2018 IEEE-RAS 18th International Conference on Humanoid Robots (Humanoids)
Beijing, China, November 6-9, 2018

The CPAM Hand: Coupling-Parallel-Adaption Merged Robot Hand

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Abstract—**The traditional underactuated fingers do not integrate the three grasping modes of coupling, parallel pinching and self-adaption grasping. In order to solve this problem, this paper proposes coupling-parallel-adaption merged (CPAM) grasping mode. By realizing the switching of two states of coupling and parallel pinching, the coupling, parallel pinching and self-adaptive grasping modes are integrated into one finger. According to CAPM mode, this paper develops CPAM finger, which includes a power input device, a power transmission mechanism, a coupling transmission mechanism, a parallel-pinching transmission mechanism, a limiting mechanism and a switching device. The switching device is a gear plate mechanism, which can freely switch the coupling mode and parallel-pinching mode, and can keep the finger posture when switching. Theoretical analysis and experimental results show that CPAM fingers can grasp in a suitable mode according to the position, shape and size of the objects, and the grasping range is large.**

Keywords: **robot hand, underactuated finger, coupling-parallel switching, self-adaptive grasping, gear plate locking**

I. Introduction

The robot hand is the contact terminal between the robot and the outside world. It is an important part of the robot, which is generally divided into humanoid multi-finger hand and special hand. Because of the high degree of dexterity, it is difficult to develop humanoid multi-finger hands. The humanoid multi-finger hand can be divided into three categories:

1) The industrial gripper: the industrial gripper has the advantages of simple structure, easy design and manufacture, reliable and stable operation. However, the industrial gripper has no adaptive ability and can not be used to grab various objects of different shapes and sizes.

2) The dexterous hand: the dexterous hand is defined by as a robot hand with more than 3 fingers and more than 9 degrees of freedom. It uses more motors to drive joints. For example, the Shadow hand[1], the Gifu hand[2], the HIT/DLR hand [3] and so on. The dexterous hand is complicated in control and expensive.

3) The underactuated hand: in the underactuated hand, the number of motors is less than the degree of freedom. Underactuated hand has the advantages of easy control and low cost.

This paper mainly studies on a novel underactuated robot hand, CPAM robot hand. Chapter 2 research on the grasping mode of CPAM grasping mode. Chapter 3 introduces the design of CPAM finger. Chapter 4 carries on the principle analysis to CADM. Chapter 5 shows the experiments of the prototype of CPAM hand. Chapter 6 summarizes the research of this paper.

* This research was supported by National Natural Science Foundation of China (No. 51575302) and Beijing Natural Science Foundation (No. J170005).

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II. Grasping mode of Coupling-Parallel-Adaption Merged

The basic grasping modes

The basic grasping modes of underactuated fingers are divided into coupling (CO) mode, parallel pinching (PA) mode and self-adaptive (SA) mode, as shown in Fig. 1.

CO mode is used for the distal phalanx grasping objects. When the proximal phalanx forward, the distal phalanx rotates forward relative to the proximal finger. Its limitation is that when the proximal phalanx is blocked by objects, the distal phalanx often fails to touch objects, causing grasping failed. For example, the NASA's linkage CO Robonaut finger[4].

PA mode is used for the distal phalanx to parallel pinching objects. When the proximal phalanx rotates, the distal phalanx holds the initial angle. Its limitation lies in the fact that only distal phalanx can be used to hold objects without the function of envelope holding.

SA mode is used for multi-phalanx to hold objects by adapting to the shape of the object. When grasping the object, the proximal phalanx rotates and touches the object firstly, and then the distal phalanx begins to rotate until it touches the object. Before the proximal phalanx touches the object, the distal phalanx maintains the initial angle relative to the proximal phalanx. SA crawling can adapt to objects of various shapes and sizes, but its limitation is that there is no pre-bending function.

B The compound grasping modes

There are two kinds of compound grasping modes for underactuated fingers: coupled self-adaptive (COSA) mode and parallel-pinching self-adaptive (PASA) mode, as shown in Fig. 1.

COSA mode fuses the CO mode and the SA mode. When grasping, the CO mode is used firstly, and the SA mode is then used when the proximal phalanx is blocked. The disadvantage is that there is no PASA mode. For example, Dollar et al. developed a tendon-driven SDM hand[5], Huazhong University of Science and Technology developed a tendon - rope finger[6] and the Tsinghua University developed a COSA finger[7].

