A Multi-Facet-Effector Soft Robot in Polyhedral Configuration for Multidirectional Function Reuse

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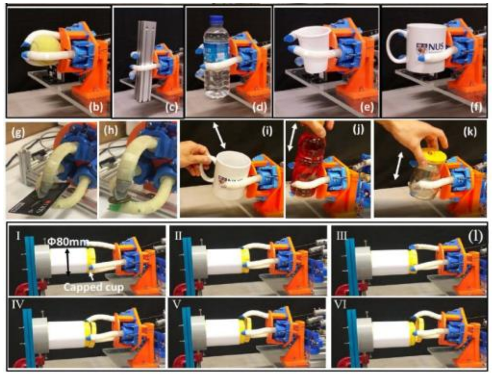
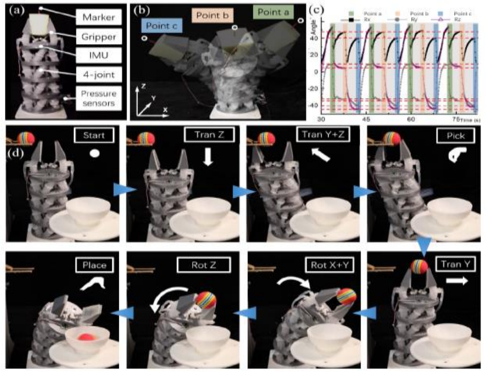
4. Experimental Results and Validation

5. Conclusions and Prospects

1. Introduction and Background



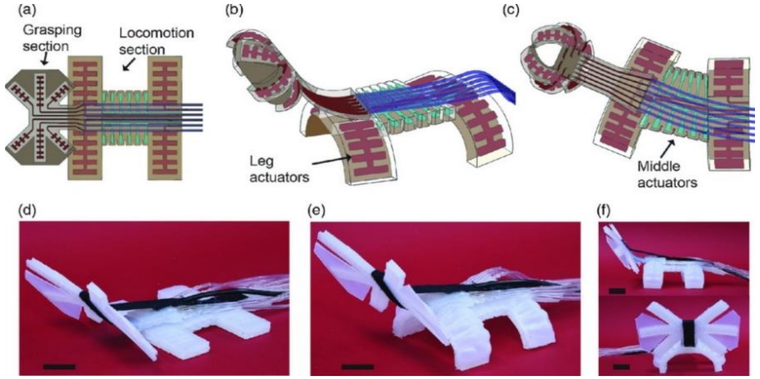
Simultaneous grasping and in-hand cap manipulation
Liu Q et al. (2020)



Six degrees-of-freedom soft robotic joint
Liu S et al. (2022)

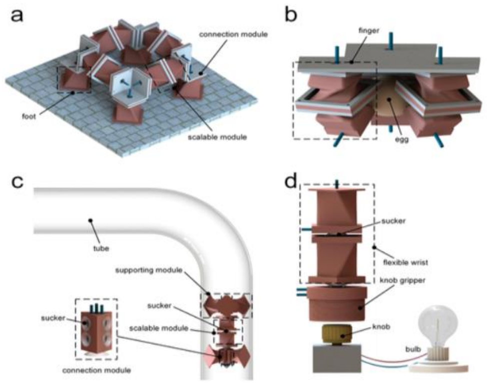
Combination

Grasping and Manipulation

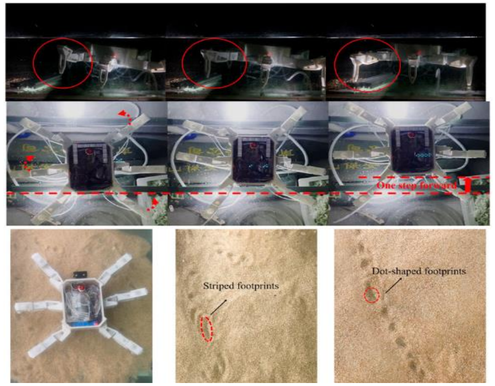


Combining locomotion and grasping functionalities
Yin A et al. (2019)

Locomotion



Flexible material-based reconfigurable soft robots
Jiao Z et al. (2019)

