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DESIGN OF A PROSTHESIS FOREFINGER

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***Abstract**. Hand prosthesis control implies the kinematics and organologic design of the hand. The first element of the hand that must by designed is the finger. The present paper tries to describe a variant of forefinger design. There are presented the dependences between the speed, needed to the finger tip and the input speed and angle.*
***Keywords**: hand prosthesis, forefinger, geometric model.*

Introduction

Designing hand prosthesis implies the geometric, organologic and the control design. In this paper it is presented the geometric design of a hand prosthesis forefinger.
There are a few steps necessary to be followed:

- the design of the finger. There are many variants of fingers depending on displacement transmission system: linkage fingers; cable fingers: muscular fingers;
- to establish the geometric inputs (the length of phalanxes, the angle between them) that should be as closed as it is possible to the real inputs of a human finger;
- to chose the purpose of the prosthesis depending on the person that it wares. This implies to compromise between force prosthesis and precision prosthesis. During this step it should be choosing the grasp force that it is needed;
- to determine the position and speed of the finger tip;
- to determine the input force of the finger needed in obtaining the grasp force chose at the previous step.

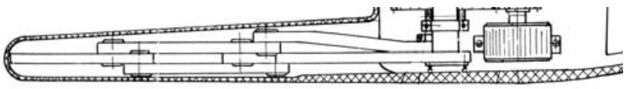
Geometric design of the finger

The human hand, "instrument of instruments" derives its agility from three essential functions:

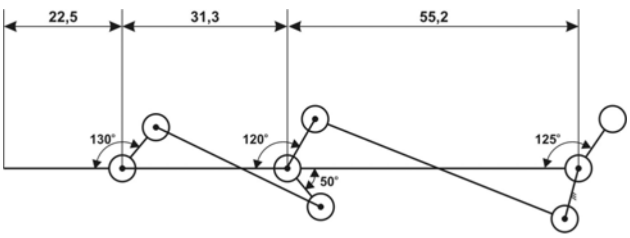
- *Pronosupination* necessitates rotation movements of the forearm around a longitudinal axis and the flexion movements or extension of the elbow or wrist. Pronosupination allows the hand to adapt in all circumstances.
- *Flexion and closing the finger*. This very important function of the hand is possible thanks, on the one hand to the superposition of the three joints of each finger and on the other to extrinsic polyarticular muscles.
- *Opposability of the thumb*. Situated in front of the palm and the fingers, the thumb can be used against them in order to form multi-finger grippers, particularly thumb-index grips, the master of our skill.

Knowledge of the exact geometric model of the hand allows one to propose a prosthesis that would in no way reduce the mobility of the fingers of the person wearing it.
In the case of a simulation, geometric modeling of the hand allows its representation and its virtual animation.
There are two types of geometric models: direct and inverse model. During designing the direct geometric model one should determine the operational coordinate vector in term of finger coordinates and finger dimensions. The inverse geometric model, which is called also the control model should be determined the finger coordinates (angular and linear displacements) depending on given geometric movements of the object gripped.

The proposed finger has three phalanxes that are modeled using three 4-bar linkages. Two of them are cross 4-bar linkages. In figure 1a it is presented an above view of the mechanisms and in figure 1b it is shown the mechanism. The linear dimensions were chosen depending on the length of human phalanxes, and the angular depending on the input angle and the width of the human finger.



a)



b)

Figure 1 a) the above view of the finger; b) the linkages of the finger

The position of the forefinger tip depends on the input angle, noted in figure 1 with φ_{10}. This means that there must be determined some intermediary angles. These are obtained by writing the contour vector equations for each 4-bar linkages. The input angle varies between 0^o and 90^o.

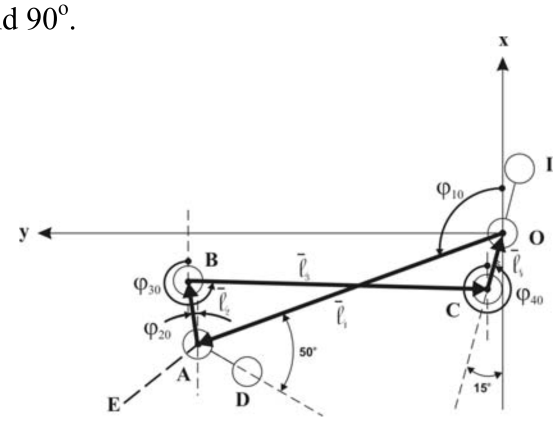


Figure 2 First linkage mechanism of the finger

In figure 2 is presented the first 4-bar linkage of the finger. The mechanism is shown in an intermediary position in term of a better understanding of the movements. The input of the mechanism is the same with that of the finger and the output is, in fact, the input of the next mechanism, the φ_{20} angle.

