F-POWER Prosthetic Research on Flexible Receptacle

Shaowei Lv, Zhiyong Zhang* and Yanhua Xu
Wuhan University of Technology, Wuhan City, Hubei Province, China

*Corresponding author: lsw-18@whut.edu.cn

Abstract. In recent years, with the development of robot technology, the application of robot structure with high speed, high precision and high load-to-weight ratio has attracted the attention of industry and aerospace. Due to the increase of the flexibility effect of joints and connecting rods during the movement, the structure is deformed, which reduces the accuracy of task execution. Compared with rigid mechanical arm, flexible mechanical arm has the characteristics of light structure, high ratio of load to dead weight, so it has lower energy consumption, larger operating space and high efficiency, and its response is fast and accurate, and it has many potential advantages, so it occupies a very important position in various application fields. F-POWER flexible prosthesis is a man-machine integrated mechanical device that can be worn by people. It can complete the combination of man and machine, control the mechanical arm by human behavior, and help the disabled to complete daily grasping tasks. It can combine the high load and high precision of the machine with the flexibility and intelligence of the human body. At the same time, using adaptive flexible materials can improve the comfort and stability of the prosthesis. The combination of flexible gripper and mechanical gripper can effectively meet the needs of people with disabilities and reduce the difficulty of operation.

Keywords: High precision, Flexible material.

1. Design ideas

1.1. Analysis of the development status of flexible artificial limb
At present, the market of artificial limbs is constantly developing. Some achievements have also been made in the research and development of new structures, new materials and new processes of artificial limb technology in China. For example, EMG artificial hand started in 1960s, and a practical series of EMG-controlled artificial limbs has been formed at present. In the aspect of lower limb artificial limbs, lower limbs with hydraulic system were developed in 1990s. However, the current artificial limbs are mainly aluminum plate, wood, leather, plastic and metal mechanical parts, which can not fit the incomplete limbs well. At present, most of the artificial limbs in the market are decorative, which can't take care of themselves in work and life, but can only make up for the beautiful appearance and balance of limbs. The second category is tool hand, which can connect labor tools and living utensils, and can restore the working ability and self-care ability of patients to a certain extent. However, the tool hand has no normal limb shape and its application range is limited. There are also high-end
electric and voice-controlled prostheses, but these prostheses are too expensive for ordinary families with disabilities to afford.

1.2. Introduction of works
According to the analysis of the current development status and market demand of flexible prosthetic, in order to adapt to the development of intelligent technology and people-oriented thought in today's society, we designed a flexible prosthetic which is suitable for daily use and helps disabled people to complete the basic grasping task. The F-POWER flexible prosthetic limb is similar to a human hand as a whole, and consists of a receiving cavity and a detachable front finger. The inside of the device is composed of flexible joints, which means that the front end is made of antiskid materials.

The flexible prosthetic limb is symmetrically arranged and equipped with a host receiving cavity and three mechanical front fingers. Compared with the traditional prosthetic limb, the device has the advantages of convenient disassembly, high efficiency, simple structure and strong controllability. Therefore, in the aspect of flexible mechanical arm, this device can fully embody its automaticity and flexibility, and realize the characteristics of high efficiency, convenience and flexibility.

2. Introduction to structure and function
2.1. General assembly structure and function
There are 2331 parts and 575 different parts in the F-POWER flexible prosthesis. The overall structure diagram is shown in Figure 1.

![Figure 1. Overall structure diagram.](image)

The design is mainly composed of 1. detachable front end of three fingers, 2. deformable receiving cavity, 3. multi-level boosting mechanism, 4. binding arm fixing device. The front end structure of the manipulator uses exoskeleton design. During the movement, the exoskeleton finger is driven by wrist and can bear the main grasping load. The first three sections of fingertips realize the rotation of joints by installing ball bearings.