PASA mode fuses the PA mode and SA mode. When grasping, the PA mode is used firstly, and then the SA mode is used when the proximal phalanx finger is blocked. The disadvantage is that there is no COSA mode. For example, the Birglen and Gosselin team developed the SARAH finger[8-9], Robotiq developed the multi-link flat clip adaptive[10], and Tsinghua University developed PASA finger[11].

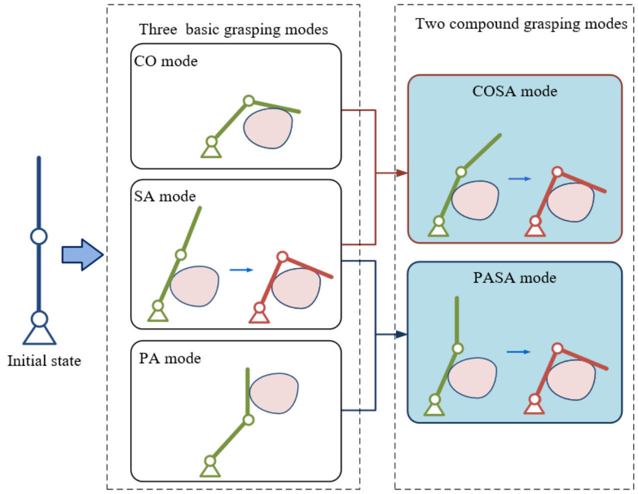


Figure.1 The grasping mode of underactuated finger

C Grasping mode of Coupling-Parallel-Adaption Merged

The traditional self-adaptive underactuated finger has less grasping modes and small grasping range. At present, there is no underactuated finger to unify the three grasping modes of coupling, parallel pinching and self-adaptive grasping in a robot finger. In order to solve this problem, this paper proposes the Coupling-Parallel-Adaption Merged (CPAM) grasping mode. By realizing the switching of COSA mode and PASA mode in one finger, the CO, PA and SA grasping mode are integrated into one finger (as shown in Fig. 2), achieving a larger grasping range. Compared with the traditional mode, the CPAM mode has an advantage in more flexible grasping mode.

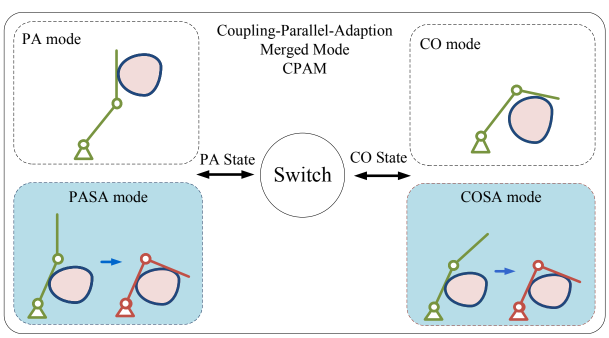
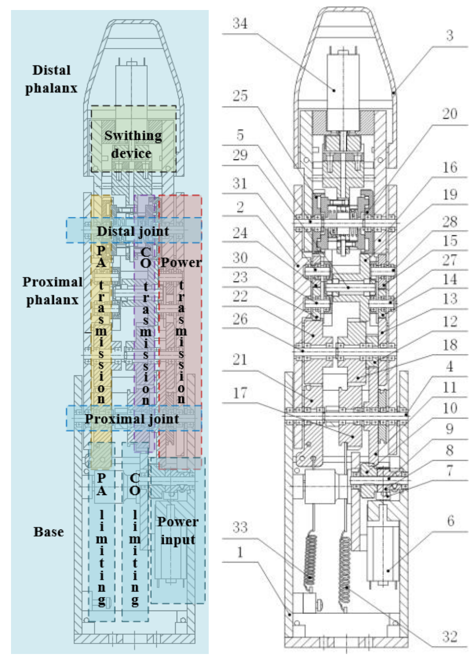


Figure.2 The grasping mode of coupling-parallel-adaption merged

III. THE DESIGN OF CPAM FINGER

The CPAM finger, as shown in Fig. 3, includes the base, the proximal phalanx, the distal phalanx, the proximal joint shaft, the distal joint shaft, the power input device, the power transmission mechanism, the CO transmission mechanism, the CO limiting mechanism, the PA transmission mechanism, the PA limiting mechanism and the switching device.

