ICRA 2020, Paris, France.

A High-payload Proprioceptive Hybrid Robotic Gripper with Soft Origamic Actuators

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May 19st, 2020

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Content

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Introduction

Motivations

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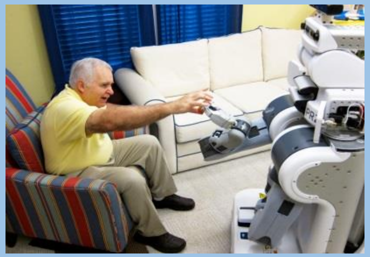
- Various applications of robotic gripper


Logistics sorting

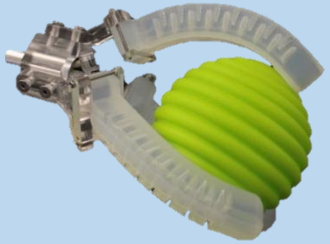

Elderly care [Monkman ‘1]

Machine tending


Human robot interaction [Chin ‘2]

Rigid robotic gripper

- High precision and large forces [Hughes & Culha '3]
- **Challenges for unstructured environments like fragile objects**. [Kim ‘4, Polygerinos ‘5, Su ‘6]


Soft robotic gripper

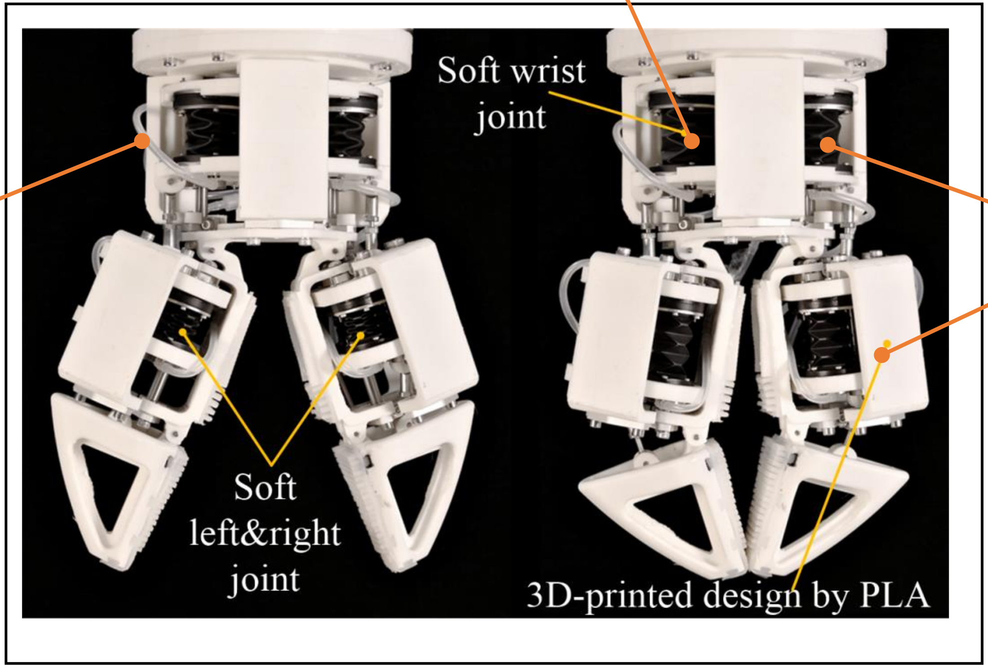
- intrinsic compliance [Polygerinos ‘8]
- simple structure and control strategy [Rus ‘9, Zhou ‘10]
- **Limited repeatability, precision, and low grasping force and speed** [Park ’13, Shintake ‘19]

There is a gap between the above robotic grippers. Therefore we need do something to fill the gap …

Contributions

- Proposed a Proprioceptive Origamic Soft Actuator joint with position and force proprioception.

- using the embedded cost-efficient air pressure sensors to realize position control and recognize the size and weight of object.

