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Research on Grasping Strategy of CTSA-II Hand

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***Abstract* - To solves the problem of insufficient generality of CTSA-II hand at different heights, four feasible grasping strategies are proposed in this paper. Four strategies are analyzed in detail from the aspects of feasibility and complexity, and Strategy D is selected for the in-depth study after comparison. The idea of Strategy D is to detect the pressure change in CTSA-II hand device to assist in determining when to use a negative pressure drive. Based on Strategy D, a complete CTSA-II hand system is constructed. Through a large number of experimental calibration and verification, this system solves the problem of insufficient generality of CTSA-II hand. and makes CTSA-II hand show good performance. It plays an important role in the application and development of CTSA-II hand.**

Index Terms – Grasping strategy, Robot hand, Universal gripper, Self-adaption, Underactuated hand.

I. Introduction

Grasp in the human environment is one of the essential functions of robot application. The research on the design of the robot hand and the corresponding grasping strategy is an important part of the research on the robot.

At present, a large number of robotic hand/gripper have been developed, which can be roughly divided into three categories: dexterous hand, underactuated gripper, and special hand.

The dexterous hand contains more than three fingers and more than nine degree-of-freedoms (DOFs) [1]. Each DOF corresponds to at least one driving source. Common representatives are Shadow hand [2], Robonaut hand [3] and DLR/HIT hand [4]. Dexterous hands can realize grasping, manipulation and complex gesture expression. But it will bring a certain degree of complex control and high cost.

To simplify the control difficulty of the dexterous hand, the underactuated hand [5] is proposed. The number of underactuated hand drivers is less than DOFs, and the structure is often composed of gears train, link, spring, and limit. Common underactuated hands are the ROBOTIQ gripper [6], PASA hand [7], VGS hand [8], octopus hand [9], etc. The underactuated hand greatly simplifies the grasping strategy with the complexity of mechanism.

The special hand is a special kind of gripper. It does not have a clear finger structure, but also has good grasping function. For example, FESTO hand [10], spherical hand [11], CTSA series hand [12-14], pin-array hands[15-16]. Special hand sacrifices some functions of in-hand operation and gesture expression, therefore it has good grasping performance.

However, although a large number of robotic hands have been developed, there are still many challenges in robotic grasping. Kemp et al. summarized the difficulties in grasping such as diversity of support surface, diversity of objects, uncertainty of measurement and so on [17].

To simplify the grasping strategy and reduce the difficulty of grasping, a large number of robot hands have self-adaptive grasping performance. Self-adaptive grasping refers to that the robot hand can grasp the object stably and effectively without knowing the shape, size, and material of the object. Many robotic hands have this performance, especially the special hand, such as FESTO hand [10], spherical hand [11], CTSA-II Hand [12].

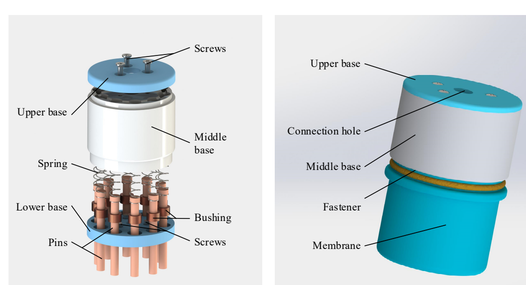
The author of this paper developed CTSA-II hand in previous research. However, in the follow-up study, it's found that although CTSA-II hand can show adaptive performance in grasping, but under some grasping conditions, the general grasping performance is inadequate due to the lack of appropriate grasping strategies. This paper will study and elaborate on the grasping inadequacies and grasping strategies of CTSA-II hand.

The next part of the article is mainly as follows: Chapter II mainly introduces the difficulties of grasping strategy of CTSA-II hand; Chapter III mainly introduces several feasible grasping strategies and corresponding theoretical analysis; Chapter IV explores and verifies the feasible strategies through experiments; Chapter V summarizes the whole article.

II. CTSA-II Hand

A. *The principle and performance of CTSA-II hand*

The structure of the CTSA-II hand is shown in Fig. 1a-1b. CTSA-II hand includes sliding pin-array, spring-array, base, and membrane, etc. The grasping principle of the CTSA-II hand is shown in Fig. 1c. The grasping process can be divided into two stages: Vertical Adaption and Transverse Grasping. When the CTSA-II hand grasps the object, it first extrudes the object vertically and adapts to the shape of the object to complete the Vertical Adaption, and then gathers the membrane and sliding pin-array by negative pressure to provide the grasping force from the lateral to complete the Transverse Grasping.



