Multifunctional Gripper Design at the End of the Robot

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Abstract: For the current robotic grasping scenario, the market for single gripper grippers to grasp items is limited, expensive, difficult to use, after-sales cumbersome, and other problems. This paper designs a multi-functional gripper, integrating electro-pneumatic functions and designing multi-functional flanges, which can be used for all kinds of robots and multi-angle mounting, and designs multiple suction cups on the basis of the electric gripper to solve the problem that some items cannot be grasped, and designs various finger grippers at the end of the gripper to solve the problem of grasping items of different shapes. In this paper, the jaws are analyzed using the ANSYS Workbench for static simulations and also tested for gripping stability with a dozen terms. The versatile gripper has the advantages of compact design, reliable grip, easy maintenance, high-cost performance, and multi-scene use.

Keywords: Multifunctional Clamping Jaws, Electro-pneumatic in One, Multifunctional Flange, ANSYS Workbench

1 Introduction

In recent years, with the rapid development of artificial intelligence industry, robots are widely used in manufacturing production, medical, service, education, transportation, communication and other fields, in which the demand for robot end gripper style is also increasing.[1-2] The demand for robot end grippers is increasing. The robot end gripper is similar to a human hand claw, which enables the gripping of workpieces and tools in the same way as a human hand claw. [3-4] The end gripper is similar to a human hand grip. The current mainstream gripper is mainly foreign-owned, the main companies are SMC, SCHUNK, Festo, the new gripper relies on the end of the collaborative robot market, the main companies are Robotiq, OnRobot[5]. Fig.1 shows a diagram of each robot gripper style. Although a large number of high performance gripper products have been launched abroad, the rapid development of grippers is also affected by their high price, single function and after-sales difficulties[6]. The rapid development of clamping jaws has also been hampered by high prices, single functions and after-sales difficulties. The same problem exists with the domestic introduction of electric gripper jaws in recent years[7-9]. In particular, schools, in order to enhance the students' ability to innovate independently and enrich the experimental content, will use all kinds of robots, all kinds of objects to do experiments. At this point the single function of the gripper cannot meet their needs. This paper is therefore about designing a multifunctional gripper that can be mounted across robots, at multiple angles, and can also grip different types of objects[10-11]. The jaws can be mounted at multiple angles across the robot and can also grip different types of objects. The jaws are screwed together, making it easier to disassemble and replace a single part than other jaws on the market, and making it easier for the user to understand the internal structure of the jaws and their operating principles[12]. It is also easier for the user to understand the internal structure of the gripper, its operating principle etc.

2 Multifunctional Gripper Demand Analysis

Fig.2 shows the main functions, structural features and other requirements of the multifunctional clamping jaws in relation to the characteristics of the end-mounting mechanisms of the many types of robots on the market and the shape characteristics of the many types of objects.

(1) Multi-functional flanges: Due to the different number and size of threaded holes in the end of the robot, the end holes of different robot models of the same brand are different, so the purchase of end grippers also requires a special end flange. Some robot scenarios require jaws that can be mounted at multiple angles due to space constraints. It is therefore particularly important to design multifunctional jaws with multifunctional flanges to ensure that the multifunctional jaws can be adapted to different robots and that they can be mounted at multiple angles. Table 1 shows the statistics for the end mounting holes for small robots commonly found on the market.