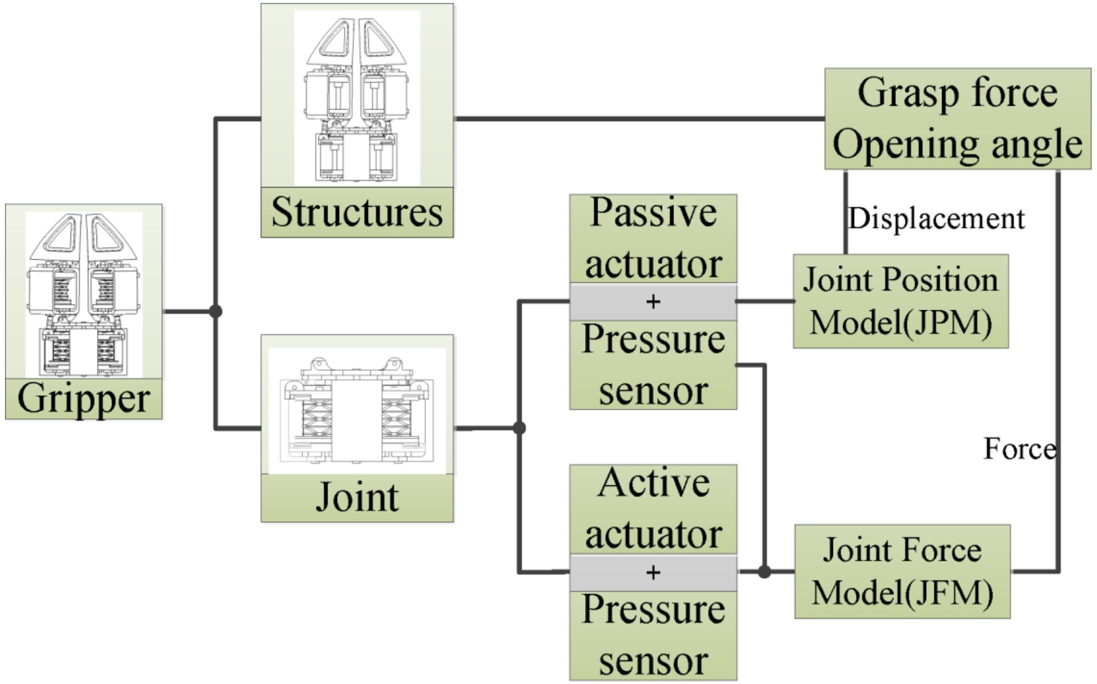


- High-payload hybrid robotic gripper with soft origamic actuator and hard mechanic structure.
- Works in *DELICATE MODE* or *POWER MODE*.

2 Methodology

Our proposed method

- The gripper is driven by POSA joint;
- Air pressure sensors are used to sense the movement and external stimulations;
- Based on the Joint Position Model, the passive actuator can measure displacement of the joint;
- Based on the Joint Force Model, the force generated by passive actuator and active actuator can be measured.



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- POSA joint consists of *n* active origamic actuators and *1* passive origamic actuator, driven by air compressor and vacuum pump.

- JPM-position proprioception

$$\frac{P_0 + P_a}{(P_{mp} + P_a)\epsilon_{s1}} + \frac{x}{H\epsilon_{s2}} = 1$$

P_0 the initial relative pressure

P_a the atmospheric pressure

P_{mp} the passive actuator pressure

ϵ_{s1} ϵ_{s2} can be calibrated by experiments

- JFM-force proprioception

$$F_{total} = \sum_{i=1}^{n} F_i + F_p$$

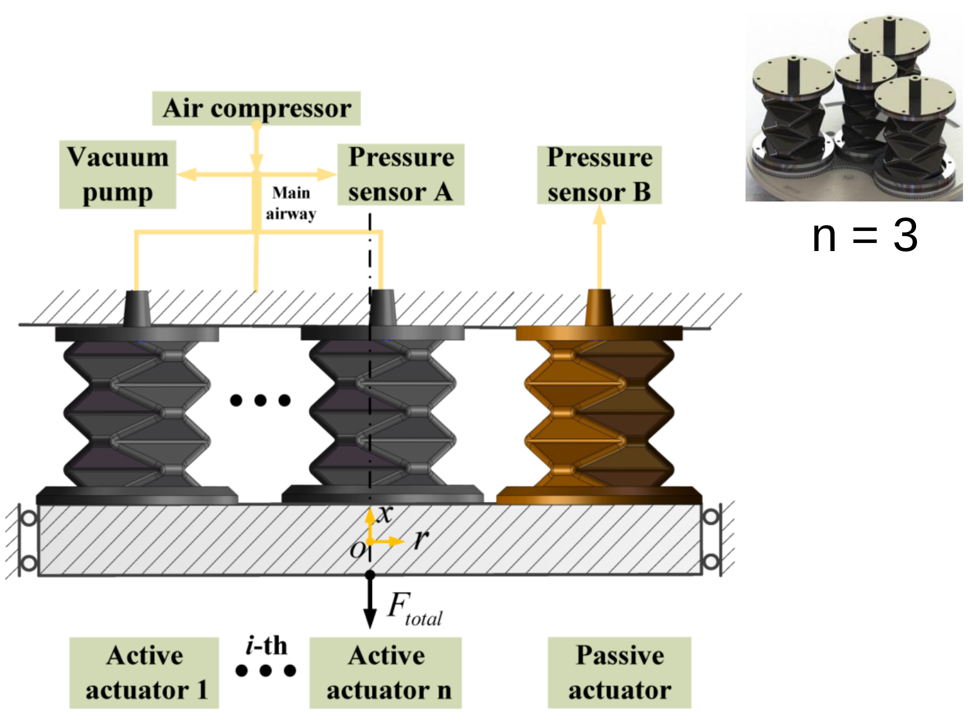
$$F_i = \frac{\pi D_{ei}^2}{4\epsilon_i} P_{mi} + g_i(x)$$