(a) Explosion view. (b) Overall appearance.

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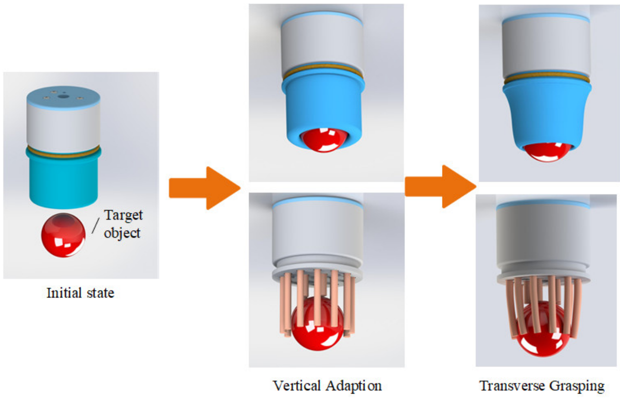


(c) Working process of the CTSA-II gripper
Fig. 1. Design and principle of the CTSA-II gripper.

When grasping objects, CTSA-II hand shows good general grasping performance. It can grasp objects of different shapes and sizes within the grasping range.

B. The Grasping Problem of CTSA-II Hand

Assuming the length of CTSA-II hand is L, the most intuitive and the initial grasping strategy of CTSA-II hand is as follows: in the Vertical Adaption phase, CTSA-II hand moves down to extruded object until the distance between the top of CTSA-II hand and the ground is L. At this time, the end of the pin-array just touches the ground, and the CTSA-II hand completes the vertical adaptation, then the CTSA-II hand goes to the phase of Transverse Grasping. If the distance L cannot be reached since the CTSA-II hand is blocked by object, the downward drive will stop after the obstruction. This grasping strategy is in Strategy A, as shown in Fig. 2.

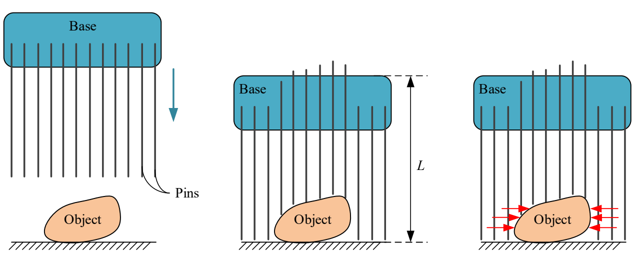


Fig. 2. Grasping strategy A.

Under Strategy A, we previously grabbed cubes of the same cross-section size (10mm*10mm) but different heights and measured the corresponding grasping force. Among them, the way to measure the grasping force. The object is slowly pulled out of CTSA-II hand by a dynamometer. The maximum value of the dynamometer in the process of pulling out is regarded as the grasping force. In addition, three sets of data were measured for the same cube and averaged.

Three CTSA-II hands with different number of sliding pins were measured, and the experimental results shown in Fig. 3 were obtained. From the results in Fig. 3, it can be seen that the grasping force of CTSA-II hand is greatly affected by the height, which is not ideal for a universal gripper.

When the height is large, the grasping force of CTSA-II hand decreases gradually with the increase of the height. Even when the height is greater than 20 mm, the grasping force decreases to 0. This can be explained as follows: at high height, under the influence of grasping strategy A, the pin-array will sliding more into the base, resulting in greater resistance to grasping, and may block the suction holes of the base.

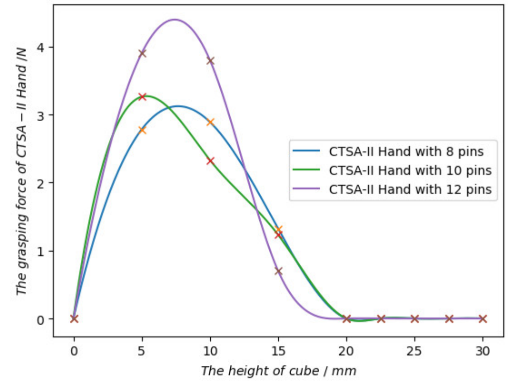


Fig. 3. Grasping Force of CTSA-II Hand at Different Object Heights.

