Research on an under-actuated bionic manipulator

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Abstract. Through the analysis and statistics of the calcaneus angle of deer, horse and other cloven-toed animals, the appropriate manipulator configuration is selected. This paper proposes an under-actuated bionic manipulator to assist astronauts in space welding tasks. The motion simulation of the manipulator was carried out utilizing ADAMS, and the relationship curve of the angular velocity at each joint of the under-actuated bionic manipulator was obtained. Through curve analysis, it is not difficult to see that the design of the fingertip spring bar is the key to ensuring the reliable operation of the bionic manipulator.

1. Introduction
With the development of the technology, the space for human activities continues to expand. And, there are more and more facilities in outer space. In order to improve the life of outer space facilities, regular maintenance is required. The maintenance and assembly of outer space facilities require welding technology, and welding technology is an important item in space operations [1]. In the space environment, due to the influence of microgravity, a sharp welding burr is often left after welding. When the astronaut grasps the welded object, this burr is likely to pierce the spacesuit, and the safety of the astronaut will be threatened. In order to improve the safety of astronauts during the welding process, research on robot which can assist space welding is carried out.

During the welding process, the manipulator assists the astronauts to grasp the welding parts, so as to avoid the danger if the astronauts directly grasp the parts and cause the welding spikes to pierce the spacesuit.

2. Configuration design of under-actuated bionic manipulator
For humans, the calcaneus is the largest bone in the foot. And also, it is an important part for keeping balance and walking. For artiodactyl animals, such as deer, horses, cows, etc., they all land on the toes, and the part above the toes will lift and leave the ground. The bones of their hind feet can be divided into three parts: phalanges, metatarsals and tarsals [1]. The calcaneus is a piece of the tarsal bone, which is prominent and long. The structural characteristics of its internal trabecular bone bear the mechanical load of sports and sports-related activities [2-3]. And many muscles are directly connected to the calcaneus, providing them with more powerful strength.

Through the measurement and analysis of the calcaneus angle of 11 kinds of animals including deer, horse, cow, and dog, it is found that the angle between the calcaneus and the leg bone of most animals is between 40° and 60°. Based on this result, the bionic design of the fingertip joints of the under-actuated manipulator is carried out. The structure is shown in Figure 1 and Figure 2.
The requirement of the manipulator studied in this paper is to grasp in space missions. Therefore, the manipulator needs to have very good envelope performance for cylindrical, plate-like, and prismatic objects when grasping. In order to ensure the simplicity of the manipulator structure, choose the three-finger structure for this manipulator. Three fingers are distributed on the left and right of the palm, one finger is installed in the middle of one side of the palm, and the other two fingers are installed on both sides of the other side of the palm. They are distributed in an isosceles triangle shape to ensure a balanced grip. The three fingers imitate the thumb, index finger and middle finger of a human hand [4].

At present, the driving methods of commonly used manipulators mainly include motor drive, hydraulic drive, and pneumatic drive [1]. In order to ensure the rigidity and stability of the manipulator, the working mode of the manipulator is driven by a motor and a linkage mechanism. The connecting rod mechanism has large grasping force, compact structure and strong rigidity [2].

The driving principle of the manipulator is shown in Figure 3. The fingers are the working part and are divided into four sections from left to right: palm connecting section, phalangeal joint, middle finger joint, and fingertip joint. The black part is the linkage mechanism. Left connecting rod is the active part, which rotates clockwise around the hinge of the palm connecting joint, and completes the finger grip movement through the linkage of the remaining connecting rods.

In order to enhance the envelope, adaptability and robustness of the under-actuated bionic manipulator, the flexible part is very important to the manipulator. Replace the three connecting rods of the manipulator with linear spring rods, as shown in Figure 4.

3. Motion simulation of under-actuated bionic manipulator

According to the shape of the object to be grasped, the under-actuated bionic manipulator designed in this paper can be divided into plate grasping attitude and column grasping attitude. For the two grasping postures of the manipulator, the motion simulation analysis is performed respectively.

Set the spring constant of the spring bar at each finger joint to 2.00 N/mm in the Motion analysis module. A rotating motor is set at the active rod with an angular displacement of 100° and a duration of...
Finally, an angular velocity sensor and an angular displacement sensor are set at each finger joint and the active rod.

The simulation analysis of the posture of the pillar is carried out firstly. The object is a cylinder with a diameter of 90mm, and the material is dry aluminum which is used in the space usually. Set the under-actuated manipulator and the cylindrical workpiece to be in physical contact, and the contact type is dry aluminum with dry aluminum. The simulation results can meet the design requirements, as shown in Figure 5a.

In addition, through simulation analysis, the relationship curve of the angular velocity of each joint of the under-actuated bionic manipulator can be obtained, as shown in Figure 5b.

