Configuration Design of an Under-Actuated Robotic Hand Based on Maximum Grasp Space

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2. Design Principle of UACT Finger

3. Grasp Model & Grasping Force Analysis

4. Knuckles Definition Based on Maximum Grasp Space

5. Prototype Robotic Hand & Grasp Experiments

6. Conclusion

1. Introduction

◆ On-orbit Service

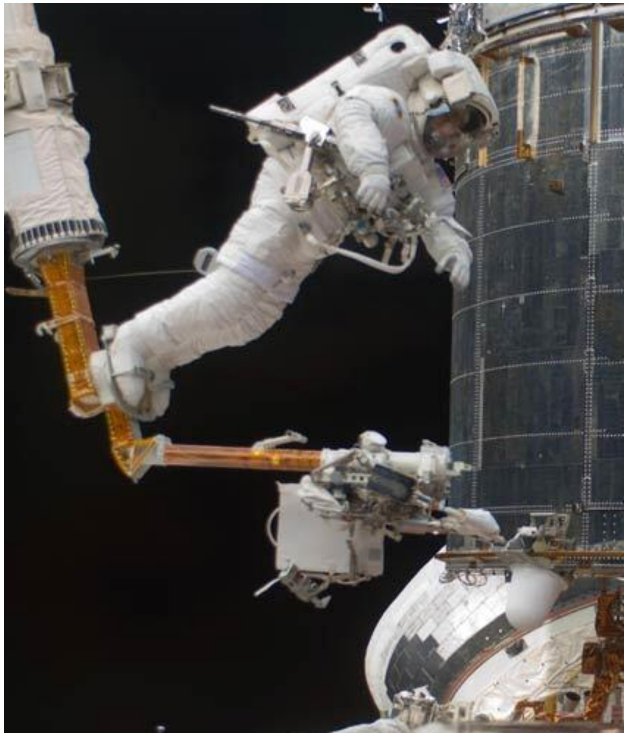
Features

- Contains **Fuel Adding**,
  Aircraft Repair,
  On-orbit Assembly and so on.
- **Capture** is an important part of the on-orbit service for a spacecraft.
- Astronauts are always playing as the end-effectors.

◆ Debris Cleaning

Features

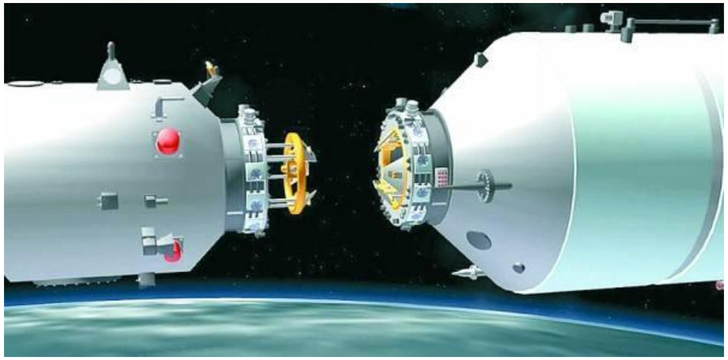
- Uncertain shapes.
- Unpredictable grasping fixtures.
- Unfriendly communication.
- Dangerous for the orbit and Astronauts



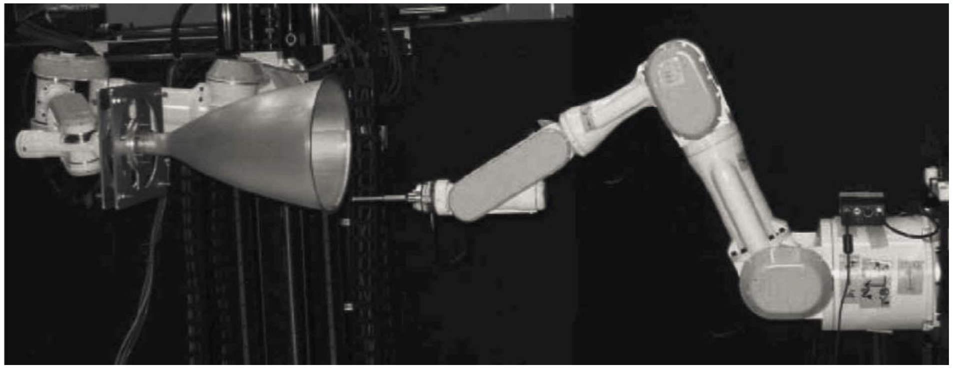
A space arm and an astronaut are used to repair the Hubble Telescope

Therefore, capture devices with self-adaptation are urgently required to be manufactured.

1. Introduction



Space Rendezvous and Docking (SRD) between Shenzhou and Tiangong



Satellite Capture Device

SRD is a special capture method, which is used to grasp coordinative object.

Satellite Capture Device is presented by Japan, which is also used to grasp coordinative object.