$$F_p = \frac{\pi D_{ep}^2}{4\epsilon_p} P_{mp} + g_p(x)$$

F_i is the output force generated from *i-th* active actuator

F_p is the output force generated the sealed actuator.

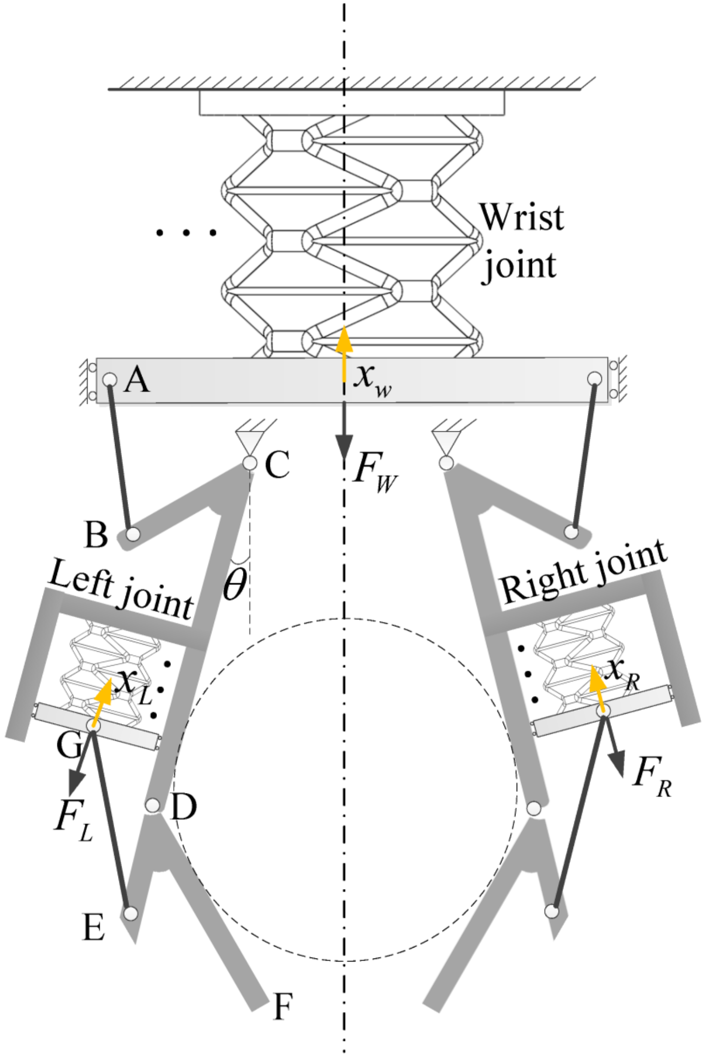
$\epsilon_i, \epsilon_p, g_i(x), g_p(x)$ can be calibrated by experiments



POSA joint

Scheme of proposed gripper

- The gripper three joints: one wrist joint and two finger joints.
- The wrist joint drives finger and finger joint drives the distal of the gripper.
- Axial displacement and output force of every POSA joint can be measured based on JFM and JPM.
- To enlarge the friction coefficient, soft contact interface layer fabricated by silicone rubber is added to the fingers.