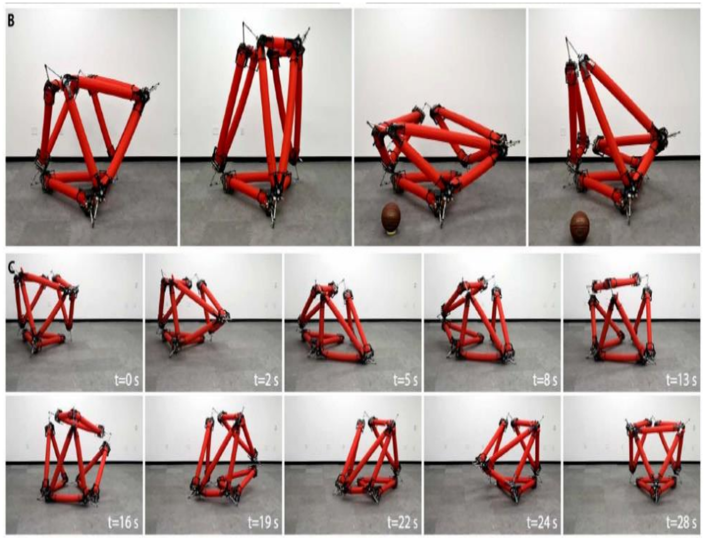


Underwater crawling robot with hydraulic soft actuators
Tan Q et al. (2021)

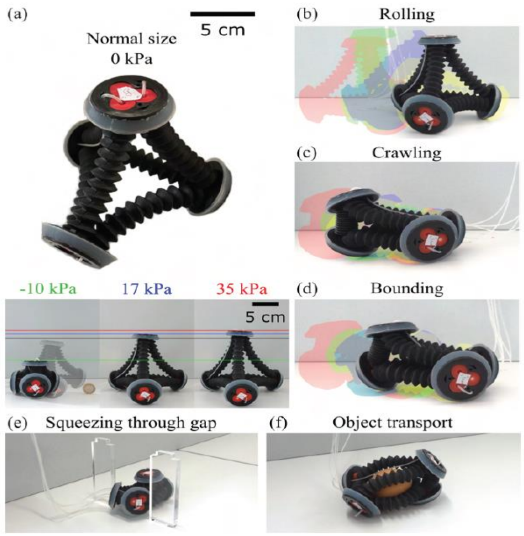
- Pneumatic soft robots have been increasingly used in unstructured environments, challenging their **multifunctionality and adaptability**.
- These robots need capabilities like **grasping, manipulation, and locomotion** to interact with their surroundings.

1. Introduction and Background

Polyhedral Soft Robots



An untethered isoperimetric soft robot
Usevitch et al. (2020)



Tetrahedral multigait soft robot
Wharton P et al. (2023)

- Soft robots with a **unified structure** capable of performing **multiple functions** have become a focus of attention.
- **Polyhedral soft robots** can flexibly change their shape to adapt to different environments.

Contributions of the Paper

Proposing a Multi-Facet-Effector (MFE) soft robotic design.

↓

Enabling the robot to operate as both a gulp gripper (MFG) and a parallel arm (MFA).

↓

Design, modeling, and control strategy detailed for an octahedral MFE robot.

↓

Theoretical results validated through experimental demonstrations.

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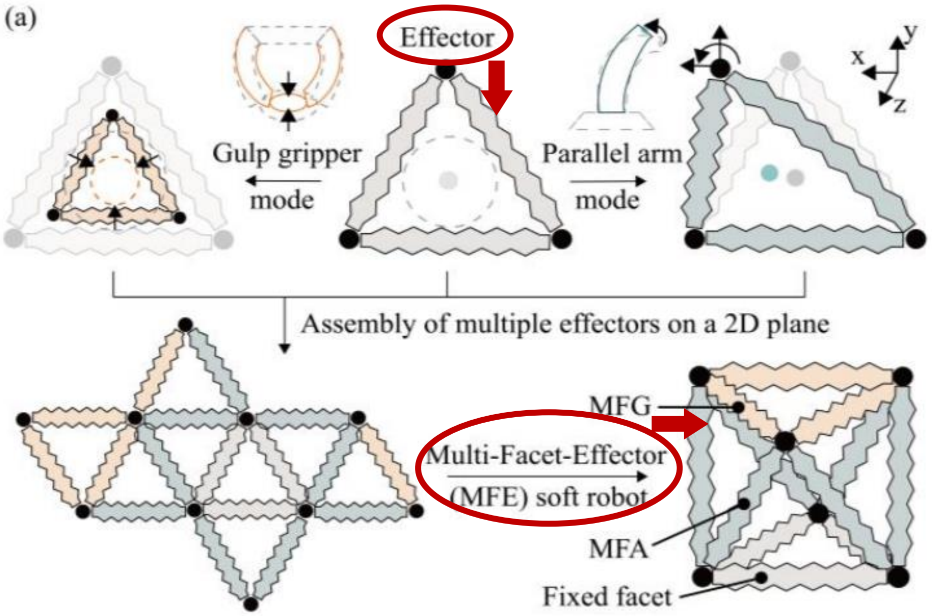
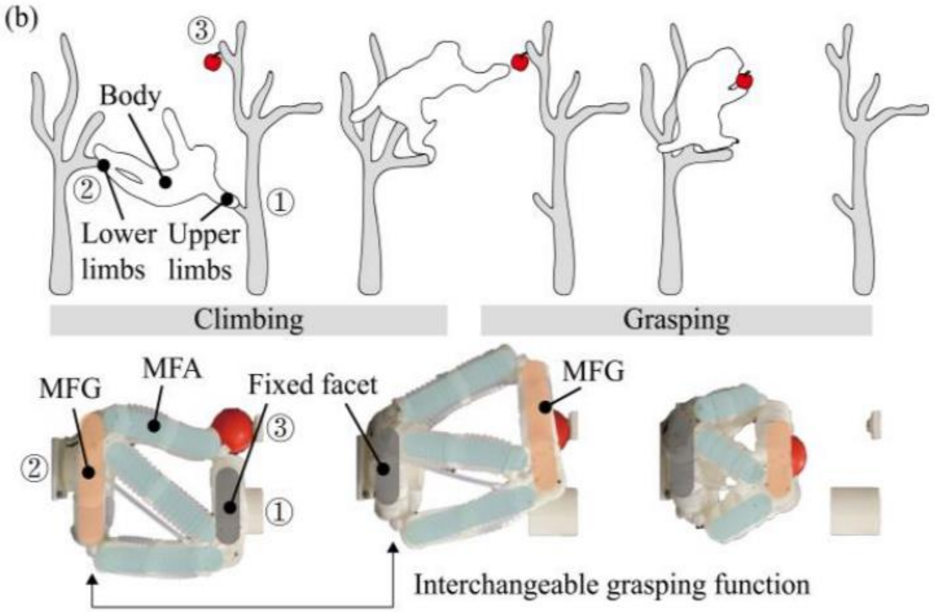
2. Concept and Design