For very small objects, the grasping force is very small, which is intuitive and can bear that CTSA-II hand can not grasp very small objects. However, for objects with appropriate cross-section size and high height, they should be graspable. This is because the grasping strategy is inappropriate, so this paper studies the grasping strategy, and plans to develop a universal CTSA-II hand grasping scheme, so that the driving system of CTSA-II hand can drive and grasp objects independently.

III. Analysis of Feasible Grabbing Strategies

A. Grasping Strategy B

From Chapter 2, we can see that grasping strategy A is reliable in grabbing small objects. However, if strategy A is stubbornly adopted in grasping some higher objects, the grasping performance will be weakened or the grasping failure will occur.

In order to get a better grasping strategy, we use several hypothetical special shaped objects to simulate the grasping, assuming that the ship-shaped object (the object that the whole area is large, the middle has a bulge). The strategy of strategy A and the strategy of human visual perception are simulated respectively, as shown in Fig. 4.

Comparing strategy A with the appropriate grasping method, we can find that every sliding pin under strategy A will have reaction force, while the grasping method of Fig. 4d-e will minimize reaction force.

It is worth mentioning that if all the pins of the robot hand are not wrapped in membrane. When the hand moves upward after applying the grasping force in the adaptive state of Fig. 4b, the object will not move upward during a short period of time. In this small period, the pins in the base sliding out of the base while the hand is upward. It is not until the friction produced by the pins against the object is balanced with the resistance produced by all the pins that the object will follow the robot hand upward. Therefore, CTSA hand [13] can automatically adjust this situation of Fig. 4b to Fig. 4d because it has no membrane.

However, the CTSA-II hand has a membrane, which shrinks as a whole when it adapts to the shape of the object, which is equivalent to solidified shape of pin-array, after which all the pin-array will not slide relative to the base. Therefore, the resistance of the pin-array of CTSA-II hand will hinder the film shrinkage, reduce the shrinkage degree, increase energy consumption and reduce the grasping force. More importantly, this situation will result in the blockage of the suction hole described in section II.B, which will lead to the failure of the grasp. Therefore, the position relationship between the CTSA-II hand and object should avoid the situation of Fig. 4b-4c.

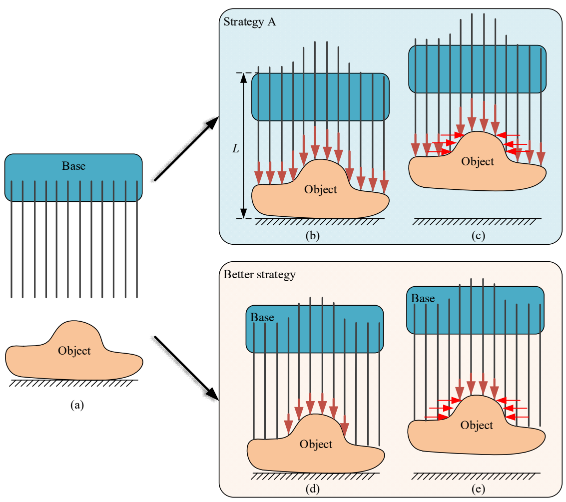


Fig. 4 Grasping simulation of ship-shaped objects.

The optimum strategy in Fig. 4 can be universally summarized as follows: Firstly, the highest height L_{oM} of the object is obtained by image processing, and then the CTSA-II hand is moved down toward the object. When the height of the CTSA-II hand is $L = L_{oM} + \Delta L$, the Vertical Adaptation is completed, in which the ΔL is a constant obtained by pre-calibration. Set this grasping strategy as Strategy B.

B. Grasping Strategy C

However, it seems that grasping Strategy B is not necessarily the best grasping strategy. For some specific objects, better grabbing performance is not necessarily achieved by using Strategy B. For example, for the shoe-shaped object (objects with protrusions on one side) shown in Fig. 5, the case of 6b-6c and 6d-6e can be obtained by using strategy A and strategy B respectively. Both strategies have their advantages.

As can be seen from Fig. 5, Strategy A and Strategy B have their respective advantages in capturing shoe-shaped objects. Strategy A will produce a larger grabbing area with the object, the grabbing area is larger, the grasping force is larger. The advantage of Strategy B is that the number of pins producing resistance is fewer, the resistance is smaller, and the grasping force is larger.

