"Weaver"— multi DOF flexible gripper device

Lingfeng Qiao* Chengzhi Wang and Minxi Lu
School of mechanical and electrical engineering, Wuhan University of Technology, Wuhan, China

*Corresponding author: qlfwake@whut.edu.cn

Abstract. In the process of automatic processing, production and assembly, flexible manipulator has the characteristics of high flexibility, multiple degrees of freedom, etc. It can transfer payload to some narrow spaces, and can carry any object, which is widely used. Therefore, a mechanical gripper based on flexible track is designed. In terms of structure, a servo drive system is built by adopting line drive. The gripper is composed of a bunch of links, which are connected with each other under passive joints. At the same time, in terms of function, the free configuration function of the flexible track can achieve the function of grabbing objects of any shape by wrapping.

1. Project background
With the rapid development of China's economy in recent years, people's living standards and consumption levels have been continuously improved, resulting in an increasing demand for labor in the service-oriented field. People hope that robots can replace part of the labor force, and put forward higher requirements for motion accuracy in manufacturing and robot fields. From the perspective of national development strategy, China promulgated "Made in China 2025" in 2015, planning that China will vigorously promote the development of manufacturing towards high-end intelligence. Therefore, from the perspective of social development or national strategy, it is of great significance to study the intelligent operation with robots instead of manpower.

In the industrial field, a large number of fixed single-arm robots and dual-arm robots have been applied and produced. They can operate flexibly, work together with human beings without safety protection measures, and work independently instead of human beings. But the robot is not flexible enough because of its fixed position. In the field of industrial production, it is very common to use robots to complete grasping tasks. The traditional method needs the robot to move to the position where the target object is located to grasp the fixed target object. This method of grasping objects is standardized, easy to operate and efficient, but it cannot be applied in unstructured environment, that is, it can not adapt to the change of the kinds of objects to be grasped.

| Product name | Working principle | Advantages | disadvantage |
|--------------|-------------------|------------|--------------|
| Industrial robot | Fixed position grab | Flexible operation can replace human independent operation | The working position is fixed and inflexible |
| Robot | Grab at the target position | Standardization, easy operation and high efficiency | Cannot adapt to the change of the structure of the target object |

Table 1. Situation of existing robot gripper.
Therefore, compared with the traditional manufacturing industry, a big change direction of contemporary manufacturing industry is flexible production. This production mode hopes that different kinds of work pieces can be processed and produced on one production line, which requires automatic production tools, including mechanical gripper, to change from specialization to generalization, from grasping only one kind or one kind of objects to grasping many kinds of objects.

Figure 1. Existing flexible mechanical gripper.

Based on the above background, a flexible gripper for weavers is designed. Its main body is a flexible track mechanical gripper driven by multi-push rod control lines, and the flexible multi-joint driving operation is realized by the underdrive operation of multiple push rods and the action of traction wires.

1) The top of the mechanical arm is a flexible mechanical claw, which is composed of a motor-driven track structure and adapts to the shapes of different objects by reconfiguring each track;

2) The two mechanical arms are merged in the non-working state, separated when clamping is needed, and the flexible material inside is used to contact the article to protect the article;

3) Due to the action of flexible materials and multi-section tracks, the track can be adapted to the clamping of objects of different sizes under various conditions by modular design and changing the length according to application scenarios;

4) Outside the track, it is wrapped with transparent silica gel to protect the taken objects.

2. Conceptual design

2.1. Global design
Weaver’s flexible gripper belongs to a flexible mechanical arm with a combination of hardware mechanism and flexible material. It adopts a wire drive structure as the motion mechanism of the mechanical arm body, a multi-section track mechanism as the driving mechanism of the front flexible arm, and flexible material covers the inner sides of two crawler mechanical arms as the contact surface between the mechanical arm and the object. Its appearance is shown in Figure 2.

Figure 2. Weaver’s flexible gripper model drawing.
The main body mainly includes a wire driving module, a snake-shaped mechanical arm module and a flexible track wrapping module. As shown in Figure 3, different modules are mainly connected by bolts and bearings. Modular design can ensure that each module has independent functions, reduce the probability of damage, reduce the complexity of the device, and simplify operations such as structural function design, debugging and maintenance.

This device is designed as a universal flexible gripper, which can grasp many kinds of regular or irregular, hard or soft objects with a certain size. Compared with the transmission mechanical gripper, it can reduce the control difficulty without increasing the structural complexity, and make the gripper stable, safe and reliable.