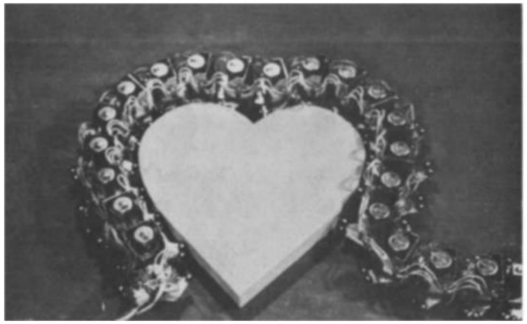
SARAH hand

SARAH is a **dedicated tool, which has been used in servicing on-orbit.**

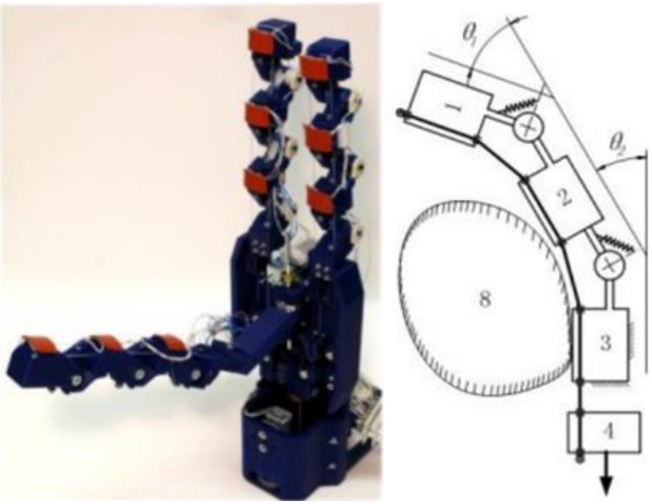
- Double-Stage mechanisms.
- 10 DOF actuated by only two drive motors.
- Same envelope as an astronaut hand.

1. Introduction

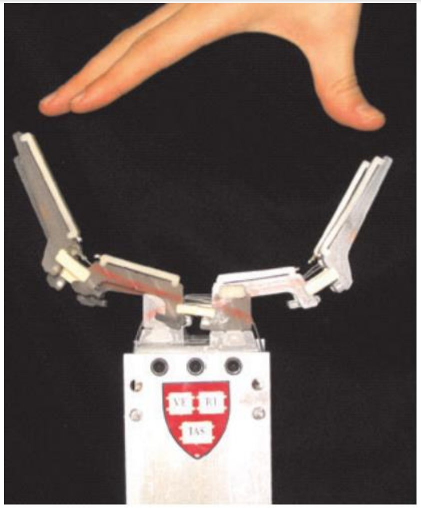
Besides, various kinds of robotic hands owing self-adaptive grasps have been designed.



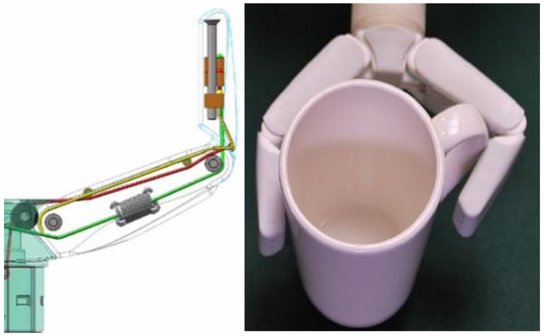
Soft Gripper



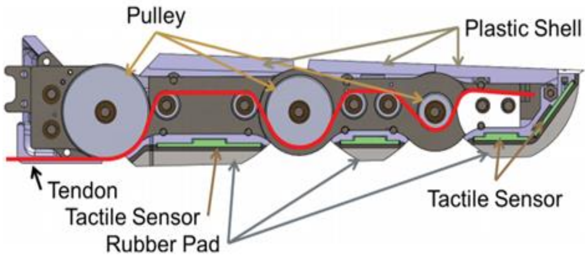
Columbia hand



SDM Hand



Velo 2G Hand



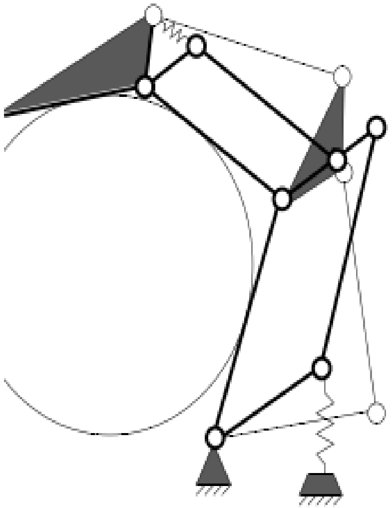
Harvord ARM-H Hand

Features

- Driven by cable/tendon.
- Underactuation.
- Enveloping grasp objects.
- Good expansibility, self-adaptability, etc…

1. Introduction

- Hand with double-stage mechanisms has an excellent grasping reliability.
- Cable-driven hand owns a good self-adaptive and less drive motors.



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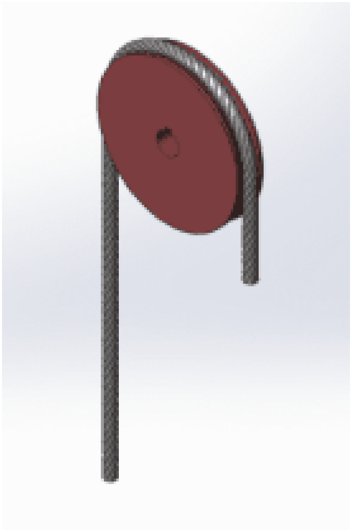