Among them, the power input device is set in the base, the proximal joint shaft connects the base and the proximal phalanx, the distal joint connects the proximal phalanx and the distal phalanx, the power, CO and PA transmission mechanism are set in the proximal phalanx, and the switching device is set in the distal phalanx. The CO limiting mechanism is set between the CO transmission mechanism and the base, and the PA limiting mechanism is set between the CO transmission mechanism and the base.



(a) (b)

Figure.3 The composes of CAPM finger

Figure 1. 1-base, 2-proximal phalanx, 3-distal phalanx, 4-distal joint shaft, 5- proximal joint shaft, 6~10-power input device (6-grab motor, 7-worm, 8-worm wheel, 9- transition shaft, 10-transition gear), 11~16-power transmission (the 1st to the 6th gears), 17~20-CO transmission (the 7th to the 10th gears), 21~25-PA transmission (11th to 15th gears), 26~31-1st to 6th intermediate shaft, 32, 33-CO, PA tension spring, 34-switching device.

The core design idea of the finger is: through the switching device, the power transmission mechanism connects with the CO transmission mechanism or PA transmission mechanism, so that the finger is in the state of the COSA grasping mode or the PASA grasping mode, so that the finger implement crawling of different modes. It is important that the switching device ensure that the finger is locked during switching.

The power input device includes grasping motors, worms, worm gears, transition shafts and transition gears. The grasping motor is fixed to the base. the worm is fixed on the shaft of grasping motor. the worm and the worm wheel mesh. the worm wheel and the transition gear are fixed on the transition shaft. the transition shaft is set between the right side plate and the intermediate plate of the base. Power is output to the power transmission mechanism through the transition gear.

The power transmission device includes 1st to 6th gears, 1st to 3rd intermediate shafts. The transition gear, the 1st and 2nd gears mesh in series. The 2nd and 3rd gears are coaxial double gears, and the 3rd to 6th gears mesh in series. The 1st to 6th gears are respectively sleeved on the proximal joint shaft, the 1st to 3rd intermediate shafts and the distal joint shaft. The 6th gear is fixed to the right side plate of the distal phalanx. The 1st intermediate shaft is sleeved on the left and right side plates of the proximal phalanx, and the 2nd and 3rd intermediate shafts are sleeved between the right side plate and the middle plate of the proximal phalanx. The transmission from the 7th gear to the 10th gear is the same direction and increase the speed.

The CO transmission mechanism includes the 7th to 10th gears, the 1st and the 4th intermediate shaft. The 7th to 10th gears mesh in series, which are connected to the proximal joint shaft, the 1st intermediate shaft, the 4th intermediate shaft and the distal joint shaft. The 4th intermediate shaft is sleeved between the left and right intermediate plates of the proximal phalanx. The transmission from the 7th gear to the 10th gear is reverse and constant speed.

The CO limiting mechanism includes CO bump, CO limiting block, CO spring, the guide wheel of CO spring, the shaft of guide wheel. The CO bump is fixed on the 7th gear, and the CO limiting block is on the intermediate plate of the base. The shaft of guide wheel is sleeved on the base. The guide wheel of CO spring is sleeved on the shaft of guide wheel. The CO spring bypasses the guide wheel, connects the 7th gear and base.

The PA transmission mechanism includes the 11th to 15th gears, 1st, 5th, 6th intermediate shaft. The 11th to 15th gears mesh in series, which are connected to the proximal joint shaft, the 1st, 5th, 6th intermediate shafts and the distal joint shaft. The 5th and the 6th intermediate shaft are sleeved on the proximal phalanx. The transmission from the 11th gear to the 15th gear is in the same direction and constant speed.

The PA limiting mechanism includes PA bump, PA limiting block, PA spring, the guide wheel of PA spring, the shaft of guide wheel. The PA bump is fixed on the 11th gear, and the PA limiting block is on the base. The shaft of guide wheel is sleeved on the base. The guide wheel of PA spring is sleeved on the shaft of guide wheel. The CO spring bypasses the guide wheel, connects the 11th gear and base.

The switching device includes switching motor, sliding block, PA pressure plate CO pressure plate and so on. The sliding block is disposed between the PA pressure plate and the CO pressure plate. The switching motor is fixed on the base of the distal phalanx. The output of the switching motor is converted to the sliding of pressure plates, so that the CO pressure plate can combine with the 10th gear or the PA pressure plate can combine with the 15th gear.

