Design and Dynamic Modeling of Flexible Rehabilitation Mechanical Glove

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Abstract. Rehabilitation gloves are equipment that helps rehabilitation doctors perform finger rehabilitation training, which can greatly reduce the labour intensity of rehabilitation doctors and make more people receive finger rehabilitation training. In the light of the defects of the existing rehabilitation gloves such as complicated structure and stiff movement, a rehabilitation mechanical glove is designed, which provides driving force by using the air cylinder and adopts a rope-spring mechanism to ensure the flexibility of the movement. In order to fit the size of different hands, the bandage ring which can adjust size is used to make the mechanism fixed. In the interest of solve the complex problem of dynamic equation, dynamic simulation is carried out by using Adams to obtain the motion curve, which is easy to optimize the structure of ring position.

1. Introduction

1.1. Background
With the aging of the population, there are a large number of patients with hemiplegia, whose motor function is damaged, which seriously affects the normal life. Rehabilitation medicine has proved that scientific rehabilitation training plays a very important role in the recovery of motor function. At present, these patients rely on rehabilitation physicians to help patients complete rehabilitation training. However, due to the problems of personnel and expenses, many patients can not receive effective rehabilitation training. Rehabilitation robot can relieve the heavy work of rehabilitation therapists and provide more scientific rehabilitation for patients. It is an ideal rehabilitation training tool. Because finger is the most flexible and fragile part of human joints, the rehabilitation robot for finger is the focus of research on motion rehabilitation robot.

1.2. Research status
As early as 2005, Wege et al. (Technical University of Berlin) designed an exoskeleton rehabilitation manipulator (Figure 1) for rehabilitation training [1-2]. Harbin Institute of Technology developed an index finger rehabilitation machine (Figure 2), and added force sensors to detect motion state [3-4]. M.Fontana, F. Salsedo and M.Bergamasco designed a finger rehabilitation treatment machine of the index finger and thumb hand (Figure 3). Because of the coupling between the fingers, only 3 degrees of freedom are used for motion control of the finger. In other words, the fingertip can be driven without joints [5]. Then, Santa Ana college pizza has developed is applied to the index finger
exoskeleton robot HANDEXOS (Figure 4). HANDEXOS has 6 degrees of freedom, which can realize the extension, flexion and abduction/adduction of the index finger [6].

Figure 1. A Hand Exoskeleton for Rehabilitation by the Technical University of Berlin.

Figure 2. An index finger rehabilitation machine by Harbin Institute of Technology.

Figure 3. Index and thumb finger rehabilitation robot hand.

Figure 4. Index finger rehabilitation robot – HANDEXOS.

Because the rigid movement is not conducive to the rehabilitation effect, Mohd Nor Azmi Bin Ab Patar et al developed the exoskeleton rehabilitation robot based on pneumatic muscle (figure 5). Then the finger movement posture is analyzed, which can improve the effect of rehabilitation movement [7].

Figure 5. Pneumatic muscle driven exoskeleton rehabilitation gloves.

1.3. The main content of this paper
The rehabilitation robot has made great progress in recent years, but it has many problems, such as huge structure, complex movement, lack of flexibility and lack of comfort. In this paper, the structure of rehabilitation mechanical glove is designed by using the soft material. The underactuated structure by rope-spring is adopted. Then the mathematical model of dynamics is established, and the simulation of ADAMS is made.

2. Structural design
2.1. Mechanical structure design
From the above analysis, it can be seen that the rehabilitation gloves not only need to realize the stretching and flexion movement of fingers, but also keep the concise structure and flexible movement design. For this reason, pneumatic method is adopted in this paper, which can reduce the volume of driving structure and have the flexibility of pneumatic drive. The rehabilitation gloves are shown in figure 6 and figure 7. Each finger knuckle has a bandage fastened to form a ring. The transmission mechanism adopts combination the rope with the rubber band. The rope is positioned on the palm of the hand and is positioned at the middle of the finger and the ring. One end of the rope is fixed on the ring of the outermost ring, and the other end is fixed with the air cylinder output lever. When the air
cylinder output lever retracts, the rope pulls the finger to complete the flexion movement (Figure 8). The rubber band is placed on the back of the hand, and one end of the rubber band is fixed on the outermost ring, while the other end is fixed on the ring of the hand back which is immobilized with the hand. When the air cylinder output lever extends, the pull from rope has been lost, meanwhile the elastic force of rubber band guides finger flexion. Because the finger belongs to the weak part of the body, generally the finger rehabilitation training only needs dozens of Newton force. For this reason, the CJ2B10-40 cylinder of SMC company is selected as the drive. Its inner diameter is 10mm with the 0.7MPa maximum pressure, therefore the maximum output force is 

\[
F = \pi * (d_m / 2)^2 * P_{\text{max}} = \pi * (10\text{mm} / 2)^2 * 0.7\text{MPa} = 55N
\]

which could provide effective output.

