Improved design and experimental research of cooperative robot’s manipulator

Leng Wei, Zhang Lei, Zhang Xian*
Beijing Institute of Spacecraft Environment Engineering
15652368545@163.com

Abstract. With the proposal of the Made in China 2025 plan, robots have been widely used in aerospace and other fields. In recent years, robots have been applied in aviation manufacturing industry in the way of man-machine collaboration. Manipulator, as an important part of cooperative robot, plays an important role in its work. In this paper, a new type of modular underactuated manipulator is designed based on the structural improvement of the underactuated manipulator. The test platform of the modular underactuated manipulator is built to verify the actual grasping ability of the manipulator. Experiments show that the design of manipulator is reasonable and can meet the requirements of grasping work.

1. Introduction
With the continuous development of science and technology, the China Made 2025 plan puts forward that robots will be one of the important fields to build a manufacturing power. As a representative of the emerging industry, robots have been widely applied in equipment manufacturing, medical treatment, aerospace and other fields. Aviation product manufacturing involves products with large size, heavy load, special materials, complex structure, high precision of performance indicators, multiple special equipment for production, complex tooling, changeable process flow, high requirements for manufacturing environment, and features of multiple varieties, small batch, and parallel design and manufacturing [1-3]. Therefore, aviation manufacturing puts forward higher requirements for industrial robots, especially for the core performance of autonomous collaborative robots, such as structure, reliability, compatibility, motion accuracy and dynamic characteristics [4]. Multi-finger manipulator, as an important part of the end tool clamping of cooperative robot, can grab and operate various complex objects with high speed, stability and reliability without changing the end-effector.

At present, the common dexterous hand drive mode is fully driven and underdriven two, which is fully driven manipulator in the manipulator finger every joint is set to drive, each joint of the manipulator can be independently controlled. Typical actuated manipulator are: the United States at Stanford university, successfully developed the Stanford/JPL Hand [5], the United States at the Massachusetts institute of technology and the university of Utah jointly developed by the Utah/MIT Hand, DIST and UB Hand in Italy, the German aerospace centre developed two generations of the DLR Hand [6-7] and NASA developed by NASA's Hand, Japan Gifu university research institute developed Gifu Hand II finger manipulator [8], etc. Underactuated mechanical finger is the whole manipulator has only one drive source, all the fingers driven by this one drive source. Typical underactuated manipulator are: Italian ARTS/Mitech Labs developed laboratory RTR II manipulator [9], the British Barrett technology company developed Barret - Hand BH8 [10], developed by Tsinghua
This paper analyses and improves the structure and performance of an underactuated manipulator, designs a new type of modular underactuated manipulator, and conducts experimental research on its grasping performance.

2. Improved design of underactuated manipulator

2.1 Analysis of shortcomings of existing manipulator

The existing modular-underactuated multi-finger manipulator is shown in fig.1. This underactuated manipulator is composed of modular fingers, finger transposition mechanism and driving mechanism. The shortcomings and shortcomings of the manipulator can be divided into: finger rotation range is limited; The structural design of finger quick change mechanism is too complex; The modular finger structure is too simple and has poor self-adaptability; the number of the modularized finger is too much and grasping function is less. There are too many connections between hands, and the integration of underactuated hands is poor.

![Figure 1 Original model of underactuated manipulator](image)

2.2 Functional requirements of underactuated manipulator

The under-actuators designed in this paper need to be able to grab a variety of objects, grab the maximum mass of the target does not exceed 2.5kg; Contains 3 fingers, each finger contains 3 movable joints, the finger rotation angle is 0°~90°; Due to the limitation of the load bearing and structure proportion of the end of the manipulator and the variety of grasping targets, the underactuated manipulator also has the advantages of light weight, high reliability, expansibility and controllability. Combined with the above requirements, the optimized underactuated manipulator uses a four-bar linkage mechanism as the finger structure, and uses a crank slider mechanism to drive the three knuckles. A torsion spring is installed at the joint to reduce the redundant degrees of freedom in the manipulator mechanism.

