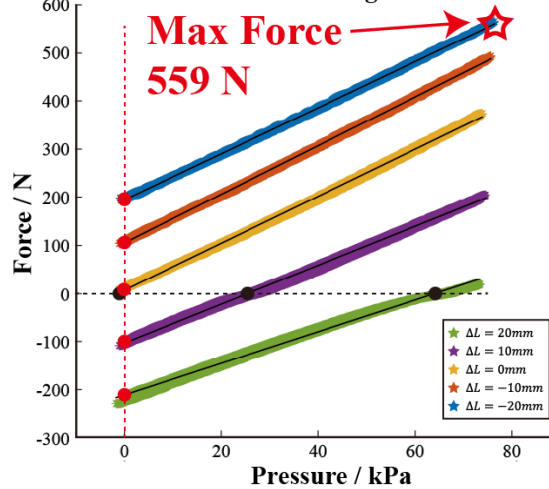
PBOC Joint

$$\frac{\text{Load}}{\text{Weight}} = 91$$

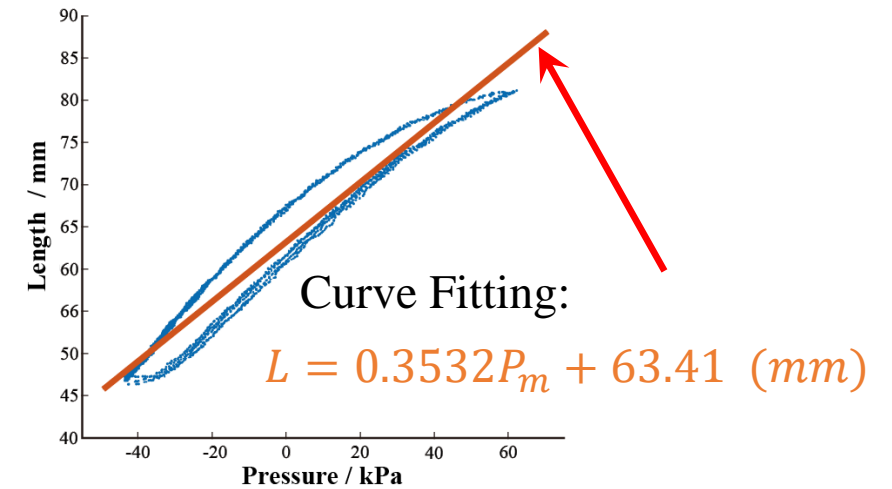
The Relationship between Force and Pressure under Different Length of DSHO Actuator



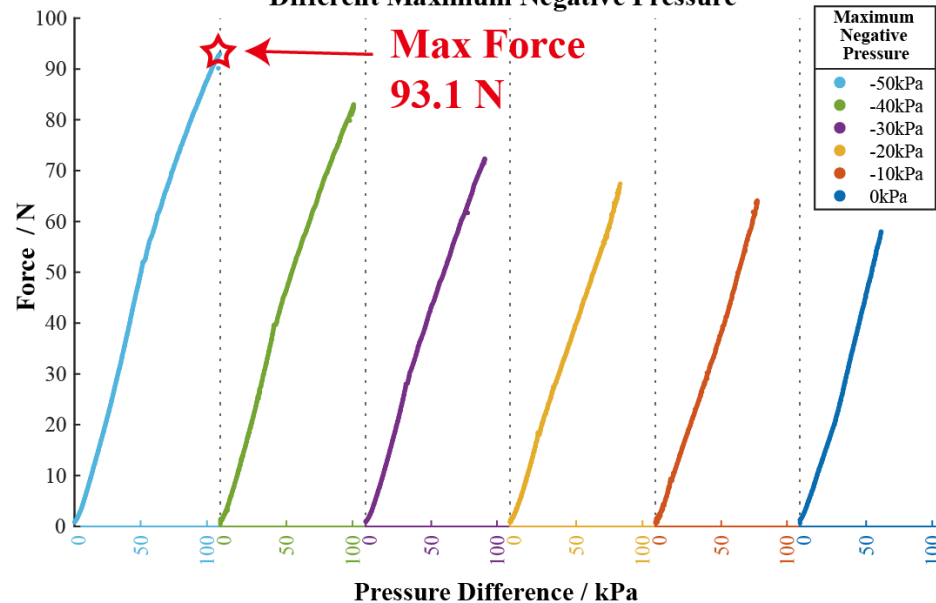
The Relationship between Force and Pressure under Different Length of Joint