Fig.1 Diagram of Various Robot Gripper Styles

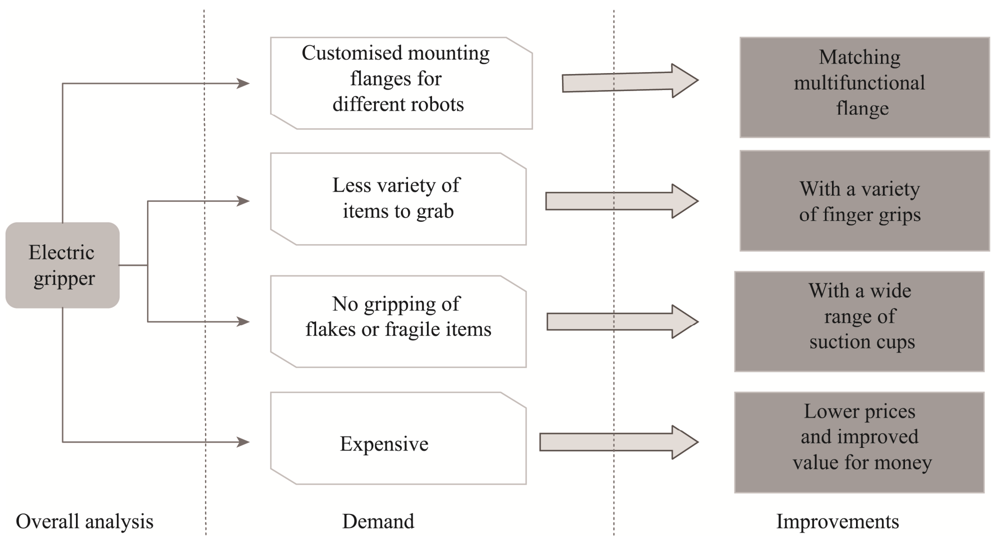


Fig.2 Demand Analysis Diagram for Clamping Jaws

Table 1 Robot End Mounting Hole Locations

Robot Models	ABB1410	ABB 1200	Yaskawa mh24	Yaskawa AR900	KUKA KR8	Fanuc M20iA	Topstar 090	HSR-JR605	HSR-hc508	UR5	AUBO3	TB6-R20
Number of Threads	4	4	8	4	7	15	4	4	8	4	4	4
Thread Size	M6	M5	M4	M5	M6	M4	M5	M5	M5	M6	M6	M6
Screw Hole Distance	40	31.5	56	31.5	50	50	31.5	40	60	50	50	63

(2) Supporting a variety of finger clamps: Due to the different shapes of gripping objects, such as square, polygon, cylindrical, spherical, etc. In the market for different goods gripping often buy several end clamps and quick change devices, and then through different goods to choose different clamps, but this will increase the cost, and replacement will be relatively troublesome. The multi-functional gripper jaws are therefore designed with different shaped finger gripper sleeves, so that for different goods, only the finger gripper sleeves need to be changed. The cost of purchasing multiple clamps and quick change can be greatly reduced.

(3) A wide range of suction cups: for items that cannot be gripped, such as face masks and books. There are also some items that are easily damaged by the packaging or the goods inside, such as packets of cigarettes, bags of biscuits, etc. The suction cups also need to be replaced. In order to solve the problem of changing different clamps, the multifunctional gripper should be designed with a suction cup suction function. Ensure that the jaws can both grip items and also suck up different types of items. Again, the cost is reduced and the jaws are multi-purpose.

(4) cost-effective: the market commonly used electric clamping jaws expensive, single function, and after-sales trouble. For example, the commonly used electric clamping jaws abroad, the price of more than 20,000, after-sales problems have to send foreign maintenance, expensive, long maintenance time, the domestic electric clamping jaws, the price is also more than five thousand. If gripping different goods, you have to buy several jaws, for companies with low cost performance. Therefore, the use of multifunctional jaws is more functional, less costly and more cost-effective.

3 Multifunctional Gripper Structure Design

The basic flow of the jaw design is shown in Fig.3. The main components of the multifunctional jaw are the jaw body module, the motor control module, the drive module, the pneumatic module and the finger gripper module. The gripper body module includes the multi-functional flange, the upper and lower cover plates, the intermediate connection block, the motor fixing block and the gripper block. Since the jaws do not require a large load, do not require a large modulus of elasticity, light weight and high cost performance, all materials are made of aluminum alloy 6061 except for the multi-function flange which is made of stainless steel. Motor control module includes DC reducer motor, power communication module, hard stone control board, switching power supply, etc. The transmission module includes coupling, screw module and slider module, of which the coupling and screw module are small size custom modules with high requirements for machining accuracy. The pneumatic module includes three suction cups, an internal small air tube, an air tube fitting and an external air inlet tube. One of the suction cup rods is fixed by screw holes to facilitate disassembly and replacement when different items are being sucked. The finger jacket module is made of a rubber material with high friction and has a slot in the middle. There are three types of finger grippers: flat, angled and triangular, which can be used for different square, round and polygonal objects. The multifunctional gripper model is shown in Fig.4.