Concept:





Design:

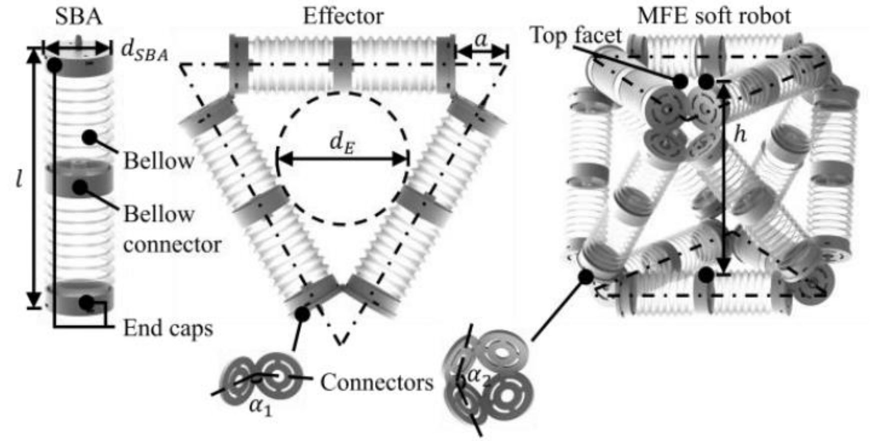


TABLE I. GEOMETRIC PARAMETERS OF THE DESIGN

d_{SBA}	Diameter of the actuator	36.3mm
l	Static length of the actuator	133.0mm
a	Distance between the center of two caps	32.6mm
α_1	Angle between the left and right caps	120°
α_2	Angle between the up and down caps	120°
d_E	Static inner diameter of the effector	78.1mm
h	Static distance between parallel faces	161.8mm

2. Modeling and Control

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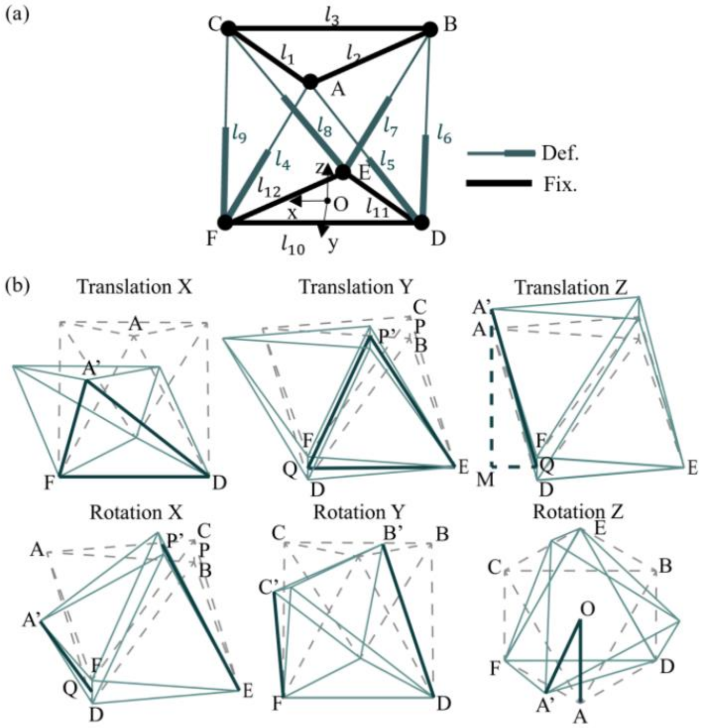
Modeling:



Translations

$$\Delta x = a'_x - a_x = \frac{l_4^2 - l_5^2}{2l_0}.$$

$$\Delta y = p'_y - p_y = \frac{l_6^2 - l_7^2}{\sqrt{3}l_0}.$$

$$\Delta z = a'_z - a_z = \sqrt{l_4^2 - \frac{1}{3}l_0^2} - \frac{\sqrt{6}}{3}l_0.$$

Rotations

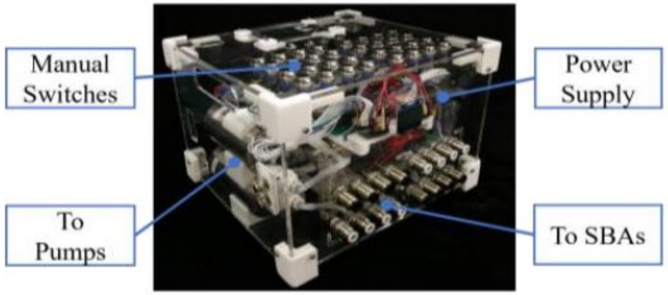
$$\Delta\alpha = \frac{P'E - A'Q}{\frac{\sqrt{3}}{2}l_0} = \frac{\sqrt{l_4^2 - \left(\frac{l_0}{2}\right)^2} - \sqrt{l_7^2 - \left(\frac{l_0}{2}\right)^2}}{\frac{\sqrt{3}}{2}l_0}.$$

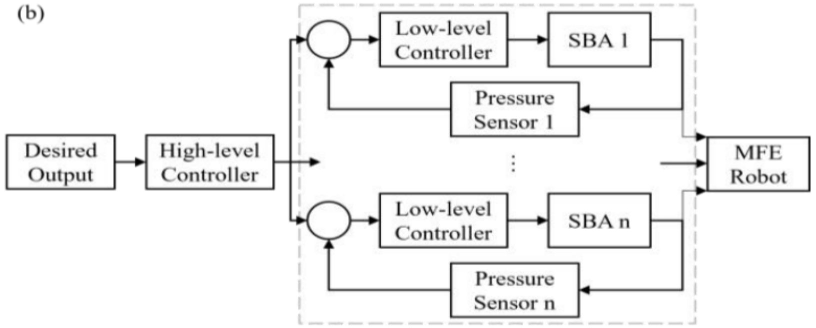
$$\Delta\beta = \frac{B'D - C'F}{\frac{\sqrt{3}}{2}l_0} = \frac{l_6 - l_9}{\frac{\sqrt{3}}{2}l_0}.$$

$$\Delta\gamma = \arccos\sqrt{1 - \left(\frac{l_4^2 - l_5^2}{2*l_0*r}\right)^2}.$$

Control:

(a)