It can be seen from the analysis that Strategy A and Strategy B are two extreme schemes when grasping "shoe-shaped" objects. One produces maximum grabbing area and the other produces minimum resistance. A compromise strategy, CTSA-II hand height maintained between Strategy A and Strategy B, may have better grasping effect. Assuming that the compromise strategy is Strategy C

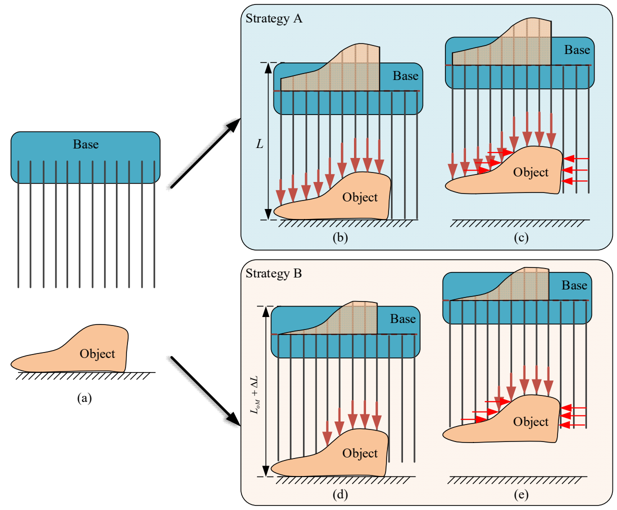


Fig. 5 Grasping simulation of "shoe-shaped" objects.

However, the implementation of Strategy C seems to be somewhat difficult. The following steps are needed: first, scanning the three-dimensional model of the object to be grabbed, then simulating and calculating the grasping on the computer, analyzing the grasping force at various heights according to the theoretical method in paper [12], and then obtaining the optimal grasping height.

The original intention of CTSA-II hand development is to abandon the complexity of dexterous hand, simplify the difficulty of control, reduce costs, and provide a universal grasper. Strategy C, which uses three-dimensional model scanning, complex grabbing simulation and a lot of calculation to obtain the optimal grabbing height, will bring a lot of consumption, so Strategy C is not considered for the time being.

C. Grasping Strategy D

When Strategy B is used to capture ship-shaped objects and shoe-shaped objects, it is found that after Vertical Adaption, the sum height of the sliding pins sliding into the base is different if CTSA-II hand continue to move downward. Among them, the sliding pins' displacements and increments caused by ship-shaped objects are twice the displacements and increments of shoe-shaped objects. Coincidentally, CTSA-II hand needs to moves downward more distances when grasping shoe-shaped objects than when grasping ship-shaped objects.

Therefore, we propose Strategy D, which determines whether the Vertical Adaptive step of CTSA-II hand should be terminated by detecting the overall deformation of the sliding pins.

Combined with the pneumatic driving characteristics of CTSA-II hand, the pressure change inside the CTSA-II hand can be detected and then transformed into the membrane deformation and the overall deformation of the pin-array.

The internal pressure of CTSA-II hand will increment because of extrusion in the process of Vertical Adaption.

When this increment reaches a certain threshold, it can be considered that the Vertical Adaption has reached the optimum height, that is, the Vertical Adaption has been completed optimally, and Transverse Grasping can be started.

Therefore, in order to achieve Strategy D, the CTSA-II hand system can be developed as shown in Fig. 6, where the pressure transmitter is a two-way range. In the step of Vertical Adaption, the positive pressure can be detected to determine when to finish Vertical Adaption. In the step of Transverse Grasping, the negative pressure can be detected to predict the current grabbing force.

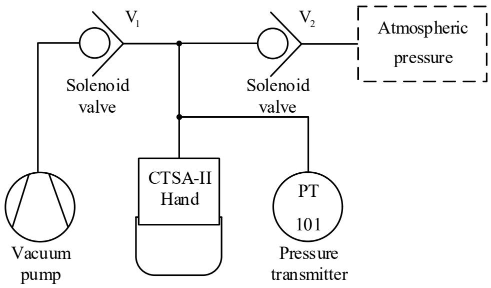


Fig. 6 CTSA-II Hand system under Strategy D.

Combining with the system shown in Fig. 6, we can get the process strategy of Strategy D as shown in Fig. 7.

