Prosthetic Hand Structure Design Based on the Principle of Connecting Rod Coupling

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Abstract

The purpose of this paper is to design a multi-degree prosthetic finger with low-weight, small-volume, high-reliability and satisfied manipulative performance. The coupling theory was introduced in the structure design of the finger, and the contradiction between small-volume and dexterity of prosthetic finger has been resolved. Based on the morphology of staff and the features of the skeleton, improve- ments have been made. Four-linkage structure is used to accomplish coupling of the finger. Kinematic design of the finger structure, and analyze the finger, the finger during exercise near the knuckle and middle section, the middle section of the fingertip rotation angle to achieve an approximate 1:1 transmission.Virtual displacement principle and use of coordinate transformation theory of static analysis obtained far knuckle joint with the base input torque output relationship of expression.

Keywords

Prosthetic hand, coupling, four-linkage structure, mechanical analysis.

1. Introduction

The study of prosthetic hand is very important for improving the lives of disabled people and helping them to better integrate into society. Therefore, this has been highly valued by all sectors of society. In the design of the prosthetic hand, the mechanism design of the finger occupies a pivotal position. Commercial prosthetic hand that are currently available generally have 3-5 fingers, but most have only one degree of freedom, so only simple stretching movements can be achieved, making it difficult to perform complex movements. Although the under-actuated finger can achieve a flexible grip, when grasping, the finger can be wrapped in the finger according to the shape of the grasping object, and has better adaptability. However, after many experiments, it has been found that the artificial hand using this kind of mechanism has problems such as small grasping power and insufficient institutional control. This paper uses the coupling principle to solve the contradiction between finger structure complexity and motion flexibility. Only a single motor drive is required to simulate the movement of the human finger through the motion of the coupling link. The finger movement is flexible and the fingertips are powerful. At the same time, the structure is simple, light in weight and easy to apply.

2. Prosthetic Hand Structure

The skeletal structure of human natural hand [1], several of its main features can be described in Figure 1, where the index finger has three joints, of which the proximal phalangeal joint (MCP) has 2 degrees of freedom, middle finger joint (PIP) and distal phalanx The joints (DIP) each have 1 degree of freedom.

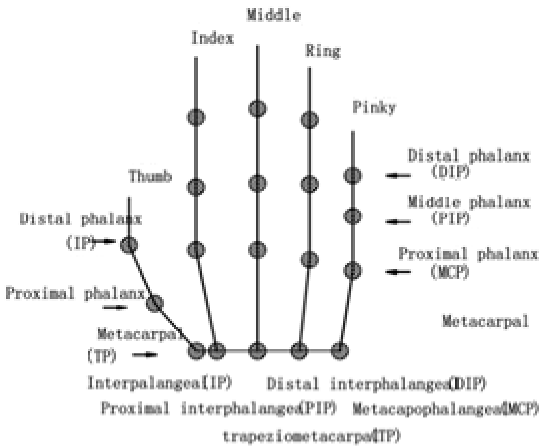

Fig 1. A brief diagram of the human hand skeleton structure

In order to make the finger movement simulate the human finger, there is a large fingertip output, and the structure of the finger is designed by the principle of the coupling link. The size of the reference index finger determines the size of each knuckle of the finger. The size of the prosthetic fingers is 85% of the fingers of the normal people, the length of the near knuckle is 32.3mm, the length of the middle knuckle is 23mm, and the length of the distal knuckle is 21mm. The fingertip output is 10N, and the base joint speed is 60°/s. Between the proximal and middle phalanx, the coupling link is used to realize the movement of the finger and the force transmission between the middle phalanx and the middle phalanx. According to the results of the kinematic analysis, it is guaranteed to achieve a coupling motion of approximately 1:1. The schematic diagram of the index finger coupling link structure is shown in Figure 2.