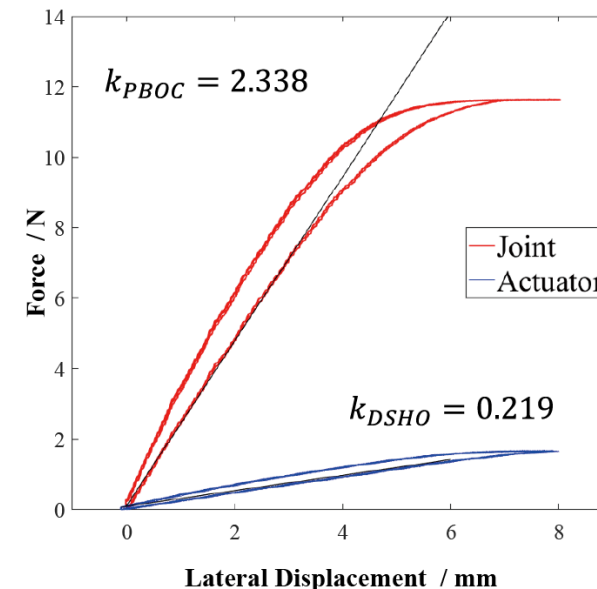
The Relationship between Elongation and Pressure



Relationship between Force and Pressure Difference under Different Maximum Negative Pressure