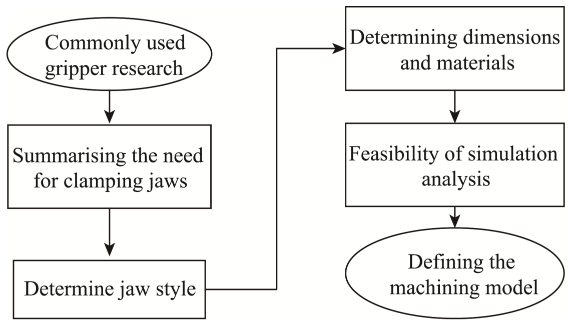
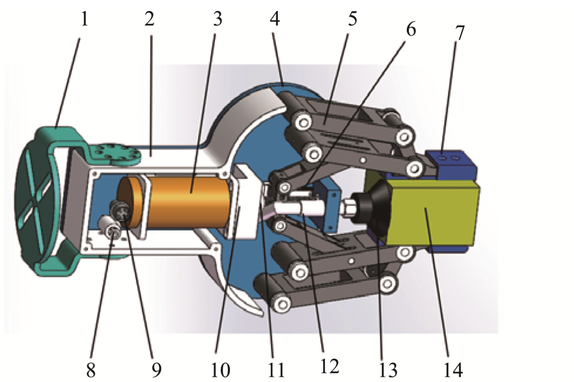


Fig.3 Basic Flowchart for Jaw Design



1. Connection flange 2. Intermediate connecting block 3. DC motors
4. Upper and lower covers 5. Clamping jaw block 6. Slider modules
7. Finger grips 8. Pnecumatic fittings 9. Power connectors
10. Motor fixing block 11. Couplings 12. Gas tube module
13. Suction cups 14. Grabs.

Fig.4 Model Drawing of the Multifunctional Gripper

3.1 Description of the Motor Design

The multifunctional gripper uses a DC gear motor, the motor type is selected by gripping the maximum load of the item. The jaws are analyzed by gripping an object weighing 2kg, Fig.5 shows a 3D sketch of the jaws in this gripping condition using SolidWorks[13] The jaws are shown in Fig.5[13]. The two connecting rods on one side form a parallelogram and are subjected to the same forces.[14] The mass of the item N is 2kg, the centre of the nut block to the tie rod connection r is 10mm, the length of the tie rod to the nut is L_1 is 40mm, the angle a_1 is 49.3°, the length of the link 1 to the connection point of the finger clamp block is L_2 is 27.5mm, the angle a_2 is 26.3°, the length of the finger clamp block connection point to the centre of the finger clamp block is L_3 is 23.5mm, the angle a_3 is 7.2°, set the backward pull of the screw nut is F, from the vertical force equilibrium can be seen that

$$F \cdot r = 2(L_1 \cdot \cos a_1 + L_2 \cdot \cos a_2 + L_3 \cos a_3) \cdot N \quad (1)$$

Known items do not fall is dependent on the friction between the weight and the jaws finger jacket, although the finger jacket for the coefficient of friction is relatively large rubber material, but taking into account the variety of grasping items, may be smooth, the coefficient of friction is small, then the integrated coefficient of friction will be a little smaller, then take the coefficient of friction f for 0.2, gravitational acceleration g to 9.8N/kg, can be derived from N.

$$N = \frac{mg}{f} \quad (2)$$

From the actual situation, it can be seen that the transmission efficiency of the filament module drive process will appear wear, then the mechanical efficiency η to take 0.9. To ensure the safety of the grasping object, then the safety factor K to take 1.2. can be obtained from the actual tension $F_{实}$.

$$F_{实} = \frac{F \cdot K}{\eta} \quad (3)$$

The formula for the combined axial force gives F_a.

$$F_a = F_{实} + \mu \text{mg} \quad (4)$$

where μ is the combined coefficient of friction of the guide, generally taken as 0.2. m is the weight of the moving object. g is taken as 9.8 N/kg.