2.2. Removable three-finger front end
The front end of the finger imitates the human finger and is connected by three sections through a hydraulic system. The motor of the finger front end 1 drives the gear to rotate, which drives the finger front end connecting rod to drive the finger front end 1 to move. The front end of the finger 2 drives the motor to drive the gear, and then drives the connecting rod of the front end of the finger 2 to move, so as to bend the front end of the finger 3, thus realizing grabbing.

In particular, the device is designed with a knuckle extension module considering the factors of infant palm growth, so as to meet the use requirements of flexible prostheses at different ages. The
motor drives the bevel gear to rotate, so as to realize the reversing of the driving force and drive the screw rod to rotate, thereby controlling the extension and shortening of the finger front end 1.

![Figure 2. Removable three-finger front end.](image)

### 2.3. Deformable receiving cavity and binding arm fixing device

The wrist fixing part adopts the common buckle form, which is matched with the self-designed deformable mechanism, and can meet the daily activities of the hands of the disabled. The inner wall of each buckle is designed with a moving mechanism and a rotating mechanism to ensure that the fixed end fits the movable wrist and arm.

Among them, in the moving mechanism, the motor drives the speed reduction mechanism to drive the middle roller to rotate back and forth along the slide rail, so as to realize the precise adjustment of each buckle. Especially, considering the left and right movement requirements of wrist, the device designs a rotating mechanism above the moving mechanism: the external force drives the movable plate to move left and right, and the slider in the movable plate realizes circular movement, which drives the rod and the special-shaped plate to rotate.

Considering the frequent use of wrist in daily life, the device adopts universal joint connection between the fixed end of deformable wrist and the front end of finger.

![Figure 3. Deformable receiving cavity (left) Tie arm fixing device (right).](image)

### 2.4. Multi-rod boosting mechanism

The multi-bar booster mechanism is driven by the electric drive pressure cylinder, transmits the driving force through multi-bars, and converts the driving force in X direction into the driving force in X-Y direction through the structure of the bar itself and the multi-bar assembly structure. On the one hand, it can drive the front-end prosthetic limb to bend, and at the same time, it can provide enough assistance for grasping the knuckle of the prosthetic limb.
2.5. **Height angle adjusting mechanism**

The height angle adjusting mechanism can drive the gear to rotate through the motor to finely adjust the angle between the X axis and the fixed plane of the prosthetic finger connected to the device. In this device, the rotating shaft can be driven by the motor to make the device perform micro-displacement in the Y direction, so as to realize micro-adjustment of the position of the prosthetic finger and meet the needs of different users.

![Figure 4. Multi-rod boosting mechanism.](image)

2.6. **Universal joint angle adjusting mechanism**

The structure is used for connecting the arm receiving cavity and the hand back receiving cavity, so that the two receiving cavities can fit the limbs of the user well and can rotate flexibly without limiting the normal movement of the wrist of the user, and the body ability of the user is retained to the greatest extent.

![Figure 5. Height angle adjusting mechanism.](image)

![Figure 6. Universal joint angle adjusting mechanism.](image)
2.7. Control modules and functions
The control system is mainly composed of radio remote control and central processing unit. The coded information is loaded on the high-frequency carrier signal by modulation, and the modulated wave is generated and transmitted. When radio waves propagate through the air to the receiving end, the electromagnetic field changes caused by radio waves will generate current in the conductor. Information is extracted from the changing current by decoding, thus achieving the purpose of information transmission. Decoded electrical signals directly drive relays, electronic switches and other devices to achieve predetermined functions. Remote controllers press different keys to generate different coded signals with alternating zeros and ones, and then use them to modulate high-frequency carriers, and finally get modulated waves.

Radio remote control is used to send signals artificially. After receiving the signals, the CPU sends out signals, executes moving commands, and simultaneously executes the grasping function of the robot gripper.

