Research on mechanical design of a multi-function finger rehabilitation robot

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ABSTRACT
Training with robots for injured fingers has achieved the efficacy of treatment. However, most of finger rehabilitation robots just have bending/extend movement. This paper presents a new multi-function finger rehabilitation robot with a simple mechanical structure, which could help fingers and thumb realize bending/extend movement and stretch/adduction movement. The paper firstly analyzes the hand physiological movement mechanism, confirming the motion range of each finger’s joint. Based on the fingers movement rules, the robot driving structure has been developed, which includes thumb training module and fingers training module and frame. In order to prove the rationality of mechanism design, an experiment was conducted. The experiment proved that the mechanism can run smoothly, and its rope wheels also drive well without skidding phenomenon as well as its tension is appropriate.

Keyword:
Finger training
Rehabilitation robot
Hand physiological structure
Mechanical design

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1. Introduction

1.1. Analysis of Current Mechanical Structures of Finger Rehabilitation Robots
Rehabilitation robotic is a new, high-tech industries, and its research application is constantly breaking through, including the innovation of the mechanical structure design and control strategy of diversification, integration, and so on [1-2]. Training with robots for injured fingers could achieve the efficacy of treatment, which also has been recognized by the clinician [3]. Different types of finger rehabilitation robot have been studied [4]. Numerous intelligent control interfaces based on advanced control strategies and human adaptive mechatronics have been developed [5-7]. The mechanical structure design of the robots can be divided into three types, 1 DOF devices, 2 DOFs devices and 3DOFs devices as shown in Table 1, where, P and R represent the sliding pair and revolve pair, respectively. P or R only has a single degree of freedom, while these two can be combined freely to be 2 DOFs devices and 3 DOFs devices as shown in Fig. 1.

<table>
<thead>
<tr>
<th>Number of Active Motion Pairs</th>
<th>Design of Composing Types</th>
</tr>
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<tbody>
<tr>
<td>1 DOF Devices</td>
<td>P, R</td>
</tr>
<tr>
<td>2 DOFs Devices</td>
<td>RR, PR, RP, PP</td>
</tr>
<tr>
<td>3 DOFs Devices</td>
<td>RRR, RRP, RPR, PRR, RPP, PRP, PPR, PPP</td>
</tr>
</tbody>
</table>

Table 1. Different mechanical structure types of the finger rehabilitation robot
Table 2. Motion range of the finger joint

<table>
<thead>
<tr>
<th>Finger Joints</th>
<th>Motion Mode</th>
<th>Range (°)</th>
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<tbody>
<tr>
<td>Metacarpal-phalangeal joint (MP)</td>
<td>Stretch/adduction</td>
<td>-20–20</td>
</tr>
<tr>
<td>Metacarpal-phalangeal joint (MP)</td>
<td>Bending/extending</td>
<td>0–90</td>
</tr>
<tr>
<td>Proximal inter phalangeal joint (PIP)</td>
<td>Bending/extending</td>
<td>0–110</td>
</tr>
<tr>
<td>Distal inter phalangeal joint (DIP)</td>
<td>Bending/extending</td>
<td>0–90</td>
</tr>
</tbody>
</table>

1.3. Design of Driving Structure

Design of the driving structure is determined by the movement mode and motion range of the hand, which should simulate a variety of gestures of fingers, and provide a various joint motion ranges. PIP or DIP joints of the four fingers just do the bending/extending movement, while the MP joint maybe do the bending/extending movement. MP joint motion has no related with the PIP and DIP joints. Assuming that when one of the joints bends, the other two joints will bend; the bending/extending motion of the four fingers can be simplified to one degree of freedom, and the four fingers bends simultaneously. When the bending/extending motion of the four fingers is limited to one degree of freedom, the stretch/adduction motion of the fingers’ MP joints is limited to the same plane, so the stretch/adduction motion of the four fingers can also be simplified to one degree of freedom. Ignore the thumb PIP bending movement, the thumb is simplified as two degrees of freedom of movement, including the bending/extending motion and the stretch/adduction motion.
By analysis above, the whole hand rehabilitation exercise can be simplified into a mechanism with 4 DOFs. Thumb works on horizontal and vertical two direction. Horizontal motion is realized by mechanical and electrical slider moving on the slide rail and vertical direction with the rope transmission method, the sleeve of the thumb is fixed on the belt. Finger sleeve will move with the belt when the motor drives belt up and down. Four fingers stretch/adduction movement also uses rope transmission method and bending/extension movement is realized through the motor driving a curved sheet swinging. This meets the needs of patients hand daily activities, simplifies the driver number and compacts mechanical structure.

2. Results and Discussion

The finger mechanism is composed of three basic parts: thumb training module and fingers training module and frame as shown in Fig. 2. Thumb training module as shown in Fig. 3 is mainly composed of two motors, motor seat, sliding rail, pulley, nylon rope and so on. Roulette wheel 1 fixed on output shaft of 1st motor, are connected to the pulley at the top of the thumb bracket through nylon rope, while thumb sleeve and the rope is fixed. When the 1st motor moves, rope will drive the sleeve in support of vertical guide rail moving up and down and then the thumb motion on the vertical direction can be realized, as the bending motion.

Similar with thumb bending motion, when 2nd motor turning and reversing, nylon rope can drive thumb moving back and forth on 2nd guide rail, thus to realize the horizontal movement of the thumb, as the stretch/adduction motion. Four fingers bracket and 4th motor bracket is fixed with the support plate as shown in Fig.4. When 3rd motor moves, output shaft of 3rd motor can drive the support plate in a circular trajectory, which will realize the bending/extension motion of four fingers. As the movement of each finger is different when the four fingers stretch, it is assumed four fingers can reach the maximum opening angle and the opening angle between the fingers is the same; then the moving distance of the index finger and little finger is same, so is the moving distance of the middle finger and ring finger; and the index finger’s motion range is 3 times of middle finger’s. So the 4th motor output shaft is installed on two concentric roulette wheel with wheel diameter ratio 3:1. Two sets of pulleys are installed on the top and bottom of the bracket. The pulleys and roulette wheel installed on the output shaft of the motor reducer constitute a rope drive mechanism. When the motor is in positive and negative rotation, the nylon rope fixed with the four finger sleeve can drive the four fingers to stretch.
3. Experimental

In order to prove the rationality of mechanism design, an experiment was conducted as shown in Fig. 5. During the whole experiment, four motors moved at the same time. When they reach the limit position at the same time, and motors’ speed just turns to zero. The mechanism runs smoothly, the rope wheel can drive well without skidding phenomenon and its tension is appropriate.

![Figure 5. Training progress of the finger rehabilitation robot](image)

4. Conclusion

In this paper, we design a simple mechanical structure and cost-effective training finger recovery machine. It could help fingers and thumb realize bending/extending movement and stretch/adduction movement. In the future, the intelligent control and clinical trial of the finger rehabilitation robot will be studied.

5. Acknowledgements

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