From the equation for screw torque, we get T_a.

$$T_a = \frac{F_a \cdot I}{2 \cdot 3.14 \cdot n} \quad (5)$$

The feed screw efficiency n is 0.9. Substituting the known values, the combined equation 1~5 can find the screw torque T_a is 1.73Nm. The motor model is selected from the value of T_a, and the motor model is selected as Long Yi 2232R DC gear motor.

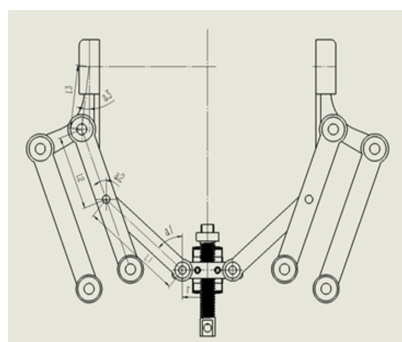


Fig.5 Sketch of Clamping Jaw Forces

3.2 Description of Flange Design

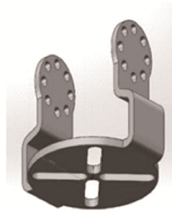
Fig.6 shows the flange multi-angle installation diagram, in which the flange is designed according to the commonly used robot end screw holes, the flange end connection hole is designed as 4 long slots, slot length 40, slot width 7.1mm. 63mm from the farthest end circle centre to the flange centre. The jaw connection is designed with 8 screw holes. Convenient for multi-angle installation of the jaws. Solve the problem of space limitation of robot movement in some scenes. The following is a diagram of the multifunctional flange at 0°, 45° and 90°. The same can be done for 45 degrees and 90 degrees.

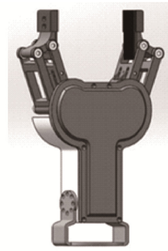
3.3 Description of the Finger Jacket Design

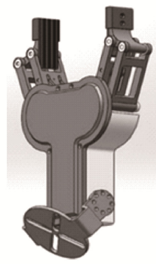
Fig.7 shows a diagram of the three finger gripper sleeves. To ensure that the experiment is versatile, that different items can be gripped and that the items are gripped reliably, grooves are cut into the finger sleeves to ensure sufficient friction between the gripping jaws and the items. The jaws are designed with three finger grippers, which are secured with screws. The finger grippers can be easily replaced. For most items the flat finger gripper is used, for large round items such as mineral water, bottles of toiletries, round cups etc. the angled finger gripper is used. For small round or polygonal items such as ping pong balls, nuts etc. use the triangular finger holder.

3.4 Suction Cup Design Notes

Fig.8 shows the three suction cups, which have been added for items that are not easy to grasp. Examples are face masks, books, wrinkle-prone packaging, etc. The suction force is too strong for small packages, which can easily cause wrinkles on the surface of the product, so use a small suction cup with one layer, e.g., cigarettes, small biscuits, etc. For heavy or large items, use a large suction cup with two layers of suction force, e.g., packaged books, boxed masks, etc. For those heavy items packed in film, which are easy to damage the surface of the film or the goods inside using the gripping claws, use the integrated suction and gripping type, first using the suction cups to absorb, and then the gripping claws to lightly clip the auxiliary, to avoid the suction cups falling off during the suction process, to protect the product double, such as cigarettes, large boxes of biscuits, etc.