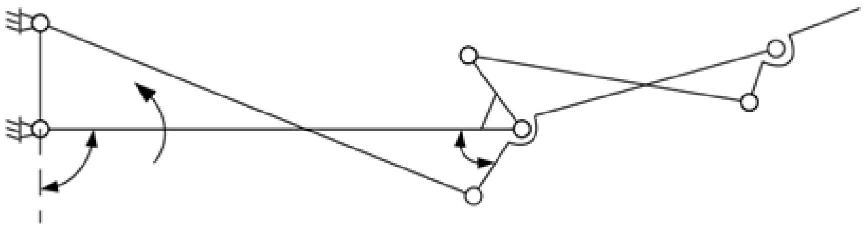

Fig 2. Index finger coupling link structure diagram

3. Kinematic Analysis

Kinematic analysis is performed in the design of coupled link parameters. The goal is to achieve a near 1:1 transmission of the proximal knuckle and the middle phalanx, the middle phalanx and the fingertip during the movement of the finger. First design the mid-knuckle coupling link parameters. The structural principle is shown in Figure 3.[2]

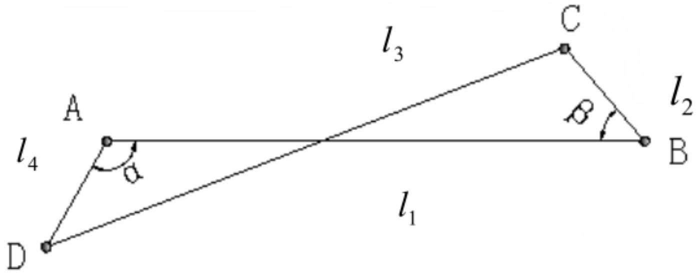

Fig 3. Schematic diagram of the structure of a medium knuckle coupling connecting rod

l1 is the driving rod, l2 is the middle rod drive, l3 is the driven rod, and l4 is the rack. In the transmission process, the knuckle in the driving part drives the far knuckle to drive the coupling. When the active part is l1, l1 moves through the connecting rod l2 to move the l3 in the same direction, then l1 is equivalent to the middle knuckle, and l2 is equivalent to the far knuckle. Thus, the l4 connecting rod mechanism is formed.

During the movement of the finger, the two knuckles of the coupled movement of the end of the finger turn in unison, that is, the angle α (active rotation angle ∠BAD) and the angle β (coupled, passive rotation angle ∠CBA) rotate in the same direction, and the angle of rotation As equal as possible, when α increases by 90 degrees, the corresponding β angle also increases by about 90 degrees. Determine the length of each rod and the initial angle to minimize the difference between the angle α and the angle β, which is approximately 1:1.

The first thing you can determine is l1, l4. To achieve an approximate 1:1 drive, this paper chooses l2 equals l4.The parameters that need to be determined in the four-bar linkage are only the initial values of the angle α and the angle β. Thereby, a series of length values of the link l3 can be calculated.

$$l_3 = f_1(\alpha_0, \beta_0)$$

$$l_{AC} = \sqrt{l_2^2 + l_1^2 - 2l_2 l_1 \cos\beta_0}$$

$$\angle CAB = arc\,\arcsin\left(\frac{l_2 \sin\beta_0}{l_{AC}}\right)$$

$$\angle CAD = \angle CAB + \alpha_0$$

$$l_3 = \sqrt{l_4^2 + l_{AC}^2 - 2l_4 l_{AC}\cos(\angle CAD)} \qquad (\alpha_0, \beta_0) \in R_2 .$$

In the transmission process of the prosthetic hand coupling link, the relationship between the following parameters can be established. The formula is as follows:

$$\alpha = \angle BAD, \beta = \angle CBA$$

$$l_{BD} = \sqrt{l_4^2 + l_1^4 - 2l_4 l_1 \cos\alpha} \qquad \angle CBA = arc\cos\left(\frac{l_2^2 + l_{BD}^2 - l_3^2}{2l_2 l_{BD}}\right)$$

$$\angle CBA = \angle CBD = \angle ABD$$

$$\delta = f_2(\alpha, \alpha_0, \beta_0) = (\alpha_0 - \alpha) - (\beta - \beta_0)$$

4. Static Analysis

The basic idea of the static analysis of the finger of the hand is to use the virtual displacement principle to find the relationship between the input torque M of the joint and the external force F of the distal knuckle[3].