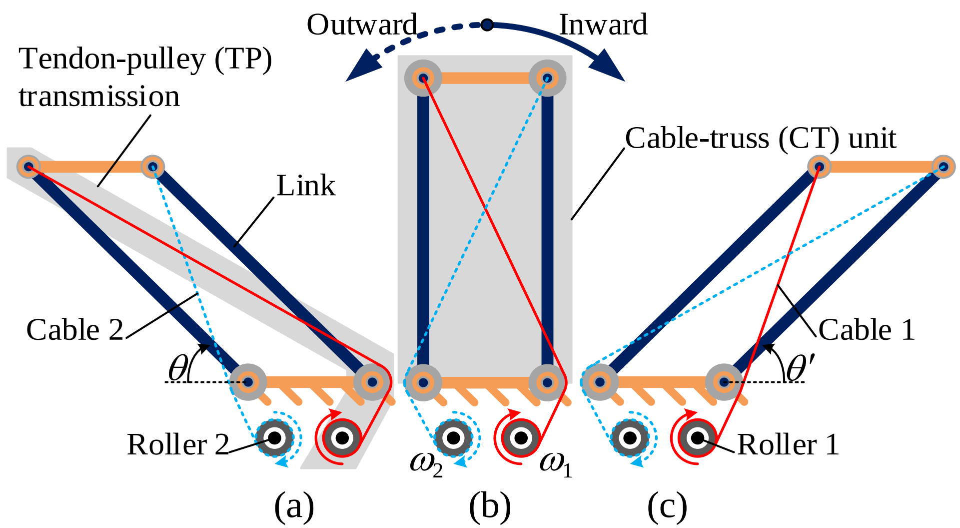
= A novel hand

Double-Stage mechanisms

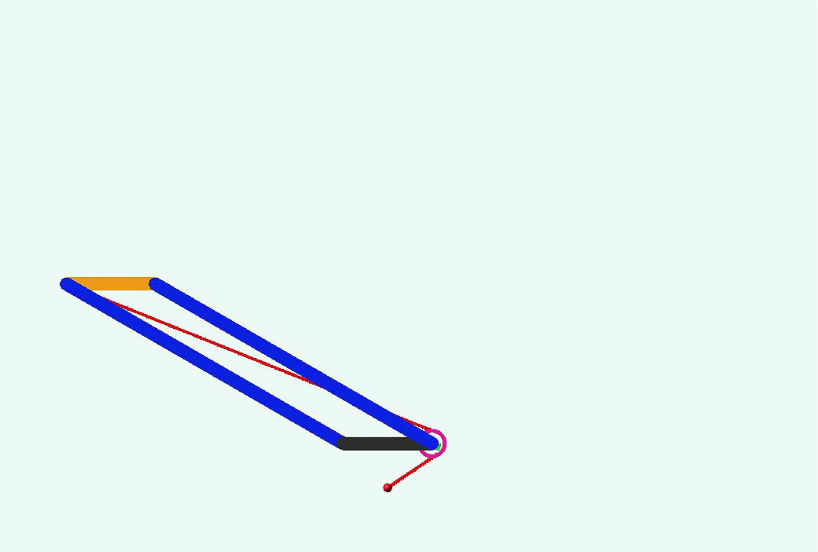
Tendon-Pulley transmission

If we combine the Double-Stage mechanisms and Tendon-Pulley transmission, then we designed a novel underactuated hand.