2.3 Improvement design of underactuated manipulator structure

According to the above underactuated manipulator needs to determine the design of the manipulator structure design. In order to ensure the simplicity of the overall structure of the manipulator, and to facilitate disassembly and maintenance, the modular design idea is adopted to design the three fingers into the same structure; Each of the three fingers is driven by a driving motor. In order to be able to make the underactuated hand grasping object type more, on the basis of based on modular fingers, and increase the rotation degrees of freedom of movement between the two fingers, the degrees of freedom in each finger is 90° rotating space, it can realize two fingers of the manipulator on cardiovascular fetching, three symmetrical grab and grab three parallel grab mode, as shown in figure 2, the rotational degree of freedom by a steering gear drive, the underactuated manipulator with a total of 10 degrees of freedom.
Underactuated manipulator main components include: two sets of finger mechanism, namely spring adaptive finger mechanism and double four connecting rod finger mechanism, finger transfer mechanism, manipulator driving mechanism and finger quick change mechanism. In addition, the fingers can be optimized according to the actual fetching requirements, so as to improve the flexibility of the fingers in the operable space, as shown in Figure 3.

3. Experimental research on underactuated manipulator

Based on the improved underactuated manipulator, the basic grasping test is completed. First of all, a suitable experimental platform is set up to capture. The underactuated manipulator is the execution equipment, whose main function is to grasp the object as the end-effector. The test equipment includes: 5-DOF manipulator, power module, grabbed object and external control system, etc. First, install the manipulator on the manipulator arm, and then connect the control system with each part of the manipulator, as shown in Figure 4.

According to the design requirements of the control system corresponding to the grasping action of the improved underactuated manipulator, the control system of the modular underactuated manipulator is designed. The control system is composed of upper computer and drive board. The main movement of underactuated hand and the control of the transposition movement are completed by the upper computer interface button operation. The drive plate installed inside the palm is designed with 10 high-speed A/D pressure acquisition channels, and the force feedback information of the pressure sensors installed in the palm and each finger knuckle is collected respectively. Finally, the pressure
data collected from the palm and each finger knuckle is transmitted back to the upper computer for waveform display. The upper computer and the driver board use RS485 optical isolation pass, and the optocoupler uses TLP113 small volume high-speed optocoupler, and the theoretical logic switching speed of TLP113 can reach up to 10Mbit/s. The selection of such optocoupler can provide basic guarantee for the pressure data back transmission of larger data stream.

The improved design of the underactuated manipulator, the object grasping experiment is divided into three parts: first, the underactuated manipulator three-finger symmetric grasping experiment, the purpose is to verify the manipulator grasping the ball like working state; Second, the underactuated manipulator three fingers parallel grasp experiment, the purpose is to verify the manipulator grasp long round shape object working state; The third is the underactuated manipulator hand two fingers to the heart to grasp the grasping experiment, the purpose is to verify the two fingers to grasp the long strip object working state; Fourth, the underactuated manipulator maximum grasping load verification.

In the test preparation stage, the wiring of each part of the manipulator was checked. Under the action of the control system, check the motion of the mechanical arm and manipulator under the no-load state. The pressure sensor is calibrated and debugged, and the grab is ready. The three-finger symmetric grasping mode was used to grasp beverage bottles and tea canisters respectively. Three fingers parallel grasping mode was used to grasp the teapot and onion respectively. The second finger carried out the fetching of rectangular blocks in the heart fetching mode, as shown in Figure 5.

Notes: (a) Grab bottles in parallel with three fingers; (b) grab the teapot with three fingers centering; (c) grab the rectangular block with two fingers opposite the center

During the experiment, the fingertip hollow flexible rubber can play a good role of buffering and underactuated, the film pressure sensor works well, and the contact force can be fed back to the control system. The variation value of the contact force of the manipulator in the grasping process is shown in Figure 7.

Notes: (a) Curve of grasping the contact force of beverage bottles with time; (b) grab the time-varying curve of the teapot's contact force; (c) The curve of the contact force of two fingers grasping the rectangular block against the center over time
The grasping adaptive experiment shows that the underactuated hand can better adapt to different kinds of grabbed objects after optimized design. In the experiment of grabbing teapot, spring onion and rectangular block, the contact force of each finger is basically the same, indicating that the manipulator can evenly distribute the grasped object between each finger when grasping the heart. In the experiment of grabbing beverage bottles and tea boxes in parallel, the contact forces of the left and right fingers differ by about two times, which is basically consistent with the results of dynamic simulation and parameter optimization.

The maximum grasping load is verified by grasping 2.5kg bottles, as shown in fig. 7. The underactuated manipulator can firmly grasp 2.5kg load.

4. Conclusion
Aiming at the defects of the original manipulator, a modular underactuated three-finger manipulator is designed. The test platform of the modular underactuated multi-finger manipulator was built and the grasping experiment was carried out. The experiment shows that the design of manipulator is reasonable and can meet the requirements of grasping various objects. The design of the underactuated manipulator can effectively support the promotion and use of cooperative robot in aviation manufacturing field.

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