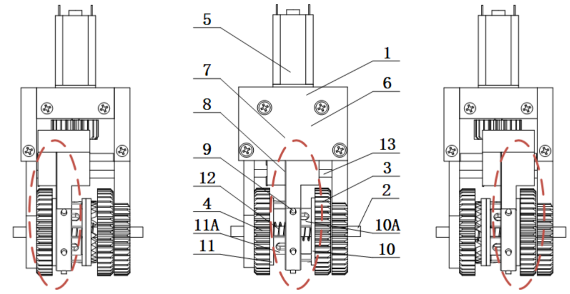
IV. Working Principle and Analysis

The movement process of CPAM finger can be divided into two categories: switching motion and grasping motion. The switching motion is to realize the switching between the PASA mode and COSA mode.

A. Definition of finger states and switching of states

In the CPAM finger, the function of the switching device is to switch different transmission mechanisms of fingers to achieve different grasping modes.

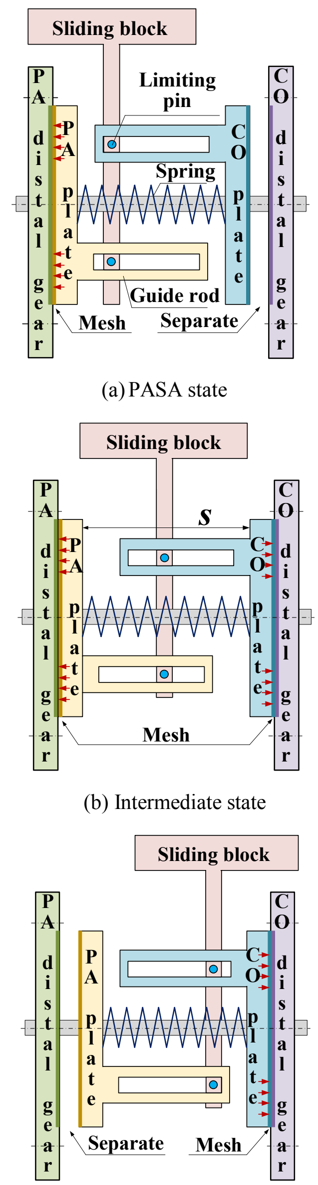
The two switching states are the COSA state and PASA state, and the switching process is shown in Fig. 4 and Fig. 5.



(a) PASA state (b) Intermediate state (c) COSA state

Figure.4 The three states of the switching device

1-distal phalanx, 2-distal joint shaft, 3-10th gear, 4-15th gear, 5-switching motor, 6, 7-switching input mechanism (6-switching gear, 7-rack), 8-sliding block, 9-limiting pin, 10-CO pressure plate (10A-guide rod), 11-PA pressure plate (11A-guide rod), 12- spring, 13-slide shaft.



(a) PASA state

(b) Intermediate state

(c) COSA state

Figure.5 The switching of PASA state, intermediate state and COSA state

The PASA state, as shown in Fig. 4a and Fig.5a, the sliding block pulls the CO pressure plate by the limit pin, make the CO pressure plate away from the 10th gear, and the distal phalanx disconnects with the CO transmission mechanism. Meanwhile, the PA pressure plate is moved toward the 15th gear, and is fixed at the 15th gear. Therefore, the distal phalanx is connected with the PA transmission mechanism.

The intermediate state, as shown in Fig. 4b and Fig.5b, the sliding block is in the middle, and the CO pressure plate and the PA pressure plate are fixed with the 10th and the 15th gear at the same time, keeping the finger posture.

The COSA state, as shown in Fig. 4c and Fig.5c, the sliding block pulls the PA pressure plate by the limit pin, make the PA pressure plate away from the 15th gear, and the distal phalanx disconnects with the PA transmission mechanism. Meanwhile, the CO pressure plate is pulled toward the 15th gear, and is fixed at the 10th gear. Therefore, the distal phalanx is connected with the CO transmission mechanism.

B. Principle and analysis

Set the transmission rate of power, CO and PA transmission mechanism be i_A, i_B and i_C. Set the rotate angle relative to the base of proximal gears to be α_A, α_B and α_C. Set the rotate angle relative to the base of distal gears to be β_A, β_B and β_C. Set the rotate angle relative to the base of proximal phalanx to be θ. Set the rotate angle relative to the base of proximal phalanx be β, then

$$(\alpha_k - \theta) / (\beta_k - \theta) = i_k \quad (k = A,B,C) \qquad (1)$$

1) COSA mode

When the finger is in the COSA mode, the power transmission mechanism is connected to the CO transmission mechanism. At this time, the distal gear of power transmission mechanism, the distal gear of CO transmission mechanism and the distal phalanx are exactly the same, which means $\beta_A = \beta_B = \beta$.