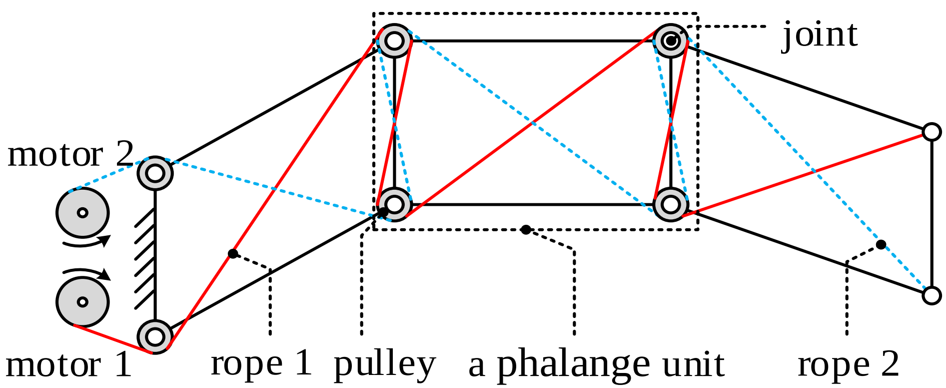
2. Design Principle of UACT Finger



CT unit and TP transmission



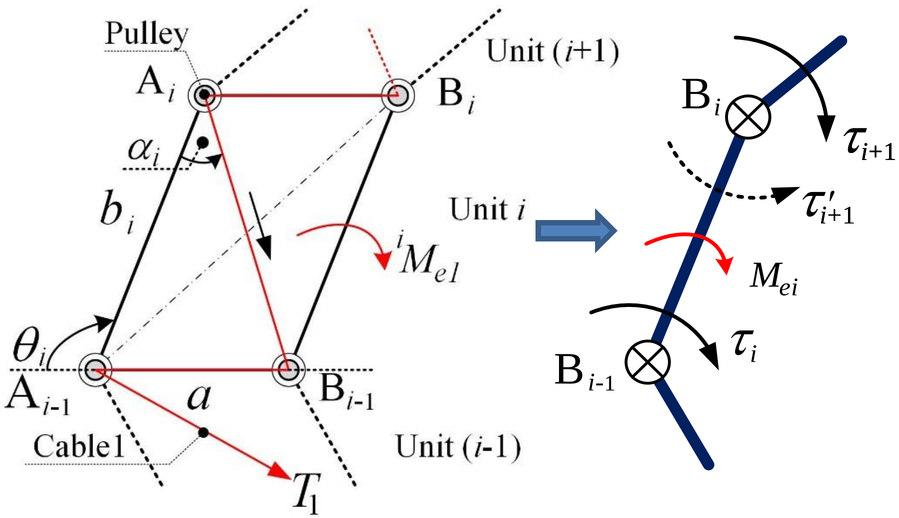
CT unit driven by a cable



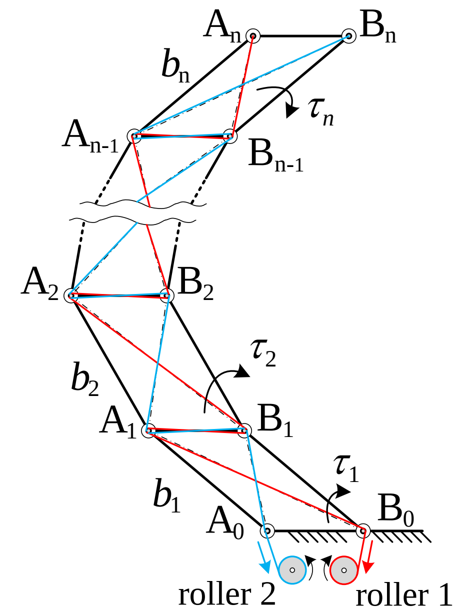
An under actuated finger consists of several CT units

- the UACT finger uses tendon-pulley **(TP) transmission** and parallel four-linkage mechanism (**PFLM**).
- Each cable crosses through the serial phalange in a Z-shaped route.
- Owing to the **damping elements** (spring or friction), the finger can move in a certain sequence.

3. Grasp Model & Grasping Force Analysis



Equivalent model of the TP transmission



virtual work principle

$$T \cdot dL = M_e \cdot d\theta$$

$$^iM_e = \frac{T_1 ab \sin\theta}{\sqrt{a^2 + b^2 + 2ab\cos\theta}}$$

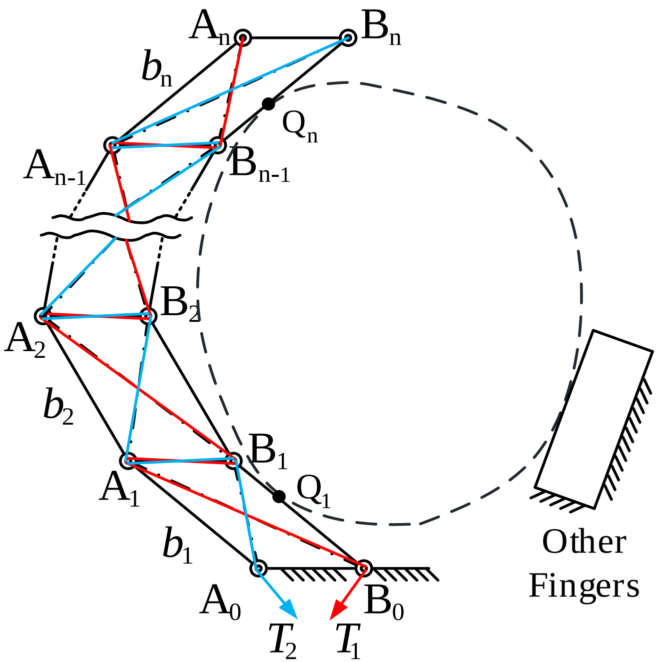
$$\begin{pmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \vdots \\ \tau_{n-2} \\ \tau_{n-1} \\ \tau_n \end{pmatrix}_{n\times 1} = \begin{pmatrix} 1 & 1 & 1 & \cdots & 1 & 1 & 1 \\ 0 & 1 & 1 & \cdots & 1 & 1 & 1 \\ 0 & 0 & 1 & \cdots & 1 & 1 & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1 & 1 & 1 \\ 0 & 0 & 0 & \cdots & 0 & 1 & 1 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 1 \end{pmatrix}_{n\times n} \cdot \begin{pmatrix} ^1M_e \\ ^2M_e \\ ^3M_e \\ \vdots \\ ^{n-2}M_e \\ ^{n-1}M_e \\ ^nM_e \end{pmatrix}_{n\times 1}$$

simply, $\boldsymbol{\tau} = T_1 \boldsymbol{PQ}$

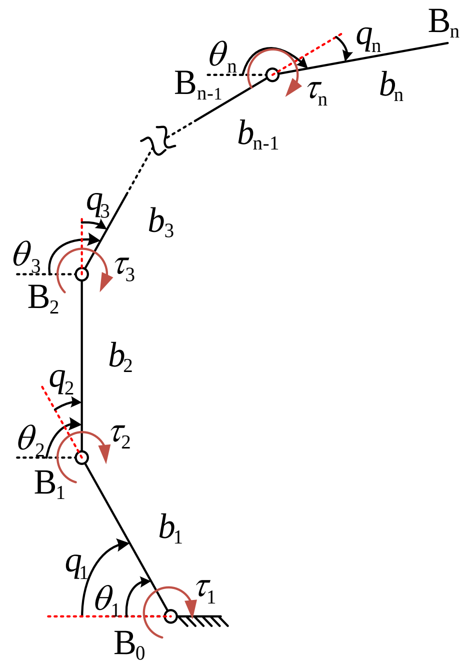
$$\boldsymbol{Q} = \left(b_1 \sin\alpha_1, b_2 \sin\alpha_2, \cdots, b_{n-1}\sin\alpha_{n-1}, b_n \sin\alpha_n\right)^{\mathrm{T}}$$

The equivalent joint driving forces are equal to the cable force.