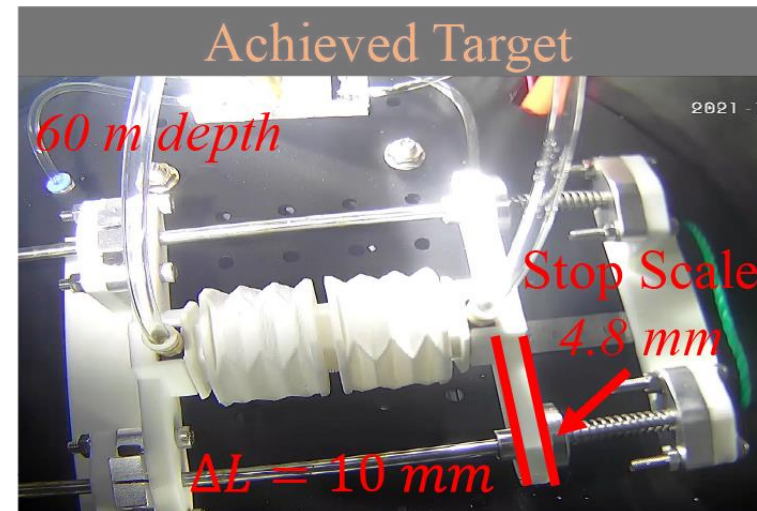
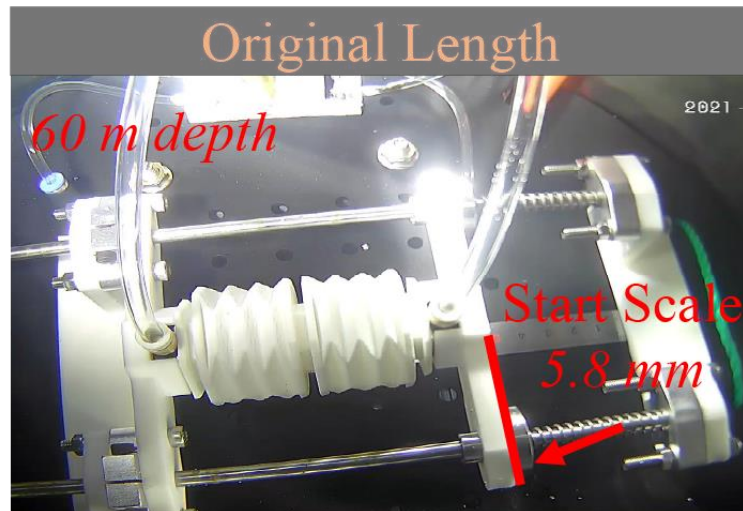
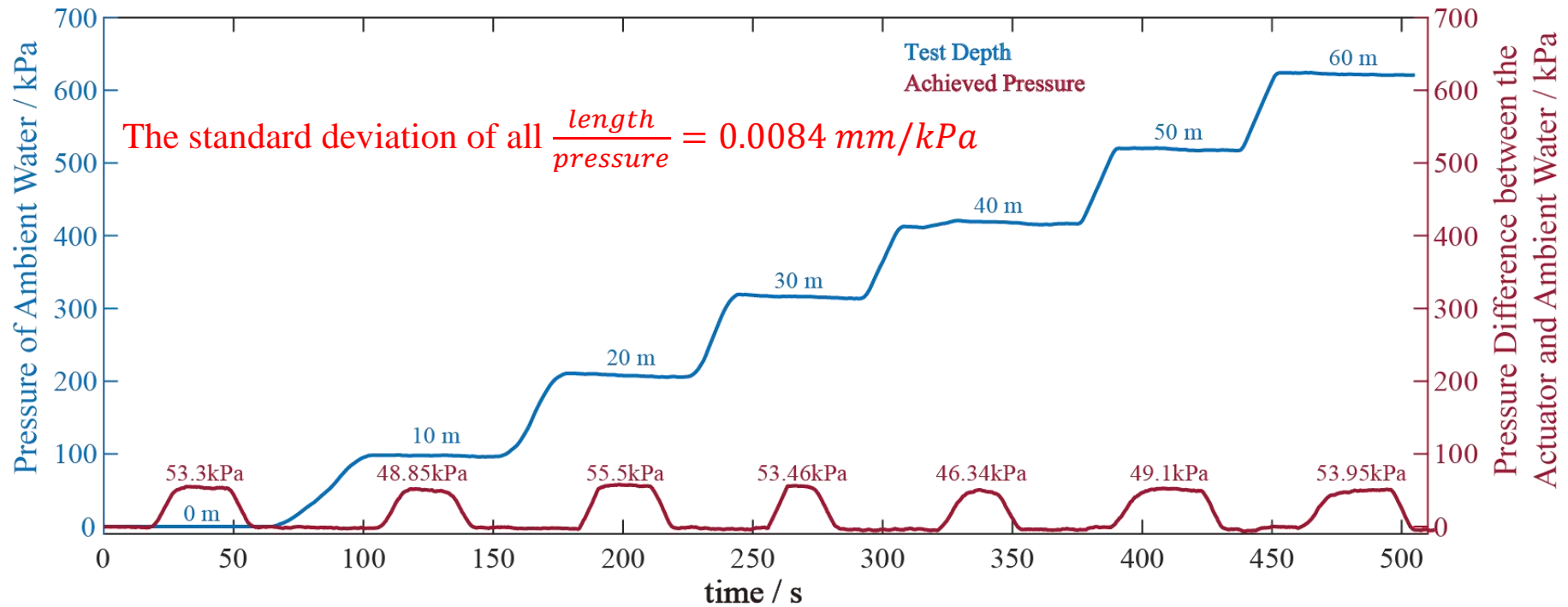
Lateral Rigidity Comparison between the PBOC Joint and the DSHO actuator