3. Design rationality analysis

3.1. Material analysis
The artificial limb is made of aluminum alloy, which is excellent in heat resistance, low temperature resistance, chemical resistance and electrical performance, and has the characteristics of easy processing, stable product size, good surface gloss, easy painting and coloring, secondary processing such as metal spraying, electroplating, welding, hot pressing and bonding, etc., and is widely used in industrial fields such as machinery, automobiles and buildings. It can reduce the cost, ensure the strength, lighten the robot gripper and reduce the energy consumption.

The mechanical fingers of this prosthetic limb are made of special synthetic silicon carbide, which has high wear resistance and is not easy to be damaged. The mechanical fingers are also covered with a layer of synthetic rubber, which increases the friction of the fingers and is convenient for grasping objects. To sum up, the design is reasonable and feasible in material selection.

3.2. Structural analysis
The main feature of this scheme is to imitate the appearance of human palm. The device can control the opening and closing of the three fingers by slightly changing the wrist, which can meet the daily use of disabled people. The front end of the three fingers can be attached and detached, which is suitable for every process of children's palm growth. The front end of the device uses flexible joints to complete the load tasks in different scenarios. This kind of actuator needs high torque density, high power density and highly integrated control system.

3.3. Functional analysis
F-POWER flexible prosthesis uses flexible joints with flexible control, which can ensure the stability when grasping easily leaked articles such as water cups and paper. In this scheme, the flexible prosthesis uses the wrist to control the opening and closing of the front end, so as to grasp the objects, and the design is reasonable in the realization of functions.

3.4. Stress analysis

3.4.1. Stress analysis of front end of detachable three fingers
When the whole manipulator is in static and dynamic state, the stress mainly comes from its own gravity, and when the manipulator is gripping objects, it will change. From the analysis, it can be seen that the mechanical finger in this state is the most stressed support, so the structural stress and strain analysis are carried out for the mechanical gripper when gripping objects.

Set the mechanical finger joint 1 to be subjected to the working load of 1000N and 5MPa, and analyze its various stress States.
As shown in Figure 7, it can be seen from the analysis results that when the natural frequency reaches the maximum, the corresponding maximum stress in X direction is 39.88MPa; the maximum stress in y direction is 13.79MPa; the maximum stress in z direction is 69.11MPa.

As shown in Figure 8, the maximum stress of the manipulator in XY and -XY directions at this natural frequency is 105.6MPa; the maximum stress in XY direction is 48.73MPa;

As shown in Figure 9, the maximum stress of mechanical finger joint in y direction at this natural frequency is 51.25MPa; the maximum stress value of the manipulator in z direction is 22.38MPa, and the strain values in all directions are at low values.
3.4.2. Stress analysis of arm-binding fixing device
The stress analysis of the arm-binding fixing device in this scheme is carried out when it is under static stress, and the stress mainly comes from its own gravity and the torsional force generated by the front end of the prosthetic limb during work. Now, the stress in all directions of the arm-binding fixing device is analyzed.

![Figure 10. Binding arm fixing device.](image)

It can be seen from the cloud picture that the data analysis of stress and contact pressure of the arm-binding fixture under normal working pressure in daily life shows that the changes are small and in a reasonable state, so the structure design of the arm-binding fixture is reasonable and reliable.

3.4.3. Stress analysis of height angle adjusting mechanism

![Figure 11. Height angle adjusting mechanism.](image)

From the cloud picture, it can be seen that the height angle adjusting device can bear the pushing and pulling force generated when the knuckle of artificial limb works in daily life, and the design of the device is in a reasonable state, so the design of the height angle adjusting mechanism is reasonable and reliable.

3.5. Technical analysis
In this design, the opto-mechatronics technology is comprehensively used, and the control chip adopts the "Arduino" platform which is popular all over the world. It is a convenient, flexible and easy-to-use open source hardware product with rich interfaces, digital I/O ports and analog I/O ports, and supports SPI, IIC and UART serial communication. The environment can be sensed by various sensors, and the environment can be fed back and influenced by controlling lights, motors and other devices. The five functional modules used in this design, namely, steering transport module, manipulator module, image information acquisition and transmission module, line patrol module and obstacle avoidance module,
are all precisely controlled by the central controller. The modular design can effectively meet the requirements of automatic transportation. To sum up, the design is reasonable in technical realization.