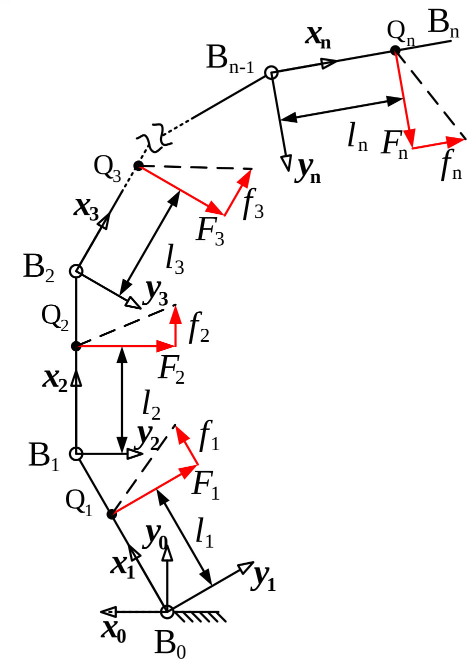
3. Grasp Model & Grasping Force Analysis



A grasping style



Equivalent joint-driven



General static grasp model

SET,

$\{\theta_i\}$: the absolute coordinates
$\{q_i\}$: the relative coordinates

the relationship between θ_i and q_i

$$\begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \vdots \\ \theta_{n-2} \\ \theta_{n-1} \\ \theta_n \end{pmatrix}_{n\times1} = \begin{pmatrix} 1 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 1 & 1 & 0 & \cdots & 0 & 0 & 0 \\ 1 & 1 & 1 & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 1 & 1 & 1 & \cdots & 1 & 0 & 0 \\ 1 & 1 & 1 & \cdots & 1 & 1 & 0 \\ 1 & 1 & 1 & \cdots & 1 & 1 & 1 \end{pmatrix}_{n\times n} \cdot \begin{pmatrix} q_1 \\ q_2 \\ q_3 \\ \vdots \\ q_{n-2} \\ q_{n-1} \\ q_n \end{pmatrix}_{n\times1}$$

Based on the virtual work principle

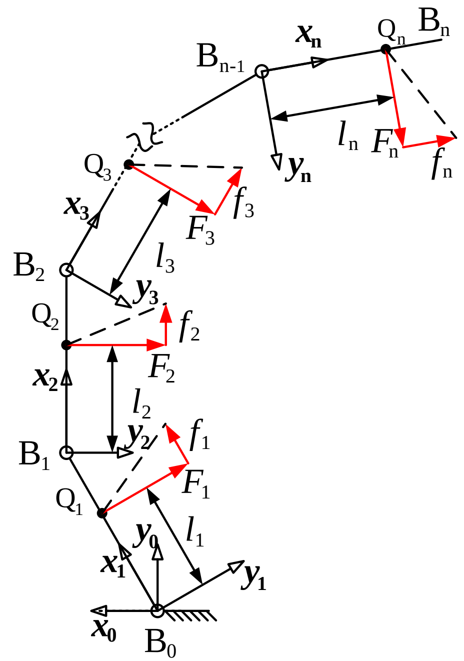
$$\boldsymbol{\tau}^{\mathrm{T}} \cdot d\boldsymbol{q} = {}^{0}\hat{\boldsymbol{F}}^{\mathrm{T}} \cdot d\,{}^{0}\boldsymbol{Q}$$

The relationship between the driving force and the grasping forces is

$$\boldsymbol{J}^{*} \cdot \boldsymbol{F}^{*} = \boldsymbol{\tau}$$

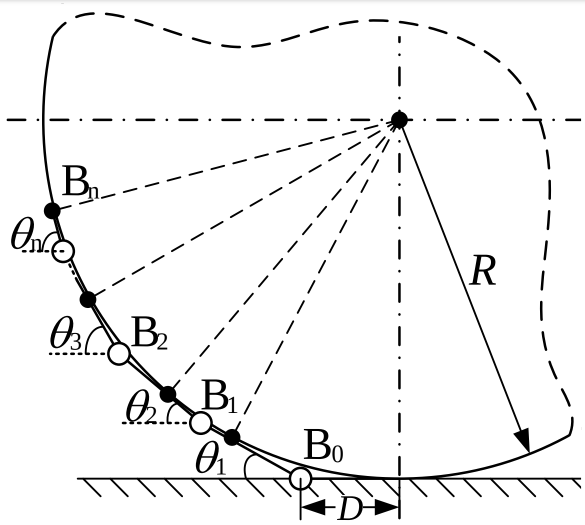
where, $\boldsymbol{J}^{*} = \left(\boldsymbol{J}_1^{\mathrm{T}}\,{}^{0}\boldsymbol{R}_1\boldsymbol{\mu}_1, \boldsymbol{J}_2^{\mathrm{T}}\,{}^{0}\boldsymbol{R}_2\boldsymbol{\mu}_2, \cdots, \boldsymbol{J}_n^{\mathrm{T}}\,{}^{0}\boldsymbol{R}_n\boldsymbol{\mu}_n\right)$

$$\boldsymbol{F}^{*} = \boldsymbol{F}_{nor} = \left(F_1, F_2, \cdots, F_n\right)^{\mathrm{T}}$$