(a) Multifunctional flanges


(b) 0 degree installation


(c) 45 degree installation

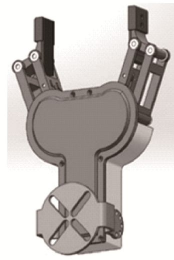
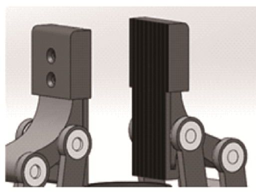
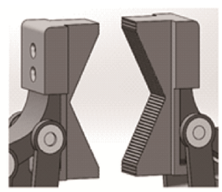

(d) 90 degree installation

Fig.6 Multi-angle Mounting Diagram for Flanges


(a) Parallel finger grips


(b) Angled finger grips

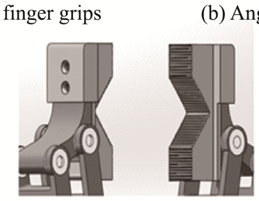
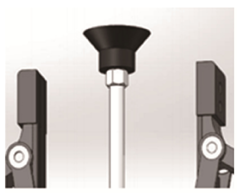
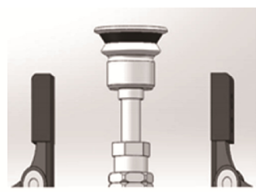

(c) Triangular finger grips

Fig.7 Diagram of Three Finger Clip Sets


(a) Small suction cups


(b) Large double suction cup

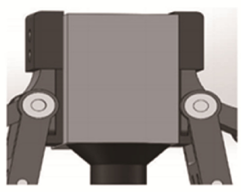

(c) One-piece suction and grip

Fig.8 Diagram of the Three Suction Cups

4 Multifunctional Gripper Function Simulation

4.1 Simulation of Multifunctional Gripper Movements

The gripping process is mainly through the screw module to convert the rotational motion of the motor into linear motion, and then through the screw nut drive both sides of the jaw linkage movement to complete the clamping and unclamping action. When the jaws are given a gripping command, the motor rotates in the positive direction and drives the screw rod through the coupling, which then drives the screw nut backwards. Conversely, when the release command is given, the motor reverses and causes both jaws to release at the same time. The gripping flow diagram is shown in Fig.9 and the jaw movement simulation is shown in Fig.10 below, which shows the position of the linkage, the angle and the maximum opening angle of the jaws in each state.

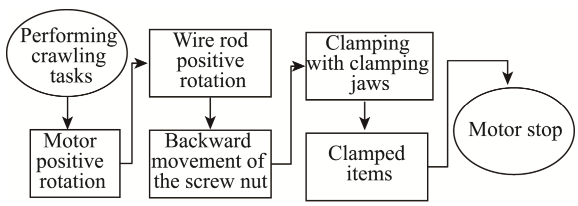
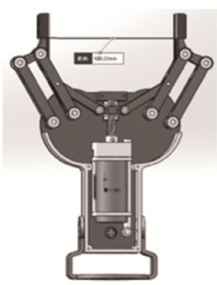
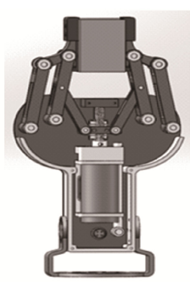


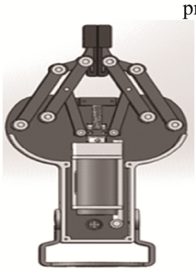
Fig.9 Crawl Flow Chart



(a) Simulation of maximum j aw angle



(b) Gripping jaws for product simulation

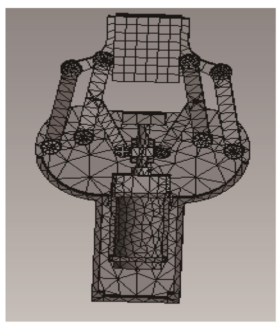


(c) Clamp jaw closure simulation

Fig.10 Motion Simulation Diagram

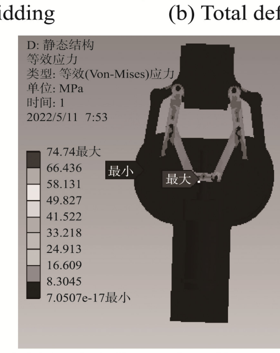
4.2 Finite Element Analysis of Multifunctional Clamping Jaws