4. Innovative design module
As a prosthetic limb, it is particularly important to control the rotation angle of the joint. First, we use the subtle movements of the wrist to control the front finger. At the same time, a sensor is installed at the front end to sense the subtle pressure and produce corresponding voltage changes. Then, the voltage is converted into electrical pulse signals through the ring oscillator. The flexible joint can be adjusted accurately to ensure the stability of the front end when moving.

5. Feasibility and economic analysis

5.1. Feasibility analysis
Predictability, reliability and scientific research and analysis are obtained from the aspects of technology, economy and engineering. The principle of the prior art is mature, and the structure is simple and feasible. Based on the prior art, the designed flexible prosthetic limb is easy to be formed. In modern society, with the development of science and technology, people with disabilities can use new profiles. Material of artificial limb, through the artificial limb to complete the daily routine.

Today's high-end prostheses are characterized by high manufacturing cost and complex operation. Therefore, this product has been developed, which can realize the functions of grabbing objects, adjusting size, moving stably and fine-tuning in real time. It has the characteristics of intelligence, automation, stable and reliable work, easy disassembly and maintenance, and greatly improves the quality of life of disabled people.

5.2. Economic analysis
The flexible artificial limb in this design uses the frame structure as a whole and profiles are used in many places. The main structure is simple and compact, which can effectively save manufacturing materials. In the design of the manipulator, simple and commonly used transmission mechanisms such as connecting rods and gears are effectively used, and the open source hardware "Arduino" platform which is convenient, flexible and easy to use is adopted on the control chip, thus reducing the overall production cost investment.

6. Popularization value and application prospect

6.1. Popularization value

6.1.1. The hardware structure is simple and the manufacturing cost is low. The whole structure is arranged symmetrically, which can save a lot of calculation and design costs in the design process. In the processing process, the types of materials are reduced a lot. The structure of hardware facilities is relatively simple, so the cost of processing and manufacturing is low, and it can gain market.

6.1.2. Both economic and social benefits are high. On the one hand, lower manufacturing cost can lower the selling price, quickly capture the market and obtain economic benefits. On the other hand, there is a huge market for artificial limbs, and making suitable artificial limbs can greatly improve the daily life quality of people with disabilities and meet the core values of people-oriented.

6.1.3. Green environmental protection. The gripper of the machine is powered by electric energy, which has no waste discharge, energy saving and environmental protection. The rechargeable lithium battery is used for power supply, so that the battery consumption is low, the generation of waste batteries is reduced, and environmental protection is facilitated.
6.2. Application prospect

6.2.1. Apply to people with muscle atrophy and insufficient hand strength. After micro-adjustment of the structure, the prosthetic limb can assist hand muscle atrophy or lack of hand strength, and help it to live a better life.

6.2.2. Apply hand assistance to adults with hand disabilities. The prosthetic limb can be applied to adults with hand disabilities after micro-adjustment of its size and structure, and has a wide application prospect.

7. Design summary

F-POWER flexible prosthesis, which is designed in accordance with the principle of balance, not only moves smoothly in work, but also has high movement precision, which can help users live at home. The overall structure requires high machining accuracy, but it is powerful, safe and stable. Suitable for various complex tasks in daily scenes.

The design is small in size, firm in structure and complete in functions, and strives to realize all functions that human upper limbs can complete, while taking into account the requirements of economy, technology, materials and other aspects, and making rational use of existing technologies and principles for re-innovation.

After the design of the work is completed, the finite element analysis and stress analysis are carried out. Through the analysis, concrete data are obtained. The values of stress, strain, contact pressure and other data are in a reasonable range under a specific natural frequency, and it is concluded that the design is reasonable and reliable.

The overall design structure and technology are reasonable and innovative, which is in line with the current national basic purpose of "people-oriented" and has great application prospects.

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