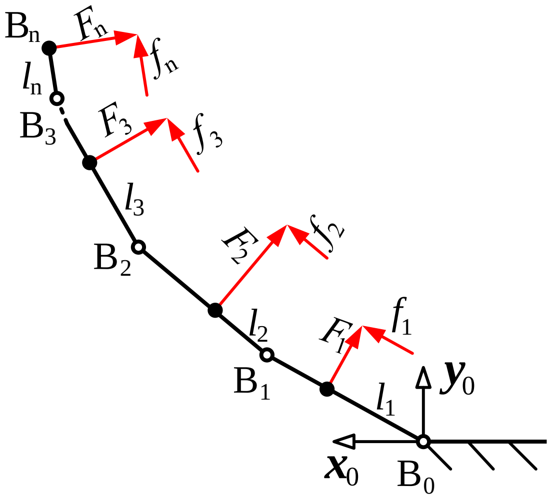


4. Knuckles Definition Based on Maximum Grasp Space

Based on general grasp equation, the configuration of a finger can be obtained.



One finger enveloping grasp a circular object



Contacting forces (consider contact friction)

$$\begin{pmatrix} l_1 & b_1 C\_q_2 + \mu_2 b_1 S\_q_2 & \cdots & b_1 C\_q_{2,3,\ldots,n} + \mu_3 b_1 S\_q_{2,3,\ldots,n} \\ 0 & l_2 & \cdots & b_2 C\_q_{3,4,\ldots,n} + \mu_3 b_2 S\_q_{3,4,\ldots,n} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & l_n \end{pmatrix} \begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_n \end{pmatrix} = T_1 \begin{pmatrix} b_1 S\_\alpha_1 \\ b_2 S\_\alpha_2 \\ \vdots \\ b_n S\_\alpha_n \end{pmatrix}$$

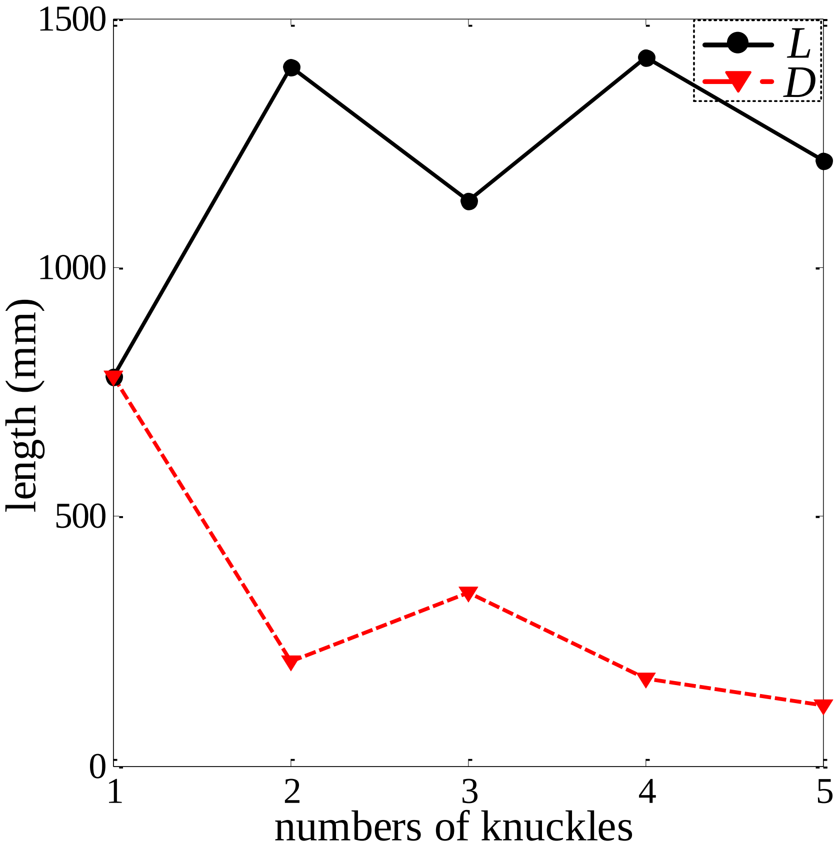
the component of grasping forces in y-axis direction

$$F_y = \sum_{i=1}^{n} F_i (C\_\theta_i - \mu_1 S\_\theta_i)$$

When $F_y \le 0$, the finger is in stable enveloping grasp.

3. Grasp Model & Grasping Force Analysis

Owing to the geometrical relationship, we have the relationship between configuration and numbers of knuckles.