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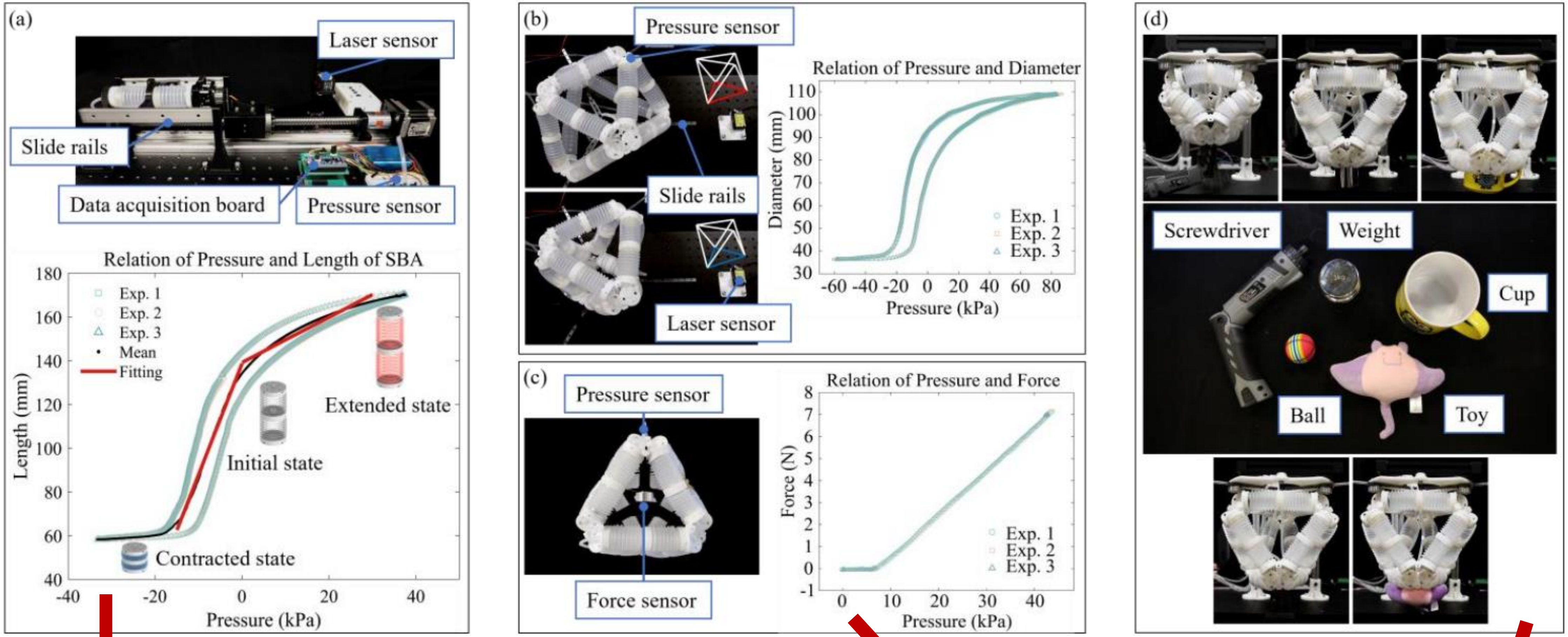
3. Versatile Functionality of Gripper



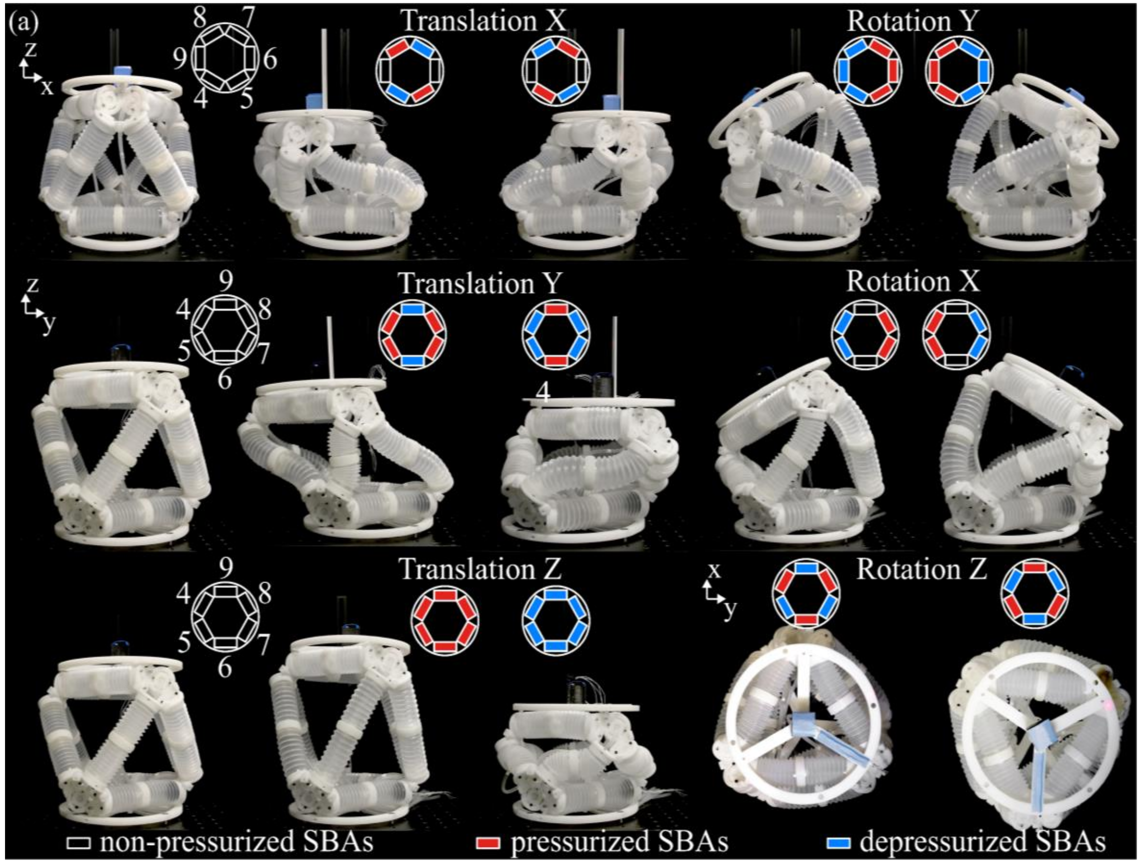
Fitting curve formulation for the pressure-length relationship of SBA:

$$\begin{cases} l = 5.0844p + 138.7415, p < 0\ ; \\ l = 1.0355p + 139.1741, p \geq 0\ . \end{cases} \qquad R^2=0.996$$

Effector's gulp gripper mode performance:

- Grasping range: 36.3-109.1 mm
- Holding force: 0-7.0 N
- Adaptability for grasping various objects

3. Versatile Functionality of Arm



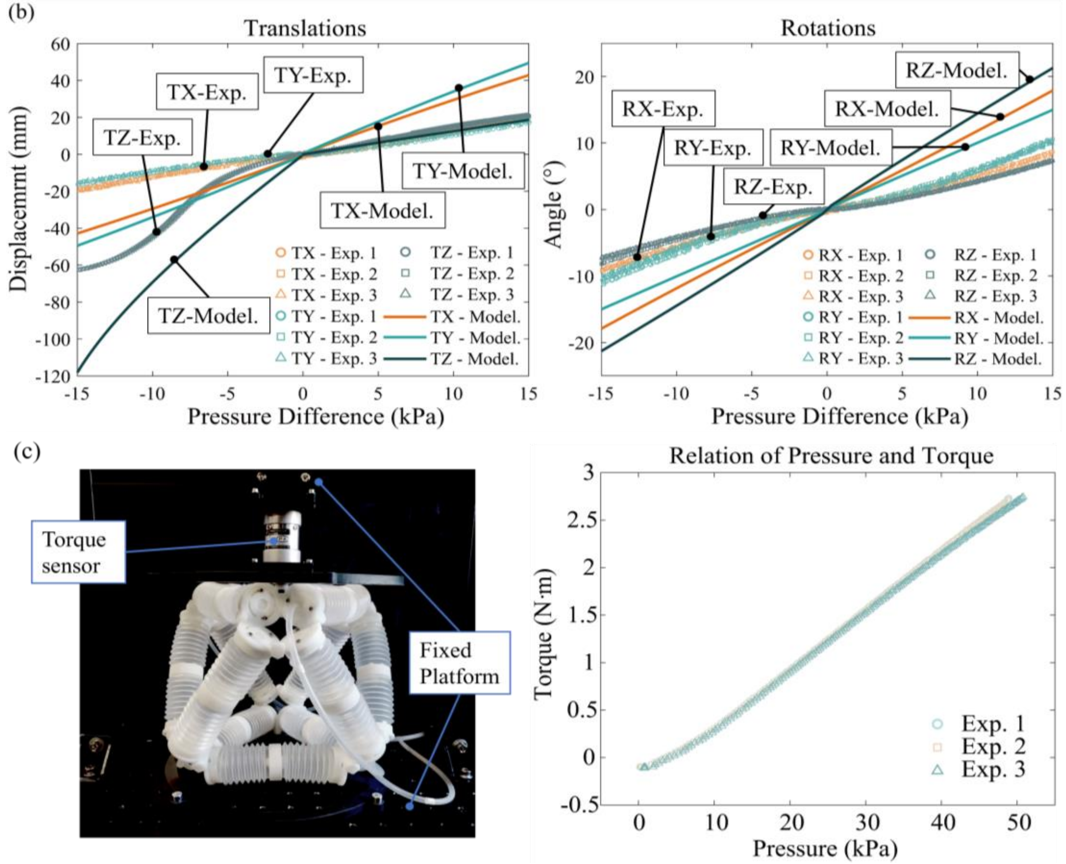


TABLE II. RANGE OF MOTIONS

Translations	Range	Rotations	Range
X	-43.7 ~ 40.7 mm	X	-28.0 ~ 26.3°
Y	-54.5 ~ 55.1 mm	Y	-29.3 ~ 32.1°
Z	-67.1 ~ 29.4 mm	Z	-35.4 ~ 35.9°

- Generally, the model data exceeds the measured data due to strong coupling in SBA motions, wherein air pressure both aids elongation and resists internal forces.
- Torque: 0-2.7 Nm