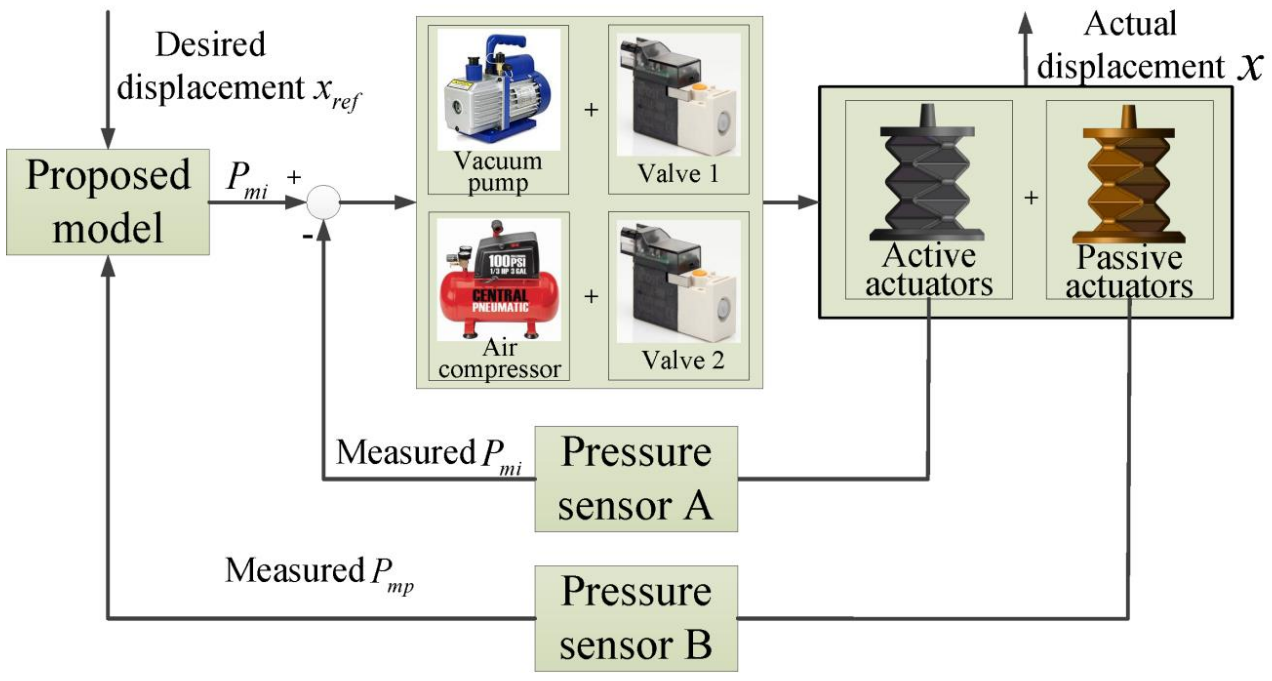
Position control strategy

- Outer loop: the displacement control for each joint
- Inner loop: pressure control for each active actuator
- Input pressure for inner loop:

$$P_{mi} = P_{mi0} + \gamma \Delta P_{mi}$$

$$\Delta P_{mi} = P_{mi0} \frac{x_{ref} - x}{x_{ref}}$$

γ can be calibrated by experiments



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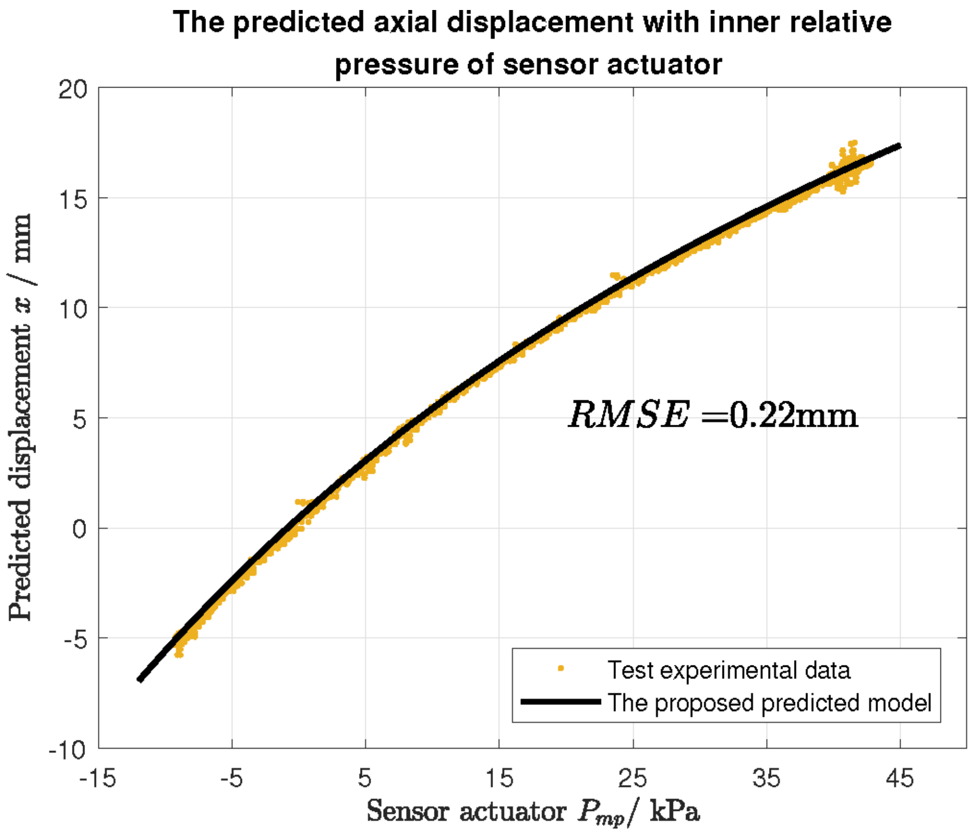
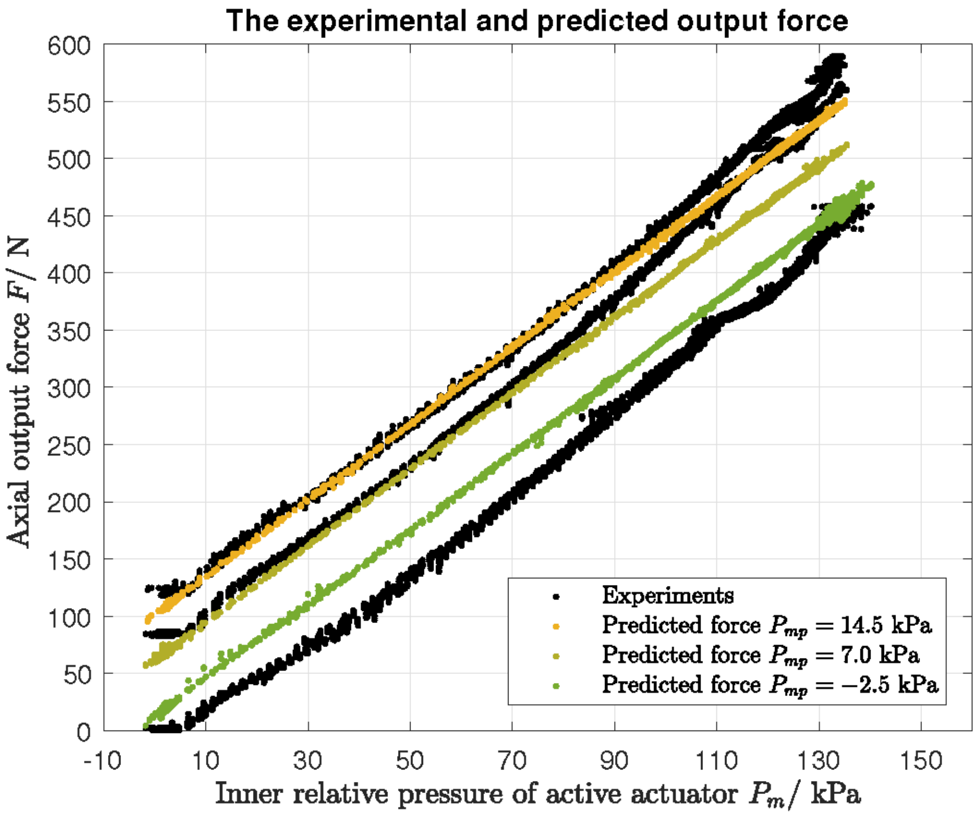
3 Results

POSA proprioceptive model (JPM & JFM)