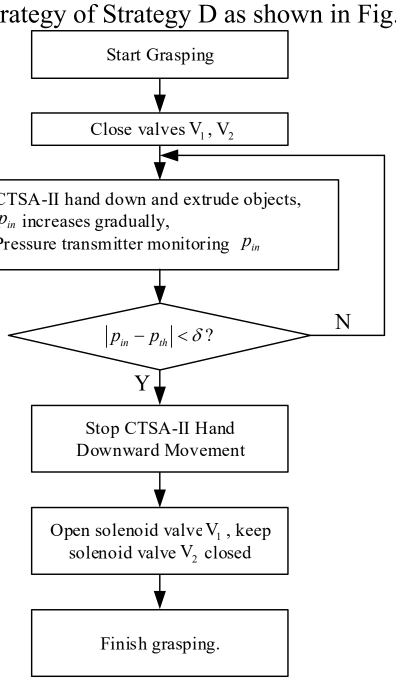


Fig. 7 Process strategy of grasping Strategy D.

Firstly, when the CTSA-II hand receives the grab command, the solenoid valve V1 and V2 are closed to ensure that the internal chamber of the CTSA-II hand is sealed. Then, the CTSA-II hand moves downward under the driving of the manipulator arm and begins to squeeze the object. As the internal chamber of the CTSA-II hand is sealed, the internal pressure p_{in} of CTSA-II hand will gradually increase. In this process, the pressure transmitter monitors p_{in} in real-time. When p_{in} and threshold p_{th} are close to a certain degree, it shows that the Vertical Adaptation has been completed. After completing the Vertical Adaptive process, stop the manipulator moving down, open the solenoid valve V1, keep the solenoid valve V2 closed, and drive pin-array to gather and grab the object to complete Transverse Grasping. It is worth mentioning that the threshold p_{th} needs to be calibrated experimentally, which will be determined in the next chapter.

Under grasping Strategy D, the release process is the same as other grasping strategies: stop negative pressure input and keep the CTSA-II chamber at the same external atmospheric pressure. Therefore, in the CTSA-II hand system shown in Fig. 6, the operation of releasing objects is as follows: close the solenoid valve V1, open the solenoid valve V2, and complete the release.

D. Comparison of Several Grabbing Strategies

At present, there are four grasping strategies, each with its own advantages. The four strategies can be judged from the aspects of adaptive performance, the complexity of implementation, the need for pressure transmitters and the need for visual processing. The result is as shown in Table. 1.

Table. 1 Evaluation of four grasping strategies.

Symbol	Strategy A	Strategy B	Strategy C	Strategy D
Adaptive performance	General	Good	Outstanding	Great
Complexity/ Difficulty	Slightly	Medium	Very	Medium
Pressure transmitter	No	No	No	Yes
Extra Visual Processing	No	Yes	Yes	No

Comparing several strategies, it can be concluded that the synthetical realizability of Strategy D is higher and the effect is very good. Therefore, this paper intends to adopt Strategy D as the primary grasping strategy for CTSA-II hand.

IV. Experimental Verification of Grasping Strategy

A. Experimental system

The CTSA-II hand developed in the article [12] is improved because adopting strategy D requires good airtightness. The new prototype is as shown in Fig. 8.

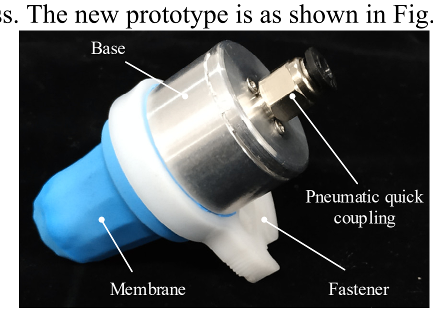


Fig. 8 Prototype of CTSA-II hand.

The CTSA-II hand is machined instead of 3D printing, a more reliable fastener is used, and pneumatic quick coupling is added. In addition, according to the results of paper [12], the new prototype developed in this paper has 12 pins.

Referring to the CTSA-II hand system block diagram of Fig. 6, the CTSA-II hand system shown in Fig. 9 is built.

Among them, the pressure transmitter model is MIK-P300, the range is -0.1-0.1 Mpa, the solenoid valve model is XINDE-VT307V, and the pressure grading value of the system shown in Fig. 9 is 1.95 kPa.