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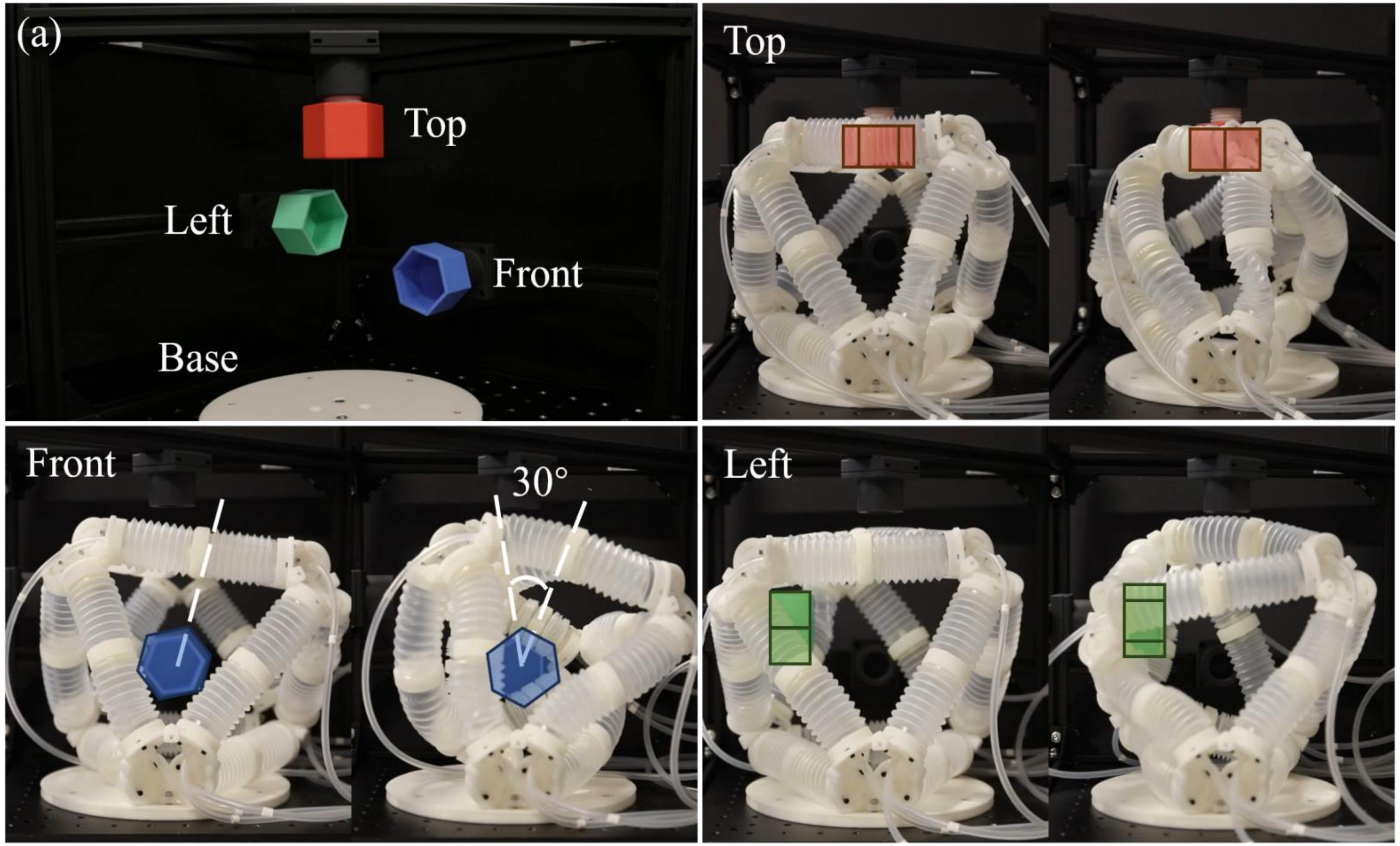
4. Experimental Results and Validation