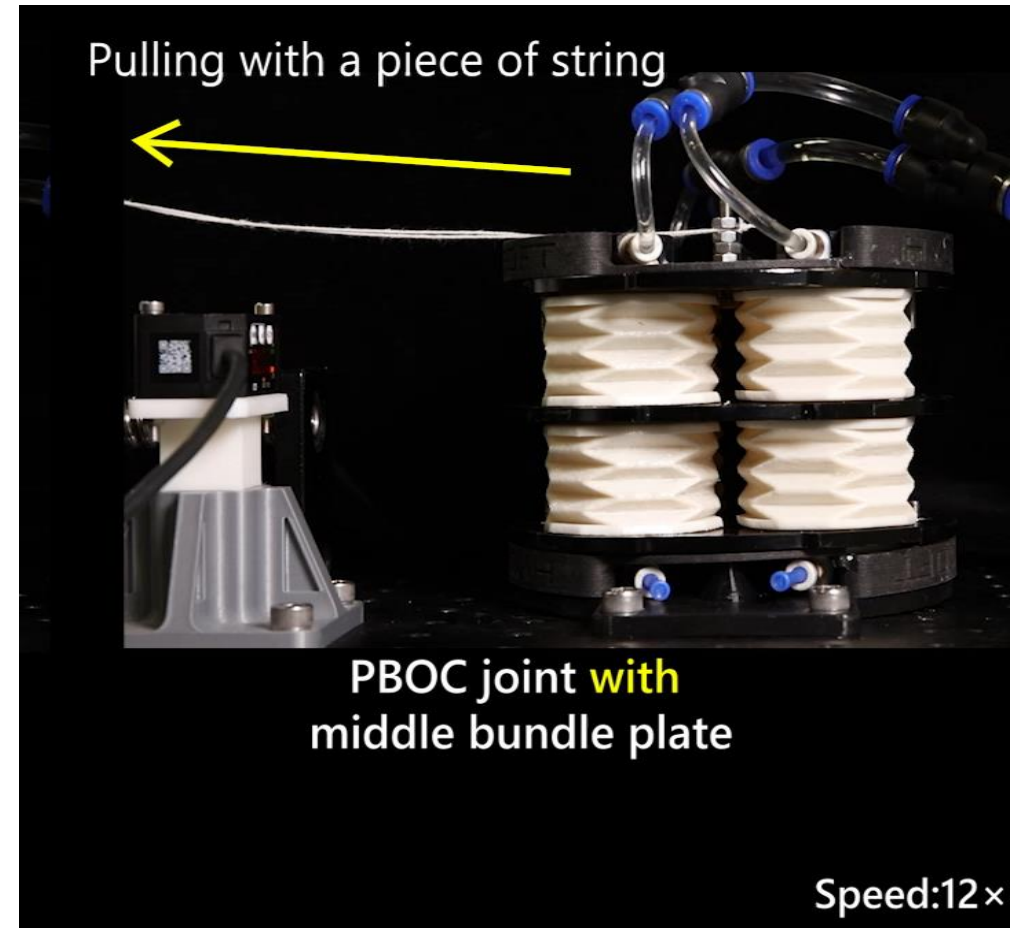
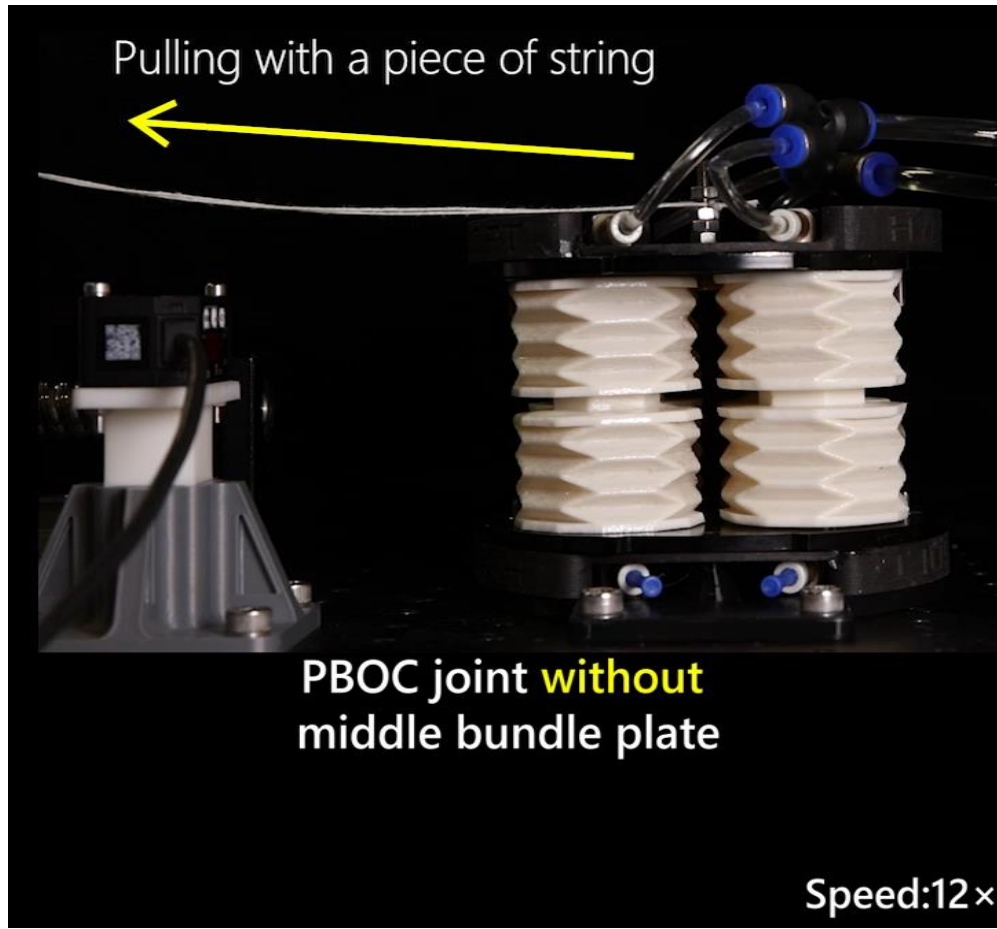
Lateral Rigidity Ratio:

$$\frac{k_{PBOC}}{k_{DSHO}} = 10.67 > 4$$

Characteristics of the FOC Hydraulic Control System



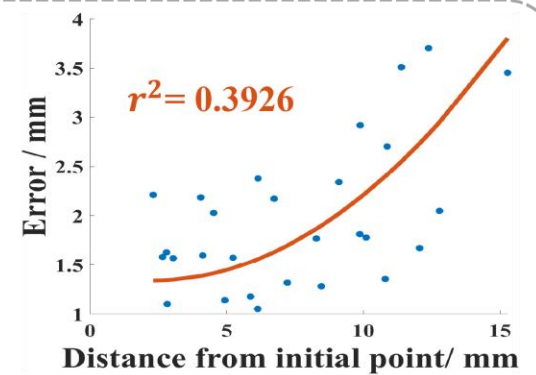
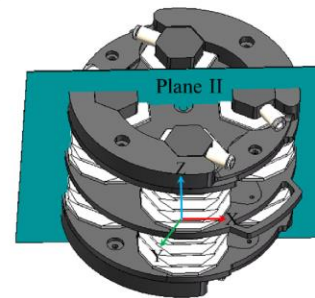
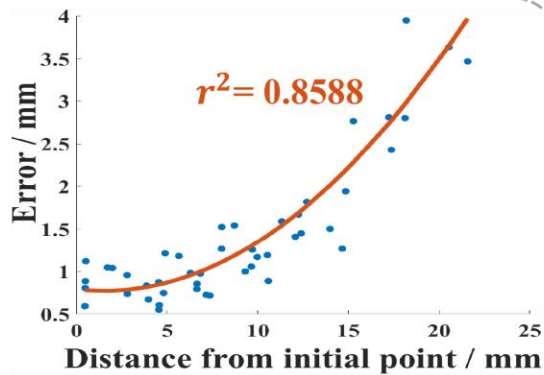
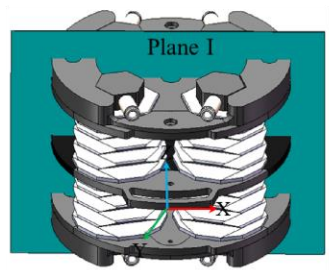
Accurate Kinematic Model of the PBOC Joint