L: finger length

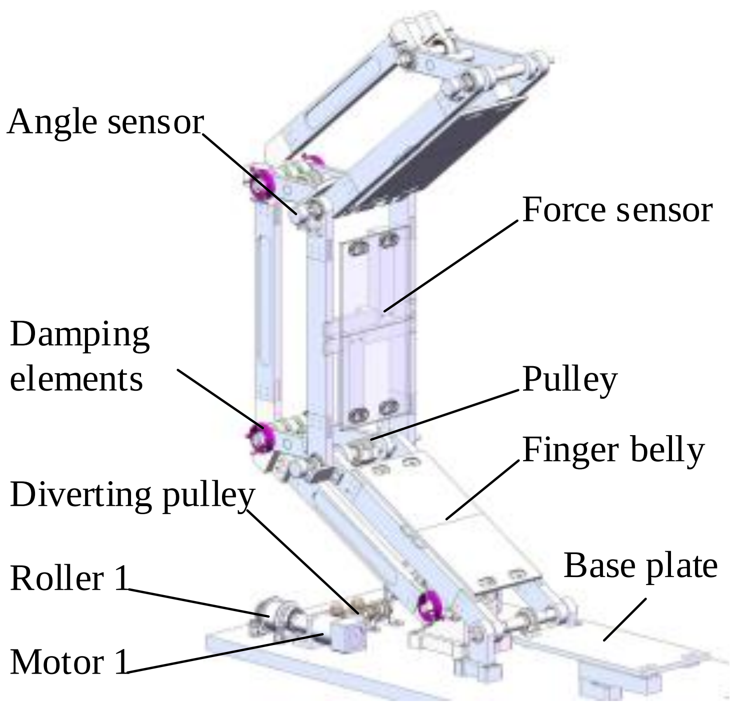
D: distance between two finger

Table 2. Parameters List of 3-knuckle finger in shortest length finger grasp

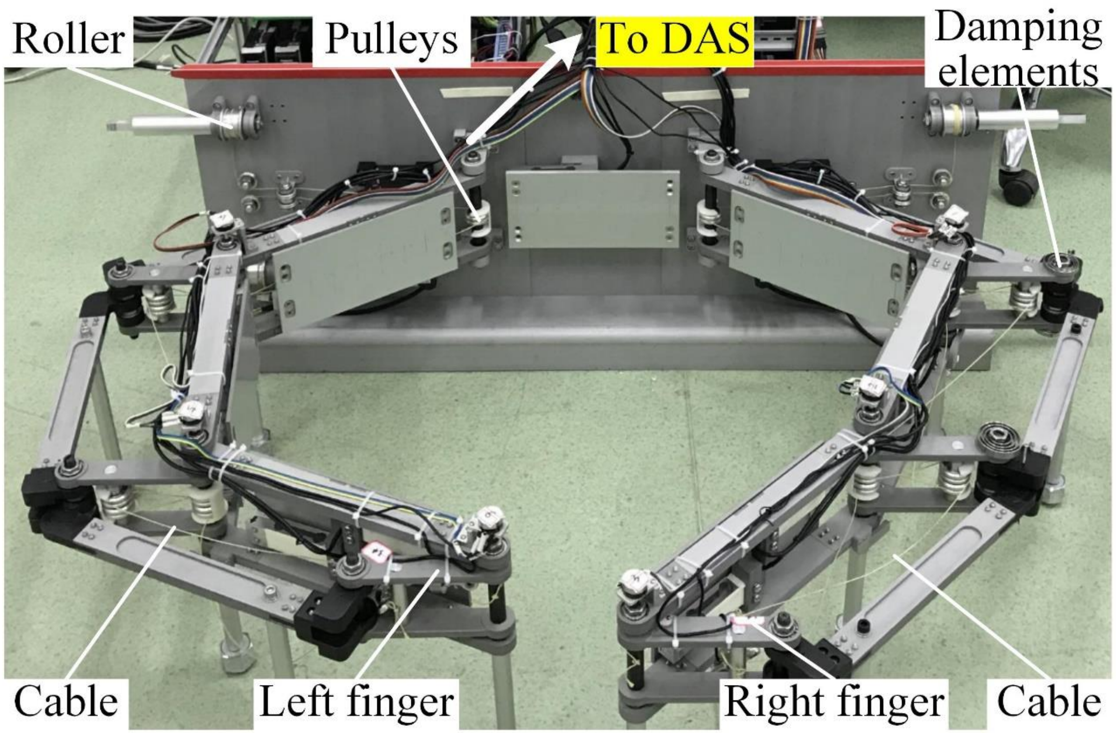
Parameters	L (mm)	D (mm)	b_1 (mm)	b_2 (mm)
Values	1132.79	346.66	357.56	393.07
Parameters	b_3 (mm)	θ_1 (deg.)	θ_2 (deg.)	θ_3 (deg.)
Values	382.16	31.00	32.01	68.02
Parameters	F_y (N)	F_1 (N)	F_2 (N)	F_3 (N)
Values	-1.50	0.61	0.32	21.12

- Although 2-DOF finger has a shortest length, it doesn't have well self-adaptation.
- Compared with 3- and 5- DOF finger, 3-DOF finger is better.