Assuming that the external force F act perpendicularly on the distal knuckle, the virtual displacement point H virtual displacement is δ_S , the AB, BG, GH corner virtual displacement is i (i =1, 2, 3), as shown in Figure 4, then by the virtual displacement Principle:

$$-F\delta_S + M\delta\theta_1 = 0$$

Assuming that the coordinate system where AD is located be the base system B. The coordinate system of the AB rod isA1 , and the origin is A. The coordinate system of the BG rod is A2, and the origin is B. The coordinate system of the GH rod isA3 , and the origin is G.

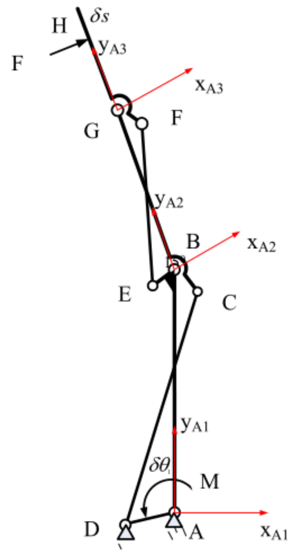

Fig 4 The principle diagram of the virtual displacement of the coupling connecting rod

The coordinate transformation matrix of A1 to B

$$T_1 = Rot(z,\theta_1)$$

The coordinate transformation matrix of A2 to A1

$$T_2 = Trans(-l_{AB}\sin(\theta_2+15^\circ), l_{AB}\cos(\theta_2+15^\circ), 0)Rot(z,\theta_2+15^\circ)$$

The coordinate transformation matrix of A3 to A2

$$T_3 = Trans(-l_{BG}\sin\theta_3, l_{BG}\cos\theta_3, 0)Rot(z,\theta_3)$$

The coordinate relation of the A3 system to the base system B is ${}^{B}\vec{P} = T_1T_2T_3\,{}^{A_3}\vec{P}$

$$T_1 = Rot(z,\theta_1) = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$T_2 = Trans(-l_{AB}\sin(\theta_2+15^\circ), l_{AB}\cos(\theta_2+15^\circ), 0)Rot(z,\theta_2+15^\circ)$$

$$= \begin{pmatrix} \cos\left(\theta_2+15^\circ\right) & -\sin\left(\theta_2+15^\circ\right) & 0 & -l_{AB}\sin\left(\theta_2+15^\circ\right) \\ \sin\left(\theta_2+15^\circ\right) & \cos\left(\theta_2+15^\circ\right) & 0 & l_{AB}\cos\left(\theta_2+15^\circ\right) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$T_3 = Trans(-l_{BG}\sin\theta_3, l_{BG}\cos\theta_3, 0)Rot(z,\theta_3) = \begin{pmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & -l_{BG}\sin\theta_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & l_{BG}\cos\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$T_2T_3=\begin{pmatrix}\cos(\theta_1+15^\circ+\theta_3) & -\sin(\theta_1+15^\circ+\theta_3) & 0 & -l_{BG}\sin(\theta_2+15^\circ+\theta_3)-l_{AB}\sin(\theta_2+15^\circ)\\ \sin(\theta_1+15^\circ+\theta_3) & \cos(\theta_1+15^\circ+\theta_3) & 0 & l_{BG}\cos(\theta_2+15^\circ+\theta_3)+l_{AB}\cos(\theta_2+15^\circ)\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{pmatrix}$$

$$T_1T_2T_3=\begin{pmatrix}\cos(\theta_1+\theta_2+15^\circ+\theta_3) & -\sin(\theta_1+\theta_2+15^\circ+\theta_3) & 0 & -l_{BG}\sin(\theta_1+\theta_2+15^\circ+\theta_3)-l_{AB}\sin(\theta_1+\theta_2+15^\circ)\\ \sin(\theta_1+\theta_2+15^\circ+\theta_3) & \cos(\theta_1+\theta_2+15^\circ+\theta_3) & 0 & l_{BG}\cos(\theta_1+\theta_2+15^\circ+\theta_3)+l_{AB}\cos(\theta_1+\theta_2+15^\circ)\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{pmatrix}$$