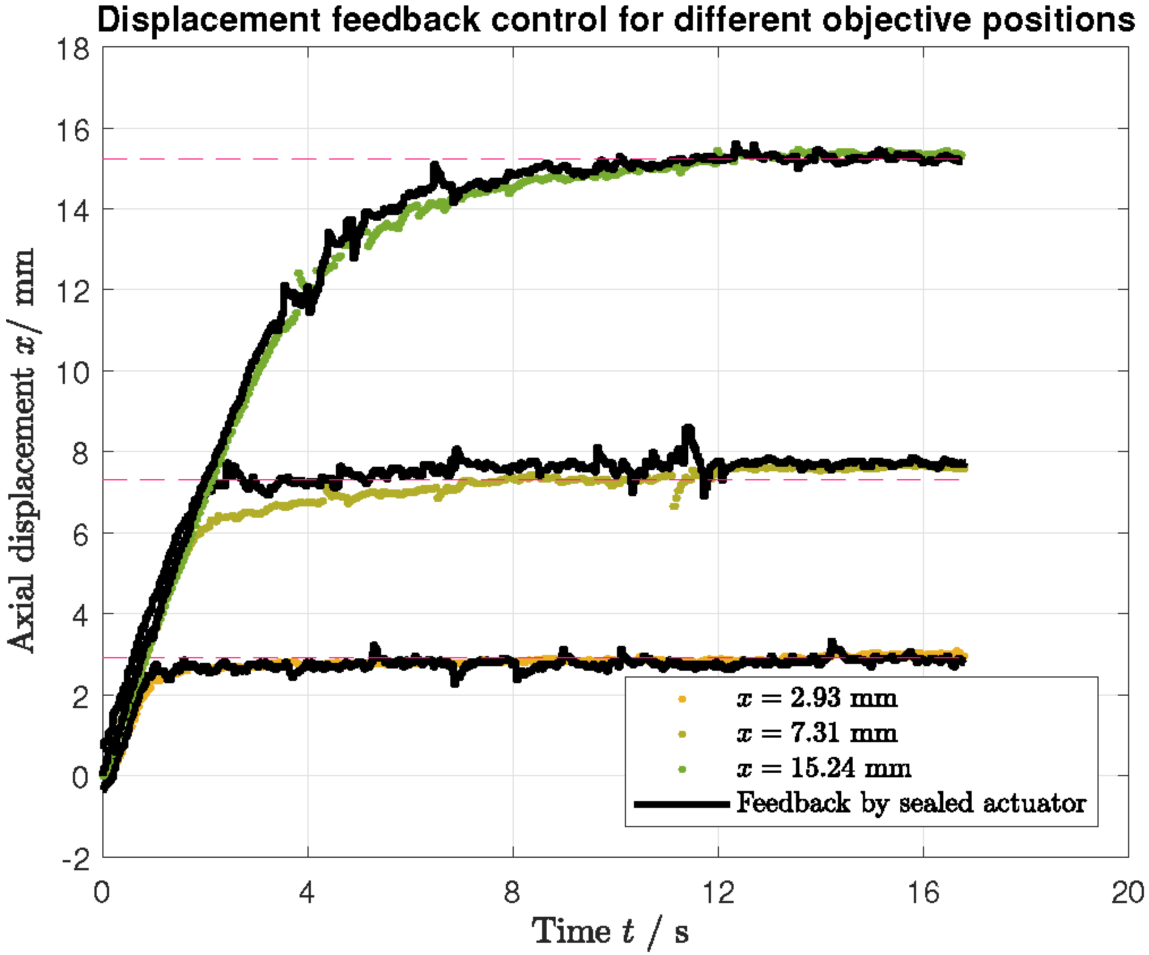


Displacement prediction of POSA joint by JPM