In order to verify the reliability of the multifunctional jaws for gripping heavy objects, the jaw structure was simplified by SolidWorks and then imported into the jaws 3D model using the transient analysis module in ANSYS Workbench. [15-16] The jaws are then imported into the 3D model via the ANSYS Workbench module. Set up the jaw connections, where the connecting rods are all connected by slewing. The mesh size of the cell is set to 2mm, a good mesh division can effectively improve the accuracy of the finite element analysis, as shown in Fig.11(a). The upper and lower base plates are fixed during the analysis. The objects in the middle are connected and 19.6N gravity is applied to the objects downwards, i.e., the maximum load gravity. The axial force of the maximum motor torque is then added to the screw nut. After performing a transient analysis of the jaw structure to solve for the total deformation and total stress, looking at the forces applied to each object in the jaws and the deformation, it was found that the maximum total deformation of the jaws was 0.016174mm, as shown in Fig.11(b) and the maximum stress was 74.74MPa. as shown in Fig.11(c).



(a) Gridding

(b) Total deformation diagram



(c) Total deformation diagram

Fig.11 Finite Element Analysis Diagram

Based on the maximum pressure in the jaws it can be seen that the maximum force on the jaws does not lead to material deformation.

5 Multi-functional Gripper Experimental Test

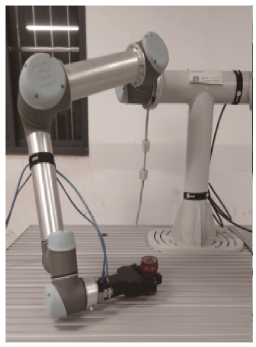
5.1 Experimental Procedure

In order to verify the versatility and stability of the multifunctional gripping jaws for grasping objects, experiments were prepared to verify two aspects. Firstly, the versatility of the gripper will be verified by using different shapes of objects from everyday life to ensure the stability of the three suction cups and the three finger grippers. Secondly, the jaws will be mounted on various industrial and collaborative robots at three angles -0°, -45° and 90° - to test the suitability of the jaws for different robots and the stability of the jaws at each angle.

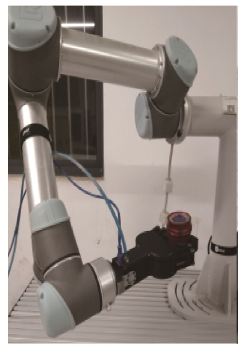
Multi-functional jaw gripping test: 6 types of jaws are verified by using common objects in life. 1) Select charger head, rectangular carton, multi-layer square board to verify parallel jaw gripping; 2) Select round tea box, water cup, beverage bottle to verify angled jaw gripping; 3) Select solid glue, M8 hexagonal nut to verify triangular jaw gripping; 4) Select mask, large cardboard to verify double-layer large (5) cigarettes, bags of small biscuits to verify small suction cups; (6) cigarettes, large boxes of food to verify small suction cups and jaws together.

Multi-function gripper multi-angle mounting test: Based on observations of flange mounting holes for industrial robots and collaborative robots commonly used in schools and factories, the mounting holes are mostly 4 or 6. The threaded holes are M4, M5 or M6. The maximum diagonal hole pitch is 63 mm. The multifunctional jaws can be mounted on the end of the robot. For testing the multifunctional jaws are mounted on the UR collaborative robot at three angles: 0°, -45° and 90°. The multi-functional jaws are tested for gripping the upper part of the object.

The test process is described as follows: the test item is placed at one end of the robot workbench, the robot is controlled to move next to the item to be grasped by means of a multi-functional gripper, then the gripper is controlled to grasp or suck the item to the other end of the workbench, then the item is placed and the gripper is released and the robot is moved back to its original position. For each item, the robot is gripped 30 times in succession and the robot is adjusted to different speeds to record the movement of the gripping jaws and the number of successful grips. Fig.12 shows one of the circular tea boxes gripping movements. This includes pictures before grasping, during grasping movement and after grasping and placing. Fig.13 shows a diagram of various types of items being grasped. Fig.14 shows a multi-angle mounted on the robot grasping the item movement.