2.2. Control system design

The design of the control system mainly includes two parts: electrical system and pneumatic system. Because of its portable characteristics, the rehabilitation gloves are powered by a lithium battery. In accordance with the battery, the small 12V-DC air compressor is selected to provide air pressure. The current of the selected air compressor is 8A, and the rehabilitation training takes about half an hour. For this reason, battery capacity is required to be greater than 4000mAh, and the battery of 6800mAh is selected in this paper. The capacity of each cylinder is 

\[
V_{\text{each}} = \pi * (d_m / 2)^2 * l_{\text{cylinder}} = \pi * (10\text{mm} / 2)^2 * 40\text{mm} = 3.14*10^{-3}L
\]

Considering of the trachea gas, 0.2L gasholder is determined to ensure the safe of this system. The two-position five-way solenoid valve 4V210-08-12V is selected to complete the two actions, expansion and contraction, of the cylinder. At the same time, the five-floors bus board is used to increase the overall system compactness. The STM32 with 5 relays is selected as the master control circuit board. The details of the control system are shown in Figure 9.

3. Dynamics simulation

Because the theoretical formula is difficult to solve, the dynamic simulation of finger with rehabilitation gloves is carried out by using virtual prototype simulation software Adams in order to analyse the relationship between driving force and motion of each joint intuitively. In this paper, the rehabilitation gloves with index finger are simulated as an example. The model is composed of three parts: the human index finger model, the flexible rope and the flexible spring. The human index finger model resembles a series of three connecting rods. According to the length and weight of the human index finger, the corresponding simplified model is established in ADAMS. Subsequently, according to the relationship of the motion among the joints, the corresponding constraint is added to the index finger model. The most widely used modeling method is discrete method for the establishment of flexible rope, that is, flexible rope is discretized into finite elements of cylinders, and bushing connections between cylinders are used. As this method can effectively
simulate the actual stress state of flexible rope, it is used to build flexible ropes in this paper. The "Create Spring Resistance" command is used in Adams software for the establishment of flexible springs. The index finger model in Adams is shown in Figure 10.

When the forefinger is in the extended state, the muscle of distal and middle knuckles and the muscle of middle and proximal knuckles are in the state of tension. And springs are added between the two joints to simulate the pull of the muscles, which ensures that the movement of the model is more consistent with the real state of the movement of the finger. After the model is created, various constraints and forces are added to the model. The joints of the finger are connected by rotating pairs; the lower part of the rope and the knuckles connected by "contact force"; the constraint between the upper part of the rope and the knuckle is defined as fixed connection. In actual rehabilitation training, the driving force of the fingers is about 4-5N, therefore the driving force is set to 4.5N. The simulation time is set to 0.45s, and the dynamics simulation is shown in figure 11. And the post-processing module of Adams software is used to output the rotation angles of the distal joint, middle joint and proximal joint under the action of $F$, which is shown in figure 12.
When the driving force in the case of 4.5 N, the angle of distal joint, middle joint and proximal joint is range of 0~38 degrees, 0~27 degrees and 0~8 degrees. The motion range of each joint accords with the actual movement condition of finger basically, and the running rule accords with the actual movement rule of human finger basically.

4. Conclusion
Aiming shortage at the existing structure of rehabilitation gloves, a new type of rehabilitation robot glove is designed. The flexible driving device and flexible structure are adopted to ensure the smooth movement of the rehabilitation process. At the same time, the simulation analysis is carried out using Adams, which lays a foundation for control research. The springs are adopted to imitate the muscles of human hands, which acquires a good result and realized simulation of the movement of the hand. In the future, the robot modeling with human muscles will be studied in order to get control model accurately.

5. References
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