The following is the description of the CO grasping and SA grasping of the finger in COSA mode.

a) CO grasping in COSA mode

When the proximal phalanx and distal phalanx have no contact with the object, the grasping motor rotates, making the 1st gear rotate an angle of α_A, then the proximal phalanx rotates an angle of θ, the distal phalanx rotates an angle of β. At this time, the proximal gear of CO transmission mechanism remains stationary. The finger will remain in the CO state until the distal or the proximal phalanx touches the object, as shown in Fig. 6.

Therefore, when CO grasping in COSA mode, the finger need to meet the following requirements:

$$\alpha_B = 0 \qquad (2)$$

$$\beta_A = \beta_B = \beta > \theta \qquad (3)$$

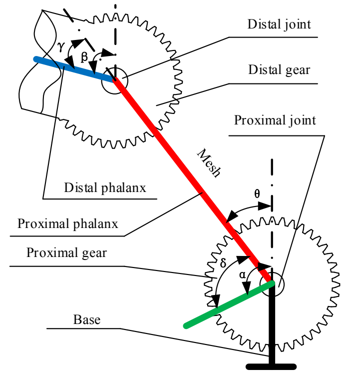
Then, according to formula (1)~(3),

$$\theta = \alpha_A \cdot i_B / (i_B - i_A) \qquad (4)$$

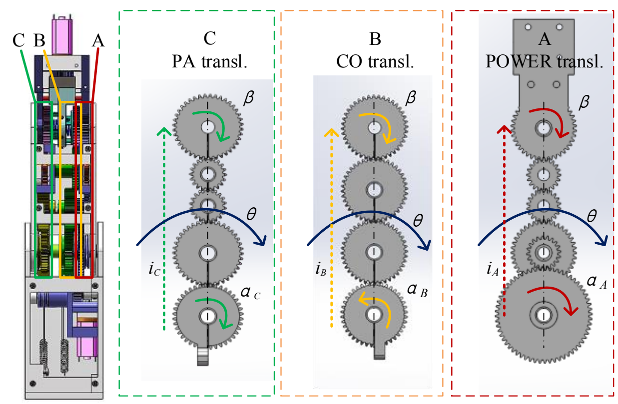
$$\beta = \alpha_A (1 - i_B) / (i_B - i_A) \qquad (5)$$

$$i_B < 0 \qquad (6)$$

If θ is required to be in the same direction as α_A, then we need $i_A > i_B$, that is, the power transmission system and the CO transmission system meet the $i_B < 0$ and $i_A > 0$ can realize the CO mode.



(a) the transmission diagram



(b) the transmission mechanism

Figure.6 The transmission principle of CPAM finger

b) SA grasping in COSA mode

When the proximal phalanx is in contact with the object, the grasping motor rotates, making the 1st gear rotate an angle of α_A. The proximal phalanx is blocked by the object, that is, $\theta = 0$. The distal phalanx rotates an angle of β. The finger will remain in the SA state until the distal phalanx touches the object, as shown in Fig. 7b, 7e.

Therefore, when SA grasping in COSA mode, the finger need to meet the following requirements:

$$\theta = 0 \qquad (7)$$

$$\beta_A = \beta_B = \beta \qquad (8)$$

Then, according to formula (1), (7) and (8)

$$\beta = \alpha_A / i_A \qquad (9)$$

$$\alpha_B = \alpha_A \cdot i_B / i_A \qquad (10)$$

Formula (9) and (10) are the angle relationship among ph alanx and gears.

2) PASA mode

When the finger is in the PASA mode, the power transmission mechanism is connected with the PA transmission mechanism.

At this time, the distal gear of power transmission mechanism, the distal gear of PA transmission mechanism and the distal phalanx are exactly the same, which means $\beta_A = \beta_C = \beta$.

The following is the description of the PA grasping and SA grasping of the finger in PASA mode.

a) PA grasping in PASA mode

When the proximal phalanx and distal phalanx have no contact with the object, the grasping motor rotates, making the 1st gear rotate an angle of α_A, then the proximal phalanx rotates an angle of θ, the distal phalanx rotates an angle of β. At this time, the proximal gear of PA transmission mechanism remains stationary.