5. Prototype Robotic Hand & Grasp Experiments



Prototype finger

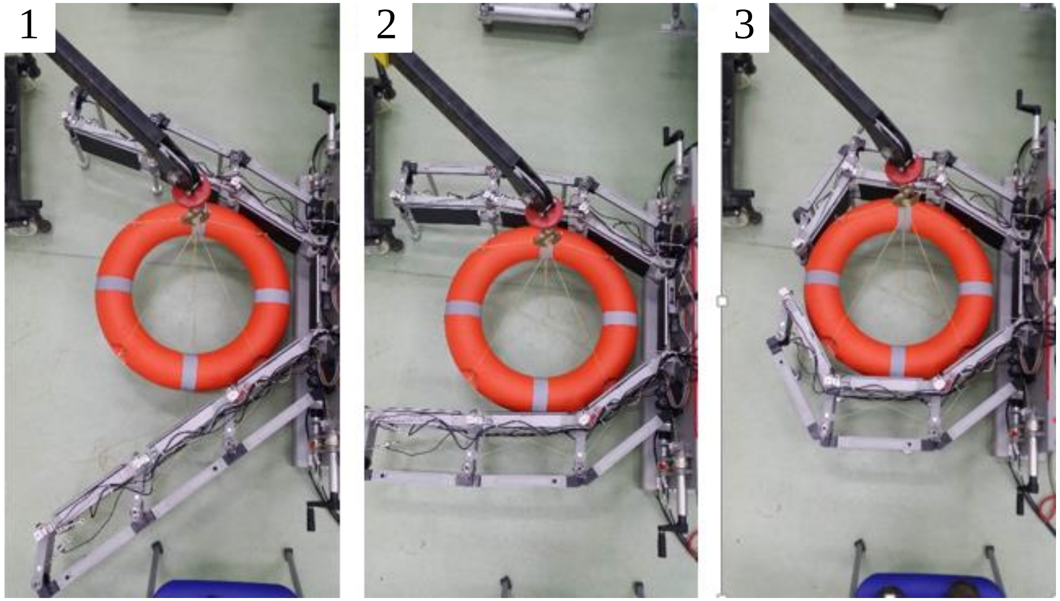


Prototype robotic hand

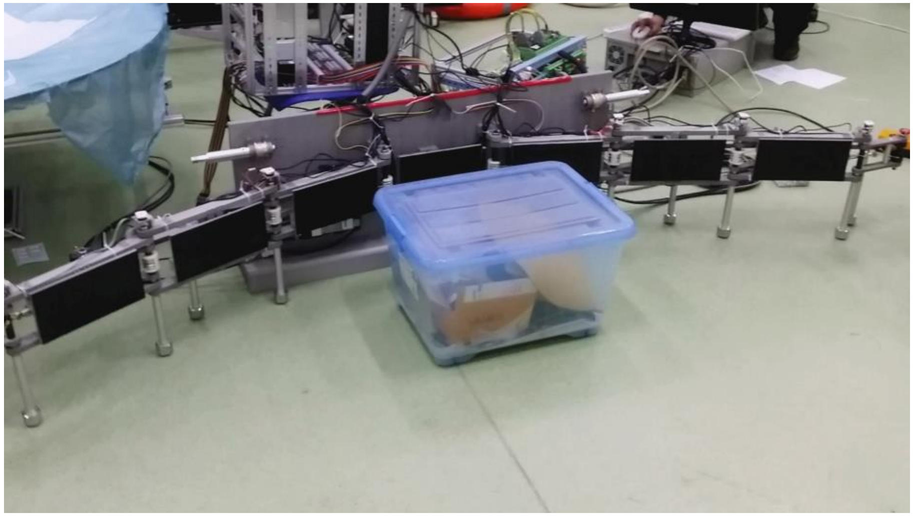
🛠 Features

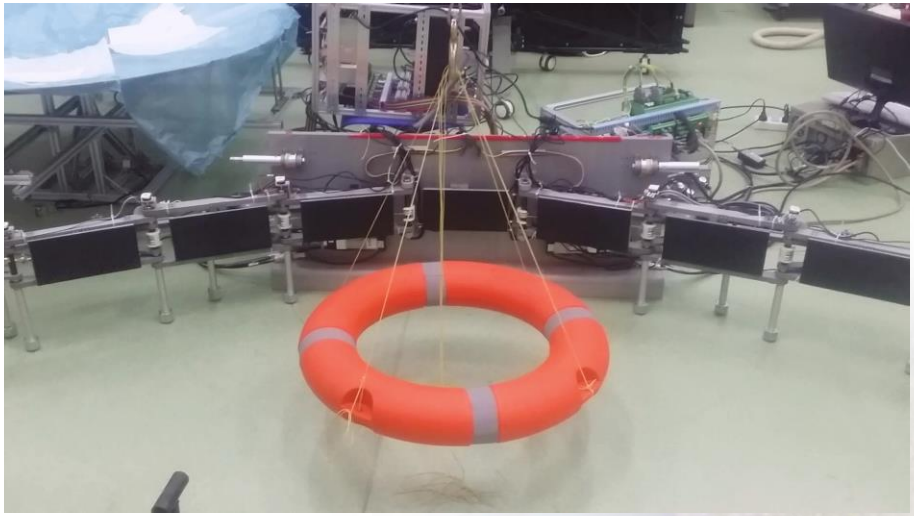
- Two fingers mounted on a common structure.
- 6 DOF actuated by only two drive motors.
- Enveloping capability: 2.5m Diameter.
- 24 sensors (4 driving force sensors,
  6 joint sensors, 14 contact force sensors)

5. Prototype Robotic Hand & Grasp Experiments



- Pre-grasping stage
- Grasp closing stage
- Grasp over





6. Conclusion

A novel underactuated principle is proposed in this paper, and the UACT hand is successful developed with this principle.

General grasping model is established. Based on the model, the equivalent joint driving force is analyzed, which are equivalent to the tendon-pulley transmission.

General grasping force equation is established by using principle of virtual work, which reveals the relationship among the driving force, the equivalent joint driving forces, and the grasping forces.

Through numerical analysis, the relationship between the shortest length of finger and the DOF is analyzed. 3-DOF finger has a shorter finger length.

Prototype robotic hand and grasp experiments are taken out to illustrate the design and verify the grasp function.