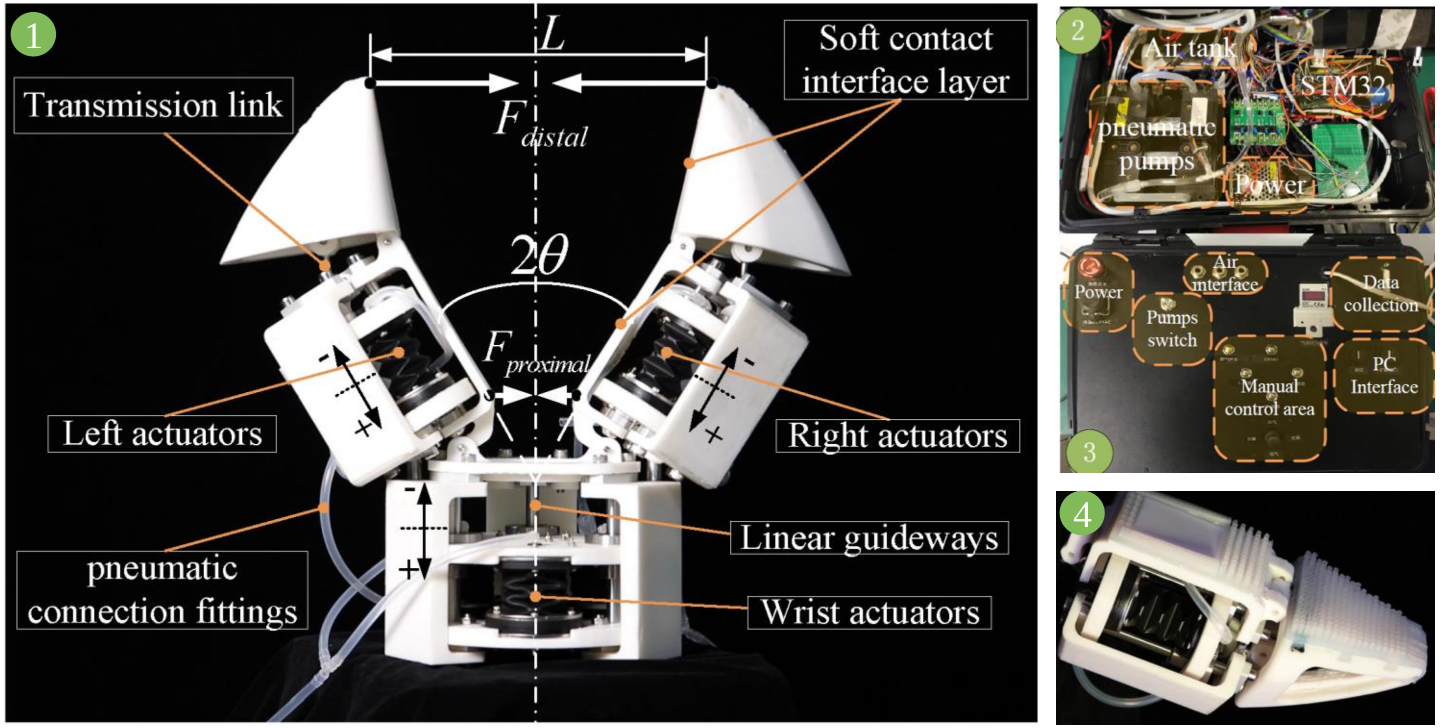
Total output force prediction of POSA joint by JFM