![Figure 3. Overall structure diagram of mechanical arm.](image)

1: line drive module; 2: Snake-shaped mechanical arm module; 3. Flexible track wrapping module

2.2. **Line drive module**

![Figure 4. Line drive model diagram.](image)

1: push rod; 2: Fixed seat; 3: Winding machine

As shown in fig. 4, the wire driving module is mainly composed of a fixed seat, a push rod and a winder. The manipulator controls the three-dimensional motion of the main manipulator by pulling the driving line through the push rod. A push rod is connected to two driving lines with the same angle and different distances from the center of the circle on the disc, and the loosening and tightening of the driving lines are controlled by the expansion and contraction of the push rod. Three groups of connecting wires are connected to one main mechanical arm, which are evenly distributed at the bottom at 120 degrees intervals, thus realizing the stable control of the mechanical arm.
The fixing seat and the winder are connected by universal joints and universal rings, and the connection design can also play a good role in supporting the weight without disturbing the motion of the mechanical arm.

The internal structure of the winder is that each push rod unit is equipped with a deceleration winding wheel mechanism with a motor as the power source, which is driven by 20 series of externally driven stepping motors to wind the driving wire and keep the driving wire in a tight state to ensure the normal operation of the mechanical arm.
2.3. Serpentine mechanical arm module
Serpentine manipulator is composed of several manipulator joint units, and each joint unit is composed of a manipulator joint, a driving motor and an independent control module. Each joint unit can swing by plus or minus 60 degrees, and the grasping operation in a large area in space can be realized through the cooperation of several joint units. According to the different needs of users, different joint units can be assembled by themselves, so that the product can meet the working requirements of various clamping environments.

![Figure 8. Snake manipulator model diagram.](image)

2.4. Clamping mechanical arm module
As shown in fig. 9, the flexible track wrapping module is composed of two parallel flexible tracks, and the two flexible national roads approach side by side under non-working conditions. When objects need to be clamped, the sensor at the front end of the mechanical arm detects the size and shape of the objects to be clamped, thus automatically adapting to the shape of objects by changing the state of the flexible tracks.

The inner wall of the actuator driving arm is covered with flexible material, so it can play a protective role when clamping fragile objects. A pressure sensor is placed between the flexible material and the mechanical arm, which can control the clamping force when the two mechanical arms are folded and clamped to realize the function of clamping soft objects. The flexibility of the mechanical arm is reflected by the independent control of relinking flexible tracks.

![Figure 9. Model drawing of flexible track wrapping module.](image)
As shown in fig. 10, the flexible track actuator mainly uses a DC brushless motor to drive the gear to rotate through the cooperation of the gear rack, and the rack moves horizontally under the rotation of the gear; The front end of the rack is a curved surface structure for driving the locking pin to rotate, and each connecting rod in the track has a locking pin structure; For the movement purpose of the actuator when moving in the orbit, the orbit behind it can be fixed at a relative angle of zero degree or 20 degrees by turning and locking, so as to achieve the function of adapting to the shape of the object.

Figure 10. Actuator diagram of flexible track.

2.5. Detection feedback module

The flexible grasping and intelligent grasping of the flexible gripper of weavers come from the structural design of the mechanical gripper itself on the one hand, and it’s supporting sensors and control systems on the other hand. The sensing system of mechanical gripper is also the electrical and control part of the whole design, which is an essential part of the design. Sensors on the gripper include pressure sensors, speed sensors, etc. The variable force control of mechanical gripper is realized by constructing closed-loop feedback.

The system mainly consists of two parts. The first part consists of a front-end membrane pressure sensor, a signal processing unit, a main control chip and a radio frequency communication module. FSR402 membrane pressure sensor converts the pressure applied to the membrane area of the sensor into the change of resistance value, so as to obtain pressure information. The higher the pressure, the lower the resistance. It is allowed to be used at the pressure of 0-10kg.

The second part is composed of upper computer, microcontroller and wireless communication module. In this paper, the sensor and Arduino chip are used to form an embedded motion detection device. The gyroscope is used to obtain real-time motion information because of its good dynamic performance. However, the gyroscope will produce offset, and the static performance of acceleration sensor and electronic compass sensor is superior, so it can be used to correct the motion detection data of gyroscope accordingly.

Figure 11. Arduino.
Figure 12. Thin film pressure sensor.

At the same time, the device uses lidar and 3D visualization platform to collect data and construct a map, so as to determine the location. The mechanical gripper is driven to reach the vicinity of the object to be grasped, so that the flexible object grasping mode is started.

Figure 13. Laser radar.

Figure 14. Three-dimensional visualization platform

3. Feasibility analysis

3.1. Stress analysis
Stress analysis is divided into static analysis and modal analysis. Static analysis refers to a series of force and moment analysis that simulates the real static stress of parts; Modal is the natural vibration
characteristic of mechanical structure, and each mode has specific natural frequency, damping ratio and modal shape. These modal parameters can be obtained by calculation or experimental analysis. Using the finite element analysis part integrated by Inventor, the strength and stiffness of the key parts of the whole device are checked.