The relationship curve of the angular velocity of the three joints of a single finger of the under-actuated bionic manipulator can be obtained. When grasping a cylindrical workpiece, during the finger touches the cylindrical workpiece to grasp the workpiece (3.5 seconds to 4 seconds), the entire grasping process of the bionic manipulator is smooth and smooth. The manipulator exerts positive pressure on the workpiece and clamps the workpiece, due to the 0.5s vibration in contact with the workpiece. After the workpiece is grasped the normal space welding work can be guaranteed goes on.

Then the simulation analysis of the posture of the pillar was carried out secondly. The object is a plate-like workpiece with a thickness of 20mm, and the material is dry aluminum. The under-actuated manipulator and the plate-shaped workpiece are set in physical contact, and the contact type is dry aluminum and dry aluminum contact. The simulation results can meet the design requirements, as shown in Figure 6a. Through simulation analysis, the relationship curve of the angular velocity of each joint of the under-actuated bionic manipulator can be obtained, as shown in Figure 6b.

![Simulation results of grasping cylindrical workpiece](image1)

**Fig. 5 Simulation of gripping cylinder**

![Angular velocity curve of each joint](image2)

Note: The root joint of the finger-blue; the middle finger joint-red; the fingertip joint-green

![Simulation results of gripping a plate-shaped workpiece](image3)

**Fig. 6 Simulation of gripping the board**

Note: The root joint of the finger-blue; the middle finger joint-red; the finger tip joint-green

Through the analysis of the relationship curve of the angular velocity of the three joints of a single finger of the under-actuated bionic manipulator, it can be obtained that at 1.55 seconds the spring rod at
the fingertip joint begins to compress when the fingertip of the bionic manipulator touches the inverted plate-shaped workpiece. The tip joint began to fit the surface of the plate-like workpiece, so there was a vibration between the middle finger joint and the fingertip joint, which lasted about 0.05 seconds. Then at 3.05 seconds, another vibration occurred in the middle finger joints and fingertip joints, which lasted about 0.55 seconds. At this time, the fingertip joints should be completely attached to the surface of the plate-shaped workpiece, and the spring rods at the mid-knuckle and knuckle joints begin to compress successively to absorb the remaining kinetic energy of the active rod to complete the grasp process. In the process of 1.55 seconds to 4 seconds, the bionic manipulator exerts positive pressure on the plate-shaped workpiece, so that the bionic manipulator can ensure the normal progress of the space welding work after grabbing the workpiece.

4. Results & Discussion

The thinking and selection of bionic institutions were carried out. Because the calcaneus is an important force-bearing bone of artiodactyla animals. Through the angle analysis of the calcaneus and leg bones of various animals, it is found that the angle between the calcaneus and the leg bones of most artiodactyl animals is between about 40° and 60°. Through a brief analysis of the finger joint structure, a suitable bionic angle between the finger joint and the driving link is designed.

For under-actuated bionic manipulators used in outer space, the following factors should be comprehensively considered: the microgravity and low-pressure environment in outer space, the weight burden on the rocket during launch, the rigidity, working stability and resistance of the manipulator Robustness of impact. Through the comparison and selection of finger arrangement schemes, under-drive schemes, and drive schemes of the under-actuated bionic manipulator, the three-finger manipulator scheme was finally selected. The manipulator was driven by a motor-driven link and part of the drive link was transposed. The spring lever provides certain flexibility and robustness for the manipulator.

We establish a MATLAB/Simulink and SolidWorks co-simulation platform to perform a motion simulation analysis on the under-actuated bionic manipulator. Then obtain the relevant motion data of the manipulator grasping plate-shaped workpieces and cylindrical workpieces. The analysis shows that the bionic manipulator is grasping smoothly, and a certain vibration will be generated when the fingers touch the workpiece and grip the workpiece. Adding a non-slip and shock-absorbing flexible material on the contact surface of the manipulator and the workpiece should be able to alleviate the vibration phenomenon and increase the gripping stability of the manipulator.

Reference

[1] Feng Jicai Wang Houqin Zhang Binggang Wang Tin. Research status and prospect of space welding technology [J]. Transactions of the China Welding Institution, 2015, 36(06): 107-112, 118.

[2] Wenchen Zoo. Talking about the three types of walking of terrestrial mammals: toe, plantar and hoof. Each has its own advantages and disadvantages. [EB/OL]. http://dy.163.com/v2/article/detail/ET375OTK05408U,[2020-05-20].

[3] Wang Min Zhang Xiao Yu Tao Wu Zhenqiang. Welding in space [J]. Welding, 2019(01): 16-20, 66.

[4] China Biological Equipment Net. Application of Micro-CT in Animal Calcaneal Research. [EB/OL]http://www.bio-equip.com/showarticle.asp?id=453111,[2020-05-20].