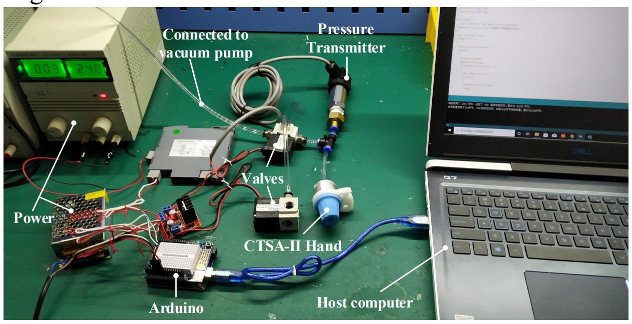
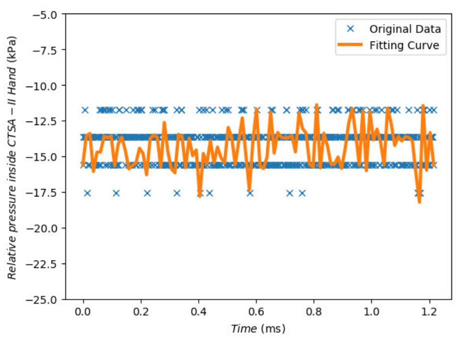


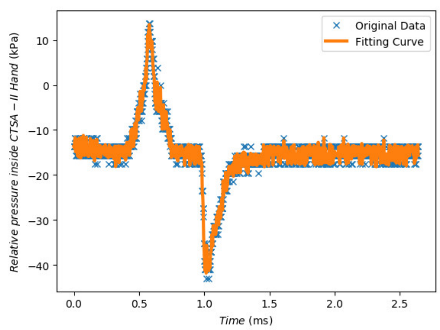
Fig. 9 CTSA-II Hand System

B. Feasibility verification

Firstly, we need to verify whether the internal pressure changes of CTSA-II hand can be detected. So we squeeze CTSA-II hand and non-squeeze CTSA-II hand respectively to collect data and process data, and get two results as shown in Fig. 10.



(a) CTSA-II Hand Squeezed



(b) CTSA-II Hand Not Squeezed

Fig. 10 Changes of internal pressure of CTSA-II hand.

As can be seen from Fig. 10a, the values detected by the pressure transmitter will still fluctuate in the range of ±5kPa in the static prototype. As can be seen from Fig. 10b, when the pin-array/membrane of CTSA-II hand is pressed, there will be obvious pressure change, which is very obvious relative to the fluctuation in Fig. 10a. Therefore, it is a feasible strategy to determine whether Vertical Adaptive has been completed by detecting the change of pressure.

It is worth mentioning that if only pressing, there will be only one pressure curve according to the principle: the pressure rises, and the pressure returns to the initial level after releasing the pressing. However, this is not the same as the case shown in Fig. 10b. Although there is no negative pressure drive, there is a depression after a bump in the pressure curve, which is worth discussing and analyzing.

Through repeated tests and analysis, the curve in Fig. 10b can be interpreted as the poor airtightness of CTSA-II hand: the pressure increases when the compression action is performed, but the airtightness does not reach the optimal level, there will be a certain degree of leakage, this leakage degree is small, so there will be a rise in the first stage of pressure. Later, although the extrusion is maintained, the pressure inside CTSA-II hand will gradually return to the atmospheric pressure level due to poor airtightness, which is the reason for the first peak decline. In the same way, after removing the extrusion, the membrane will return to its original state because of its elasticity, then the volume of the device will increase, resulting in a reduction of pressure, resulting in a trough in Fig. 10b, and due to poor airtightness caused the recovery of the trough.

However, the complexity of the curve does not affect the measurement of deformation by air pressure. Therefore, when the CTSA-II hand is working, when to stop Vertical Adaption can be judged by detecting the change of pressure.

C. Threshold determination

In this part, the threshold pressure p_{th} will be determined by the experiment. The idea is as follows: setting different thresholds and grasping object separately, all other grasping conditions (including object, position, negative pressure, etc.) are the same, and then evaluate the grasping performance of each threshold. Here, the grabbing performance is mainly judged by the average grasping force and the grasping success rate.

The specific experimental scheme is as follows: under different thresholds, the driving pressure device is -50kPa, and the cube of $10\text{mm}\times10\text{mm}\times50\text{mm}$ is grabbed. Each group of thresholds is grabbed 10 times, and the grabbing force is measured separately, and the success rate of grabbing is recorded. According to the pre-experiment shown in Fig. 10b, the threshold pressure designed is to increase the current average pressure to 0~19.5kpa. Since the indexing value is 1.95 kpa, the thresholds involved in the measurement were as follows:

$$p_{thi} = \overline{p_{in}} + 1.95i, i = 0,1,2,...,9\,,$$

where $\overline{p_{in}}$ is the average pressure of CTSA-II hand in the first 500ms before grasping.