The finger will remain in the PA state until the distal or the proximal phalanx touches the object, as shown in Fig. 7c.

Therefore, when PA grasping in PASA mode, the finger need to meet the following requirements:

$$\alpha_C = 0 \tag{11}$$

$$\beta_A = \beta_C = \beta = 0 \tag{12}$$

Then, according to formula (1), (11) and (12)

$$\theta = \alpha_A / (1 - i_A) \tag{13}$$

$$i_C = 1 \tag{14}$$

If θ is required to be in the same direction as α_A, then we need $i_A > 1$, that is, the power transmission system and the PA transmission system meet $i_C = 1$ and $1 > i_A > 0$ can realize the CO mode.

b) SA grasping in PASA mode

When the proximal phalanx is in contact with the object, the grasping motor rotates, making the 1st gear rotate an angle of α_A. The proximal phalanx is blocked by the object, that is, $\theta = 0$. The distal phalanx rotates an angle of β.

The finger will remain in the SA state until the distal phalanx touches the object, as shown in Fig. 7d, 7f.

Therefore, when SA grasping in PASA mode, the finger need to meet the following requirements:

$$\theta = 0 \tag{15}$$

$$\beta_A = \beta_C = \beta \tag{16}$$

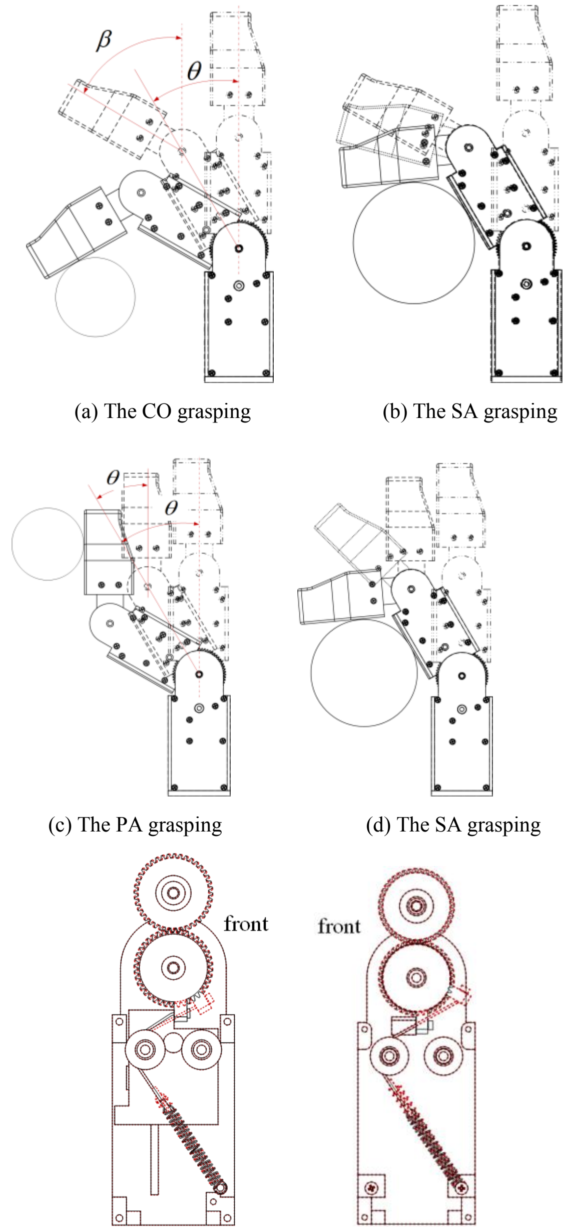
Then, according to formula (1), (15) and (16)

$$\alpha_C = \alpha_A \cdot i_C / i_A \tag{17}$$

$$\beta = \alpha_A / i_A \tag{18}$$

Formula (17) and (18) are the angle relationship among phalanx and gears.

The release process of the finger is just opposite to the process of grasping objects, this article will not go into details here.



(a) The CO grasping (b) The SA grasping

(c) The PA grasping (d) The SA grasping

(e) COSA (f) PASA

Figure. 7 The CO grasping and SA grasping in COSA mode

3) The merged of CO, PA and SA mode

The power transmission mechanism is set as a forward transmission mechanism.