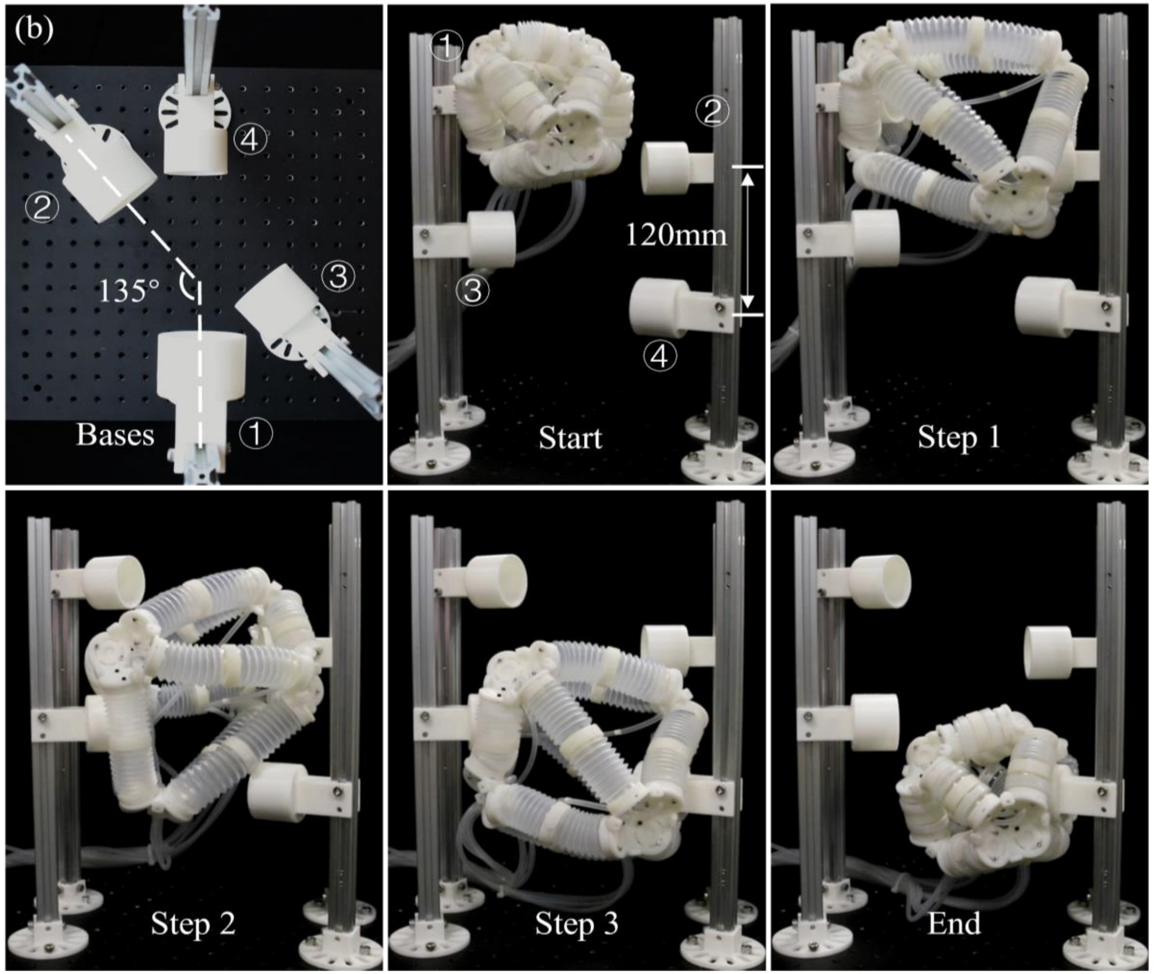
Task 1: Manipulation

- The robot unscrews bolts from distinct orientations while stationed at a fixed position.
- It performs a cycle of grabbing, twisting, releasing, and returning, showcasing its multifaceted manipulation capabilities.

4. Experimental Results and Validation

Task 1: Manipulation

4. Experimental Results and Validation



Task 2: 3D-climbing

- The robot achieves 3D climbing in the intricate terrain by coordinately adjusting its opposite facet-effectors for grabbing, repositioning, and moving.
- The robot grabs and repositions four times to descend an 18 cm distance and travel a 135° angular displacement, avoiding the spatial obstacles.

4. Experimental Results and Validation

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Task 2: 3D-climbing

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Conclusions:

- **Innovation:**

Introduction of a 2D triangular Multi-Facet-Effectors (MFE) design on discrete surfaces of an octahedral configuration.

- **Gripping Capability:**

The gulp gripper (MFG) mode can grasp objects within a diameter range of 36.3-109.1 mm, with a maximum holding force of approximately 7 N.

- **Motion Capability:**

The parallel arm (MFA) mode shows symmetric behavior in five degrees of freedom. Translations in the X and Y directions reach approximately 42.2 mm; in the Z direction, it ranges from -67.1 to 29.4 mm. Unidirectional rotation angles around the X, Y, and Z axes are approximately 27.2°, 30.7°, and 35.7°, respectively.

- **Multifaceted Collaboration Functionality :**

Demonstrates excellent operational capabilities and mobility in 3D spaces. Coordinated actions among MFEs allow for diverse task execution and climbing on complex terrains.

5. Conclusions and Prospects

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Prospects:

- **Design Refinement:**

Further refinement to ensure alignment between the model and the prototype.

- **Inverse Kinematics:**

Deriving inverse kinematics models for feedback control.

- **Extended Capabilities:**

Further exploration of capabilities for complex tasks and environments.

Thanks for Listening!