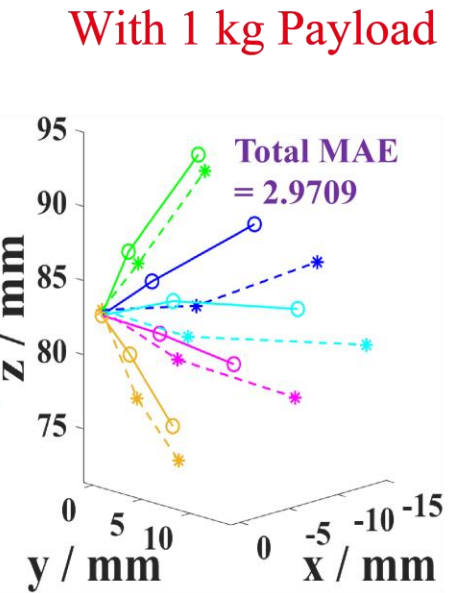
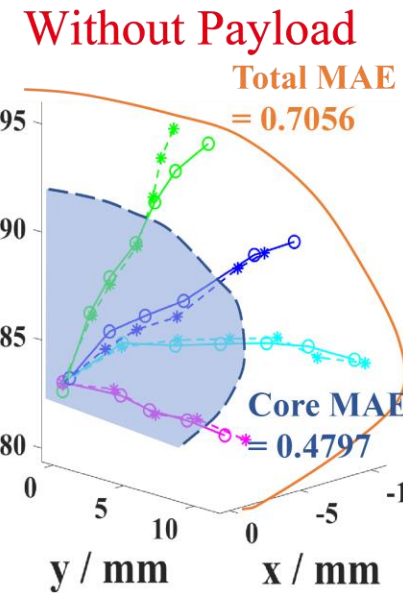
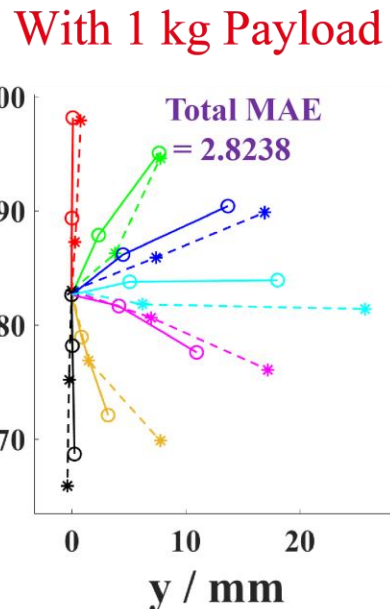
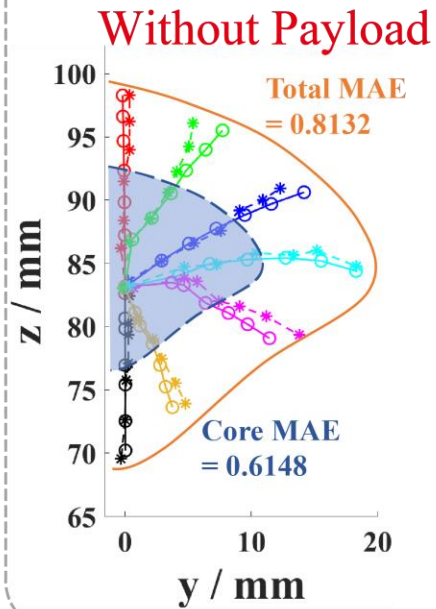
Accurate Kinematic Model of the PBOC Joint

CCA Compliance:

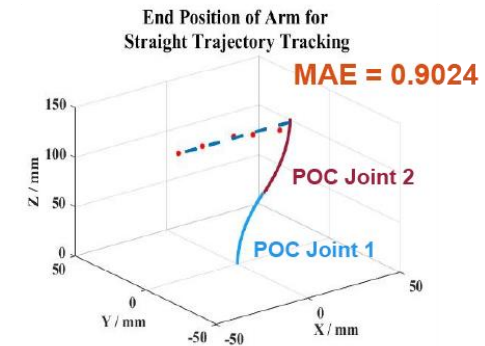
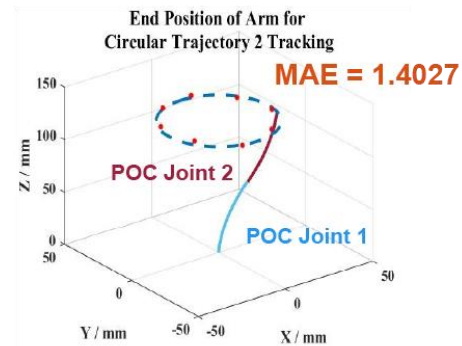
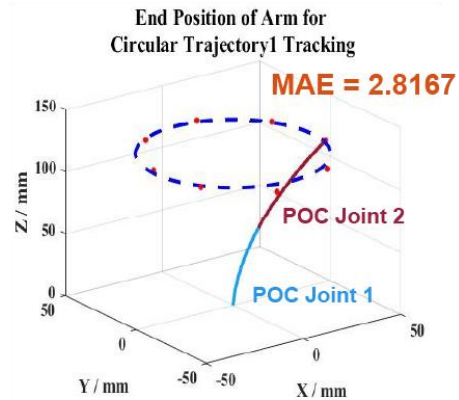
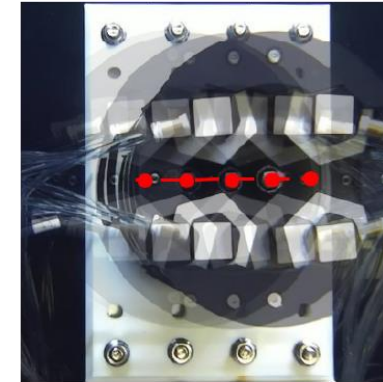
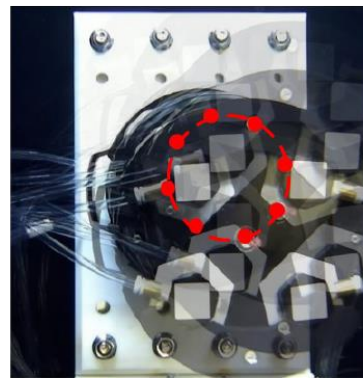
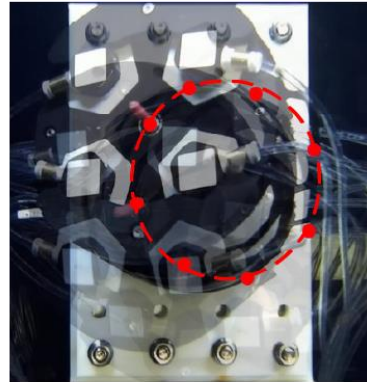
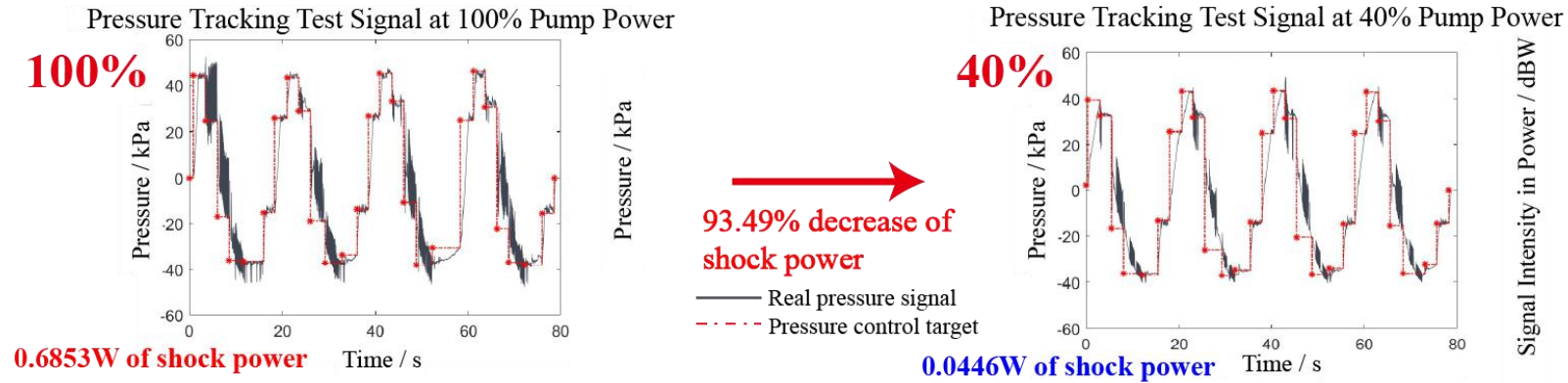
P_1 deviation ratio : 0.27%



P_2 deviation ratio : 51.16%



Smooth Trajectory Tracking with the FOC System



- Measured Trajectory Point
- Planned Trajectory Point

Summary

- **Mechanical characteristics:** The proposed PBOC joint was proposed with outstanding payload capability, excellent structural stiffness, and accurate kinematic operation. The maximum payload capacity of a single joint achieved 559N without buckling, and the manipulator system weighs 5.83 kg with a load-to-weight ratio of 9.78. The middle constraint plate could sharply decreased the prediction deviation by CCA-based kinematic model from 51.6% to 0.27% under lateral payload.
- **FOC actuation and control:** the actuation system could keep consistent performance within 60 meter depth without depth compensation. And the pressure oscillations on pressure regulating progress are reduced by 93.49% with flow control.
- Based on the developed kinematic models and semi-open-loop controller, the manipulator system achieved accurate trajectory tracking in validation experiment.

Future Work

- Focusing on fully close-loop position control in the underwater manipulator system.
- Exploring multi-modal sensing to recognize the interaction with environment to improve control accuracy.



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Thank You!

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