Again

$$^{A_3}\vec{P}_H=(0\quad l_{GH}\quad 0\quad 1)^T$$

$$\text{By } ^{B}\vec{P}_H=T_1T_2T_3\,^{A_3}\vec{P}_H$$

$$^{B}\vec{P}_H=\begin{pmatrix}-l_{GH}\sin\left(\theta_1+\theta_2+\theta_3+15^\circ\right)-l_{BG}\sin(\theta_1+\theta_2+\theta_3+15^\circ)-l_{AB}\sin(\theta_1+\theta_2+15^\circ)\\ l_{GH}\cos\left(\theta_1+\theta_2+\theta_3+15^\circ\right)-l_{BG}\cos(\theta_1+\theta_2+\theta_3+15^\circ)-l_{AB}\cos(\theta_1+\theta_2+15^\circ)\\ 0\\ 1\end{pmatrix}$$

$$\text{By } \theta_1=\theta_2=\theta_3$$

$$^{B}\vec{P}_H=\begin{pmatrix}-\left(l_{GH}+l_{BG}\right)\sin(3\theta_1+15^\circ)-l_{AB}\sin(2\theta_1+15^\circ)\\ \left(l_{GH}+l_{BG}\right)\cos(3\theta_1+15^\circ)+l_{AB}\cos(2\theta_1+15^\circ)\\ 0\\ 1\end{pmatrix}$$

$$\therefore \delta x_H=-3(l_{GH}+l_{BG})\cos(3\theta_1+15^\circ)\delta\theta_1-2l_{AB}\cos\left(2\theta_1+15^\circ\right)\delta\theta_1$$

$$\delta y_H=-3(l_{GH}+l_{BG})\sin(3\theta_1+15^\circ)\delta\theta_1-2l_{AB}\sin\left(2\theta_1+15^\circ\right)\delta\theta_1$$

Substitute

$$l_{AB}=32.3, l_{BG}=21, \theta_1=0^\circ$$

$$\delta x_H=-3(21+23)\cos 15^\circ\delta\theta_1-2\times 32.3\cos 15^\circ\delta\theta_1=-189.901\delta\theta_1$$

$$\delta y_H=-3(21+23)\sin 15^\circ\delta\theta_1-2\times 32.3\sin 15^\circ\delta\theta_1=-50.884\delta\theta_1$$

Again

$$\delta s_H=\sqrt{\delta x_H^2+\delta y_H^2} \qquad (3.17)$$

$$\therefore \delta s_H=196.600\delta\theta_1$$

By $-F\delta s+M\delta\theta_1=0$, M=196.6F

Consider the actual situation

$$l_{AB}=32.3, l_{BG}=23, l_{GH}=10, \theta_1=0^\circ$$

$$\delta x_H=-3(10+23)\cos 15^\circ\delta\theta_1-2\times 32.3\cos 15^\circ\delta\theta_1=-158.025\delta\theta_1$$

$$\delta y_H=-3(10+23)\sin 15^\circ\delta\theta_1-2\times 32.3\sin 15^\circ\delta\theta_1=-42.342\delta\theta_1$$

$$\therefore \delta s_H=164.0\delta\theta_1$$

By $-F\delta s+M\delta\theta_1=0$, $M=164.0F$

5. Conclusion

Based on the principle of coupling, the structure design of artificial fingers was carried out, and the static and dynamic analysis of artificial fingers was carried out, so that the adjacent knuckles of fingers could approximately realize 1:1 transmission in the process of motion.

References

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