(a) Grab



(b) Grabbing Campaign

(c) Placement

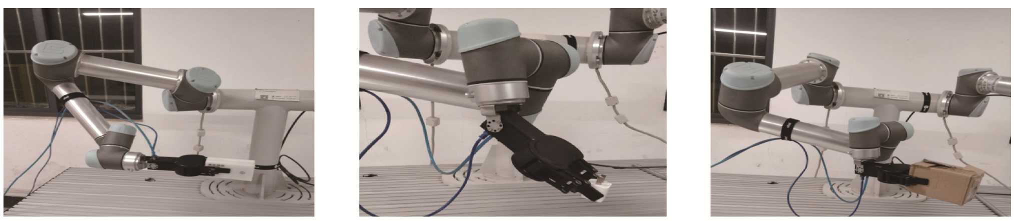
Fig.12 Diagram of the Whole Process of Grabbing a Round Tea Box

5.2 Experimental Results

The test results are shown in Table 2 and Table 3 below, where we can see that the success rate of grabbing is basically 100% and the different angles of installation do not affect the success rate of grabbing, although items grabbed at an angle of 45 degrees sometimes slide in the air due to gravity but do not fall.

The main reason for this is to avoid the problem of the robot rotating 90 degrees and interfering with the object next to it. During the gripping process, it was found that the gripping jaws were very stable, and the robot was set to a speed of 90% or more to keep the gripping motion stable. The items were not easily dropped by tapping them during the gripping process. From the experimental results it was found that all three types of finger gripper jaws were stable in gripping the items, but the hexagonal nut was not very good due to the small size and the contact was not very good at first, resulting in two failed gripping attempts. The suction cups are also very stable. The product is not easily knocked off when tapped by hand. The number of times a packet of cigarettes is sucked can lead to suction marks on the packaging film. For the strip cigarettes, the suction and gripping process is a double layer of protection for the strip cigarettes, although the strip cigarettes are longer, they do not fall off.

Fig.13 Test Chart for Different Item Grabs



(a) 0 degree mounting grip (b) 45 degree mounting grip (c) 90 degree mounting grip

Fig.14 Graph of Different Angle grip Tests

Table 2 Gripper Gripping Test

Test Points	Flat Clamping Jaws		Angled Jaws		Triangular Clamping Jaws		Large Suction Cups		Small Suction Cups		One-piece Suction and Grip	
Grabs	Square Electrical Panels	Charger Head	Mug	Round Tea Box	Solid Glues	Hexagon Nuts M8	Facial Mask	Large Cardboard	Pack of Cigarettes	Biscuits	Strips of Cigarettes	Boxed Snacks
Number of Catches	30	30	30	30	30	30	30	30	30	30	30	30
Number of Successes	30	30	30	29	30	28	30	29	30	30	30	30

Table 3 Grip Tests at Different Mounting Angles

Test Points	0 Degree Installation		45 Degree Installation		90 Degree Installation	
Test Object	Square Electrical Panels	Biscuits	Charger Head	Pack of Cigarettes	Polygonal Iron Box	Boxed Snacks
Number of Tests	30	30	30	30	30	30
Number of Successes	30	30	30	30	30	30

6 Conclusion

With the rapid development of the artificial intelligence industry, more and more companies as well as universities will introduce robotic applications and introduce various robotic equipment for production or research. In this paper, we make some improvements to the gripper jaws in the robot gripping scenario. The main performance is: 1) to improve the applicability of installation: to ensure that a gripper can be installed at multiple angles on different robots; 2) to improve the diversity of grasped items: through the combination of multi-finger gripper and multiple suction cups, to ensure that most items in the robot grasping scene can be grasped; 3) to improve the cost performance: relative to the market mainstream gripper price of 10,000 to 20,000, and after-sales trouble. Through the compact design to reduce costs, easy to disassemble after-sales; 4) to enhance the open usability: the jaws of each part are used small screw connection, can facilitate the individual replacement of each damaged object, more conducive to the use of personnel to disassemble the internal parts to understand its internal design, and grasping and sucking are foolish one-key operation, easy to use. The jaws have been tested on a large number of items to ensure the stability and versatility of the jaws.

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