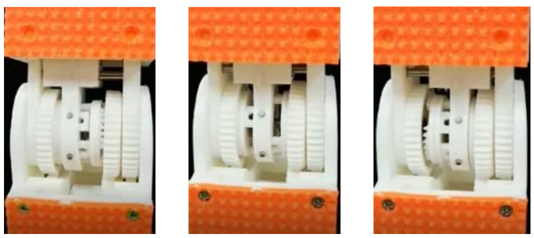
According to the analysis of B1 section in chapter4, when the finger is in CO state, we need $i_B < 0$ and $i_A > 0$, which is the combination of the power forward transmission mechanism and CO reverse transmission mechanism, can be used to realize the COSA mode.

According to the analysis of B2 section in chapter4, when the finger is in PA state, we need $i_C = 0$ and $1 > i_A > 0$, which is the combination of the power forward transmission mechanism and PA forward transmission mechanism, can be used to realize the PASA mode.

Based on the above analysis conclusion, this paper designs the following specific dimensions: the transmission ratio of the power transmission mechanism is i_A=1/3. In the CO mode, when the proximal phalanx rotates an angle of θ, the distal phalanx rotates an angle of β= 2θ, which requires that the transmission ratio of CO transmission mechanism is $i_B = -1$. The transmission ratio of the pinch transmission mechanism is $i_C = 1$.

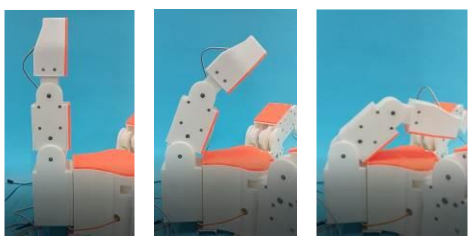
V. EXPERIMENTS

The switching experiment of CPAM finger is as shown in Fig. 8. Fig. 9 and Fig. 10 show the CO and PA grasping mode, respectively. Fig. 11 shows the grasping experiment.



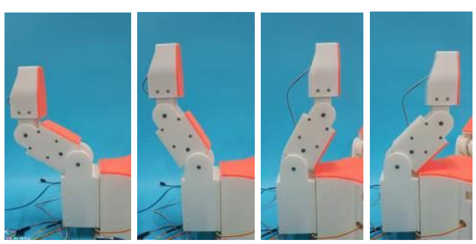
(a) PASA state (b) Intermediate state (c) COSA state

Figure.8 The switching experiment



(a) (b) (c)

Figure.9 The action in CO grasping mode



(a) (b) (c) (d)

Figure.10 The action in PA grasping mode

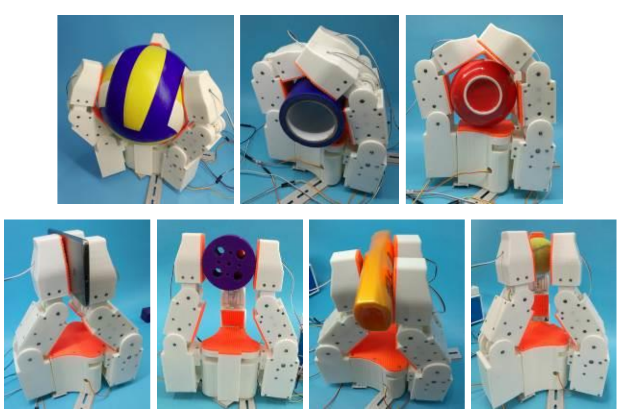


Figure.11 The grasping experiment of CAPM robot hand

The experimental results show that the CPAM hand can parallel pinch the object, coupled grasp the object, and self-adaptively grasp the object. The finger gesture is maintained when switching at any position. Depending on the position, shape and size of the object, CPAM fingers can grasp in a suitable mode: grasping small-sized objects by pinching; grasping large-sized objects by enveloping, the grasping efficiency is high.

VI. CONCLUSION

This paper proposes a Coupling-Parallel-Adaption Merged (CPAM) grasping mode, and develops a CPAM robot hand. By implementing switching COSA mode and PASA mode, the CPAM finger merged CO mode, PA mode and SA mode. Theoretical analysis and experimental results show that the switching mechanism can switch the COSA mode and PASA mode freely at any angle, and maintain the finger gesture when switch. The CAPM robot hand can achieve COSA mode and PASA mode by mesh the power transmission mechanism with the CO or PA transmission mechanism. The CPAM robot hand is suitable for robots which need universal crawling.

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