However, during the experiments, p_{thi} is adjusted as

$$p_{thi} = \overline{p_{in}} + 1.95i, i = 1,2,...,7\,.$$

Then the experimental data are processed and the results shown in Fig. 11 are obtained. In Fig. 11, advance driving refers to the grasp failure caused by advance driving CTSA-II hand, while no driving refers to the grasp failure caused by not driving CTSA-II hand when press object. From the results shown in Fig. 11, it can be determined that the most appropriate threshold for grabbing objects is the pressure that $i = 3$.

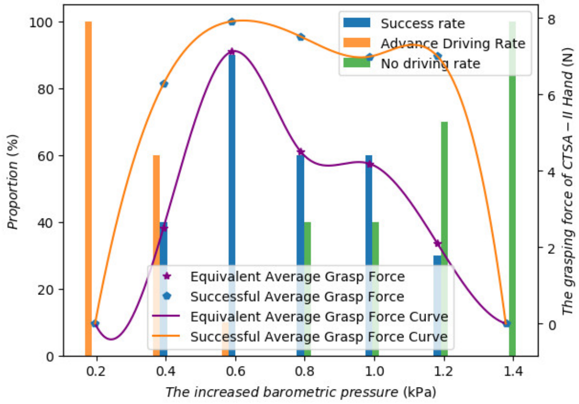


Fig. 11 Grasping success rate and grasping force under different thresholds.

It is worth analyzing that the effect of automatic grasping is not particularly ideal, the highest success rate is 90%, and there is a large proportion of false grabbing just near the optimal threshold. The main reason for the mistake is that the airtightness of the CTSA-II hand is still insufficient, and the structure of the device needs to be adjusted, which will be improved in future research.

D. Performance Verification

Using the parameters developed above, CTSA-II hand is used to grab objects of different heights and explored whether the problems described in Fig. 3 have been solved. Therefore, the cubes with $10\text{mm} \times 10\text{mm}$ cross-section but different heights are grabbed, and the results are shown in Fig. 12. As can be seen from Fig. 12, using Strategy D to grasp well solves the shortcoming that the grasping performance of CTSA-II hand is easily affected by the height of the object.

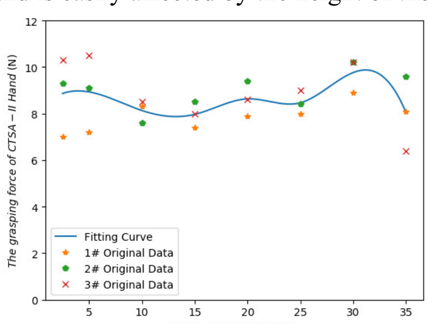


Fig. 12 Relation between grasp force and object height under Strategy D.

In addition to achieving universal grabbing at different heights, CTSA-II hand seems to be more intelligent under the processing of Strategy D and can decide to grab quickly and independently. Therefore, the universal grabbing experiments of various common objects are carried out. Through a lot of experiments, it can be found that CTSA-II hand has a fast grasping reaction speed, and maintains a good general grasping performance.

V. Conclusions

In view of the shortage of generality of the CTSA-II hand grasp, several new and reliable grasp strategies are proposed in this paper. The grasping steps of CTSA-II hand can be divided into two stages: Vertical Adaptation and Transverse Grasping. According to the analysis, the reason for the lack of universal grasp of CTSA-II hand is that there is no suitable universal strategy to decide when to stop the Vertical Adaptation phase, so the grasp strategy is used to decide when to stop Vertical Adaptation and start Transverse Grasping.

Four grabbing strategies are proposed in this paper. Through detailed analysis and comparison, grabbing strategy D is adopted. The idea of grasping Strategy D is to detect the pressure change in the CTSA-II hand to determine whether the Vertical Adaptation has been completed. Through a large number of experimental calibration and verification, Strategy D has been revised, and Strategy D solved the shortage of generality of CTSA-II hand grasp, shown good application performance.

The innovative grasping strategy proposed in this paper plays an important role in the application and development of CTSA-II hand.

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