POSA joint position control for three reference displacements



Proposed fabricated gripper and its control section

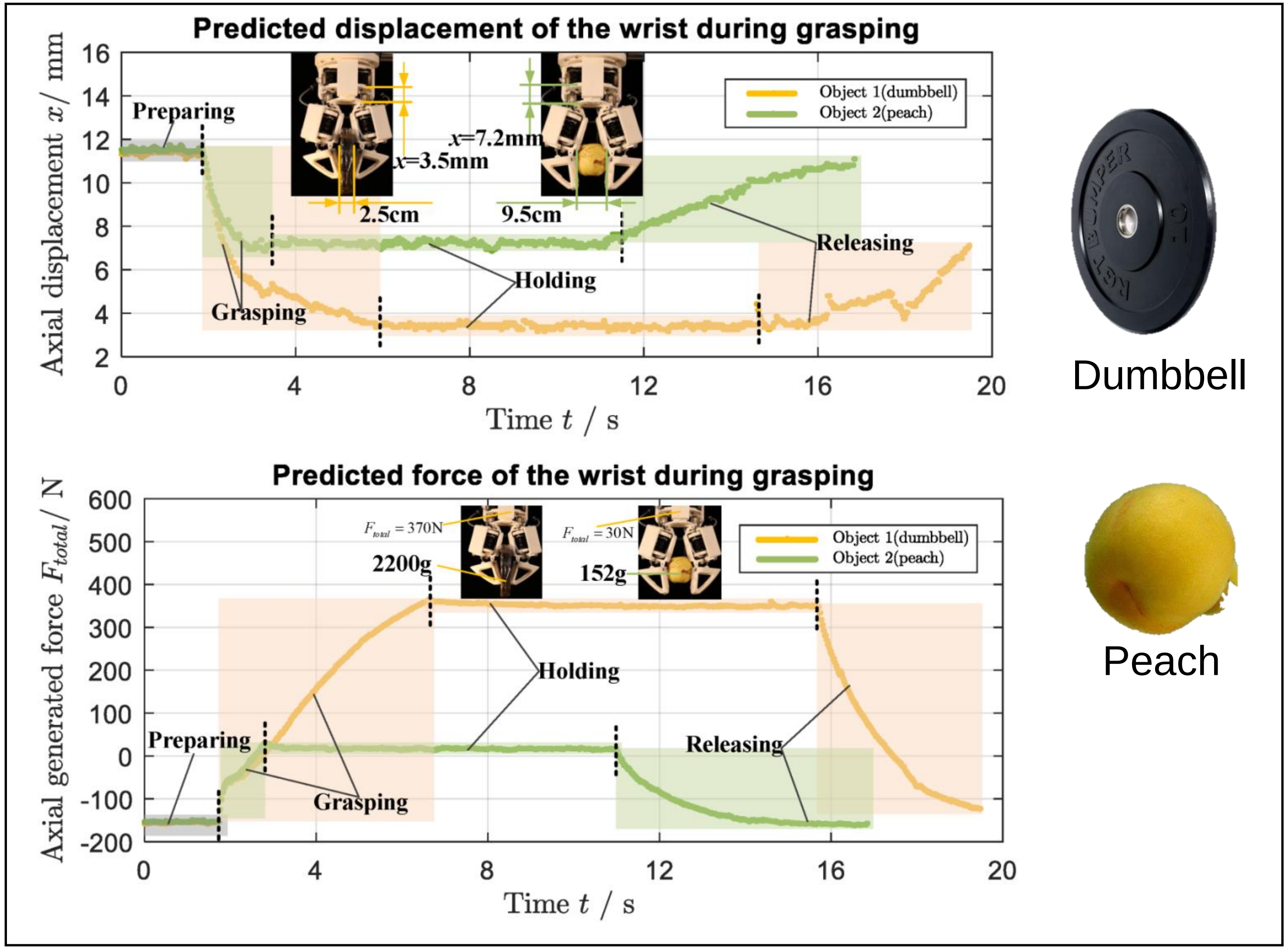
- The gripper are driven by three POSA joint with 3 active actuators.
- Linear guideways guarantee linear movement.
- $F_{proximal,\ max}$= 302.4N, $F_{distal,\ max}$= 52.1N, L_{max}= 305mm, and 2θ = 84° .
- Geometrics of control box: 400mm*300mm*180mm, the weight: 4.4kg.



1. Proposed fabricated robotic gripper
2. Control box
3. Control panel
4. Finger covered with interface layer

Proprioception validation (wrist) for size and weight of items

- The representative objects: dumbbell and peach.
- Four stages: preparing, grasping, holding and releasing.
- Can recognize the size and weight successfully.



Comparisons of the previous proposed gripper in our lab

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	BCL-4 [Zhou '25]	BCL-6 [Zhou '10]	BCL-13 [Zhou '15]	Bellows hybrid gripper [Wang '26]	Our proposed gripper
Fingers	2	3	4	2	2
DOFs	4	6	13	1	3
Self-weight	0.2kg	0.4kg	1.27kg	-	3.2kg
Actuators	Bellows actuator	Ellipse-shaped bending actuator	3-DOF soft pneumatic actuator	Bellows actuator	Origamic actuator
Grasping force	Joint: 50N Distal: 12N	40N	9.6N	6N	Joint: 564.5N Proximal: 302.4N Distal: 52.1N
Proprioception	No	No	No	By air pressure senor based on antagonistic bellows actuator	By air pressure senor based on proposed "n+1" joint

Video show of the proposed gripper

[The proposed video]

4 Conclusions

4 Conclusions

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- POSA joint with position and force proprioception based on parallel origamic soft actuators has been proposed. The minimum perceivable displacement and force for single joint can reach 0.2% and 5.6%, respectively.
- A high-payload two-finger hybrid robotic gripper was presented. The maximum $F_{proximal}$ and F_{distal} are 302.4N and 52.1N, respectively. The desirable feature of passive compliance was also preserved.
- The gripper can recognize the size and weight of object by the only kind of embedded cost-efficient air pressure sensors.
- A soft contact interface layer was introduced to improve contact stability.

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Future work

5 Future work

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- Design optimization to further reduce the size and weight.
- Control algorithm iteration to improve dynamic performance.
- Further development of the proprioception algorithm to enrich the feature and to improve functionality.

Thank you for your time

Questions
&
Answers