3.2. Motion analysis

In order to know the motion state of the mechanism in the real motion environment, the crank-slider mechanism in the snake-shaped mechanical arm is selected for motion simulation. The simplified model diagram of crank-slider mechanism is as follows:

![Figure 15. Schematic diagram of crank-slider mechanism.](image)

Setting the structural parameters of the mechanism, giving the crank a uniform angular velocity, giving $R_1=40$, $R_2=120$, and slider $L=10$, the slider (red) can be driven to make periodic reciprocating motion on the guide rail. After all constraints are set, it is simulated by the motion simulation function, and its displacement, velocity and acceleration curves are obtained. Set the rotation speed of crank to 9 rad/s.

![Figure 16. Displacement diagram of crank slider.](image)
3.3. Rolling bearing design
Different modules are connected and transmitted with bearings through screws, and the bearings are mainly subjected to radial force during movement, so radial bearings are selected.

3.3.1. Failure modes and life calculation of bearings. The failure modes of rolling bearings mainly include fatigue pitting, plastic deformation and wear. Under the action of load, the pulsating cyclic stress causes fatigue pitting corrosion on the inner and outer race raceway and roller surface, resulting in noise and vibration, which leads to bearing failure. In addition, excessive static load or impact load will cause the local stress on the working surface of the bearing to exceed the yield point of the material, resulting in plastic deformation, which will also lead to bearing failure. For rolling bearings with normal rotation, fatigue pitting damage is the main cause. The fatigue strength (life) is calculated below.

Under normal circumstances, it is convenient to express the life of rolling bearings with rotation time, and the formula is as follows:

$$L_h = \frac{10^6}{60n} \frac{f_i C_v}{f_d P}$$  \hspace{1cm} (1)

In which: $n$ is the rotating speed of the shaft, and $n = r/\text{min}$ when the device works; $f_i$ is the temperature coefficient, and $f_i = 1.0$ in the working environment used by the device is taken; $f_d$ is the load factor, and $f_d = 1.2$ is taken under moderate impact; $C_v$ is the basic rated dynamic load of rolling bearing, taken as; $P$ is the equivalent dynamic load on the bearing, and its general calculation formula is:

$$P = X F_R + Y F_A$$  \hspace{1cm} (2)

Because the axial force $F_A$ on the bearing can be approximately zero, so $\frac{F_A}{F_R} < e$, then $X = 1, Y = 0$;

The load acting on the shaft is mainly the weight of bevel gear and pulley, and the estimated total mass is $M=1\text{Kg}$.

Figure 17. Angular velocity diagram of crank-slider connecting rod.
Therefore, the equivalent dynamic load \( p = m \times 10 = 10 \); the radial basic rated dynamic load of radial ball bearing \( CR = 12.8 \text{KN} \);

The life of the rolling bearing is:

\[
L_h = \frac{10^6}{60n} \frac{f_C}{f_dP} \quad (3)
\]

According to the above calculation, the life of deep groove ball bearing can be obtained:

\[
L_h = \frac{10^6}{60n} \frac{f_C}{f_dP} = \frac{10^6}{60 \times 50} \frac{1\times 12.8 \times 10^3}{1.2 \times 10} = 3.55 \times 10^5 h \quad (4)
\]

The module works 8 hours a day, which is a gear transmission with high utilization rate. The expected life of the module is 30,000 h, \( L_h = 3.55 \times 10^4 h > 30000h \), so it meets the requirements of expected life.

As the diameter of the shaft is 15mm, the inner diameter of the bearing is 15mm, and the deep groove ball bearing code 6202 and model GB/T 63/32-2LS can be selected.

4. Application prospect

This product realizes flexible multi-joint driving operation through under actuated control of multiple push rods and the action of traction wires. The top of the mechanical arm is a flexible mechanical claw, which is composed of a motor-driven track structure. It adapts to the shapes of different objects by reconfiguring each track. Its characteristics meet the needs of intelligent manufacturing in the current manufacturing industry, respond to the call of "Made in China 2025", and meet the needs of mechanical claws to grab common items in daily life, so that mechanical claws really enter thousands of households and have a large size.

5. Conclusions

(1) The matching of gear rack and locking pin constitutes the relinking characteristic of flexible track, which makes the gripper grasp objects adaptively.

(2) The telescopic control line driving module of the push rod can realize the stable control of the mechanical arm and improve the safety and stability when taking things;

(3) Serpentine manipulator can grasp in a large area through the cooperation of several joint units, and meet the working requirements of various clamping environments.

References

[1]. Tang Zengbao, Chang Jian'e. Mechanical Design Course Design. 3rd edition. Wuhan: Huazhong University of Science and Technology, 2006.
[2]. Peng Wensheng, et al. Mechanical Design. Second Edition. Wuhan: Huazhong University of Science and Technology, 2000.
[3]. Xiong Liangshan, et al. Mechanical Manufacturing Technology Fundamentals. 1st edition. Wuhan: Huazhong University of Science and Technology, 2007.
[4]. Longuan yuan. Development status, patent analysis and development trend of home service robots [J]. Technology Wind, 2018(22):5.
[5]. Jia Ning. Target recognition and detection of home robot based on binocular vision [J]. Modern Electronic Technology, 2017, 40(23):51-54+58.