The contour equation is

$$\overline{OA} + \overline{AB} + \overline{BC} + \overline{CO} = 0 \tag{1}$$

$$(1) \xrightarrow{axes\ pr.}$$

$$\begin{cases} l_1 c\varphi_{10} + l_2 c\varphi_{20} + l_3 c\varphi_{30} + l_4 c\varphi_{40} = 0 \\ l_1 s\varphi_{10} + l_2 s\varphi_{20} + l_3 s\varphi_{30} + l_4 s\varphi_{40} = 0 \end{cases} \tag{2}$$

where $c\varphi_{i0}$ means $cos\ \varphi_{i0}$ and $s\ \varphi_{i0}$ - $sin\ \varphi_{i0}$.

Solving the system (2) will obtain the equation that defines the dependence between the input angle, φ_{10}, of the finger and the output angle, φ_{20}, of the first mechanism

$$\begin{aligned} l_3^2 - (l_1^2 + l_2^2 + l_4^2) = 2l_1 l_4 c(\varphi_{10} - \varphi_{40}) + \\ + 2l_1 l_2 c(\varphi_{10} - \varphi_{20}) + 2l_2 l_4 c(\varphi_{20} - \varphi_{40}) \end{aligned} \tag{3}$$

Figure 3. Trajectories of the A, E and G joints, depending on the input angle

To obtain the position of the finger tip one should write the contour vector equation of the second mechanism, considering that the input of it is the φ_{20} angle and the equation for the last element. Finally there is obtained the following system that defined the position of the finger tip depending on the input angle of the finger:

$$\begin{cases} x_G = l_1 c\varphi_{10} - l_8 c(\varphi_{10} - \gamma) - l_7 c\varphi_{70} - \\ \quad - l_6 c\varphi_{60} + l_9 c(\varphi_{60} + \theta) \\ y_G = l_1 s\varphi_{10} - l_8 s(\varphi_{10} - \gamma) - l_7 s\varphi_{70} - \\ \quad - l_6 s\varphi_{60} + l_9 s(\varphi_{60} + \theta) \end{cases} \tag{4}$$

In figure 3 is presented the graphical representation of the dependence between the intermediary angle of the finger and the input angle. It is also shown the dependence between the position of the finger tip and the input angle.

Cinematic design of the finger

At the beginning it was chosen that the prosthesis is used by a man. That implies two values for the force depending on the grasp type. Thus, the power grasp is characterized by a force of 400N and the precision grasp is characterized by a 65N one [2].

It should be noticed that, during the power grasp, one it is not capable to detect, with high sensitivity, the orientation of the force applied on the finger. Consequently the force is considered to by applied normal to the finger.

The speed of the finger tip is obtained using the rigid body kinematics theory. Figure 4 shows the speeds diagram for the finger joints.

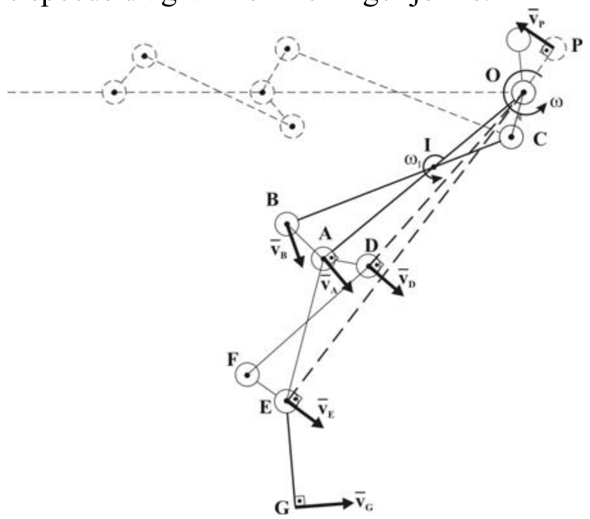


Figure 4 Speed diagram for finger joints

Solving the equations determined by using the rigid body kinematics theory [3], and considering the variations of the intermediary angles obtained before it is possible to represent the dependence between the speed of the finger tip and the input angle of the finger (figure 5).

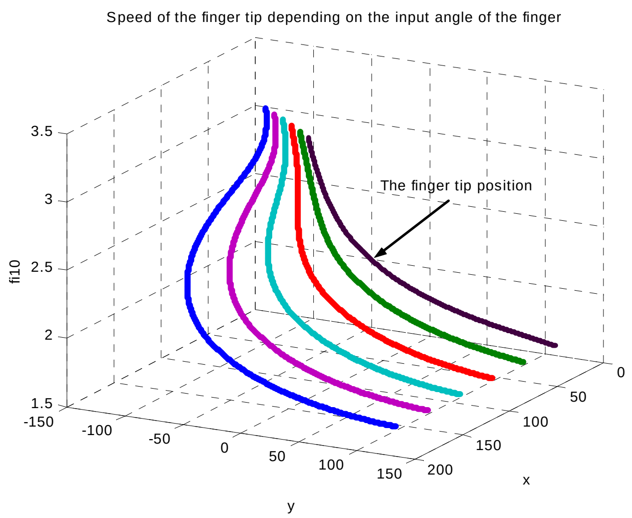


Figure 5 Dependence between finger tip speed and input angle of the finger

Figure 6 shows the dependence between the finger tip speed modulus and the input angle.

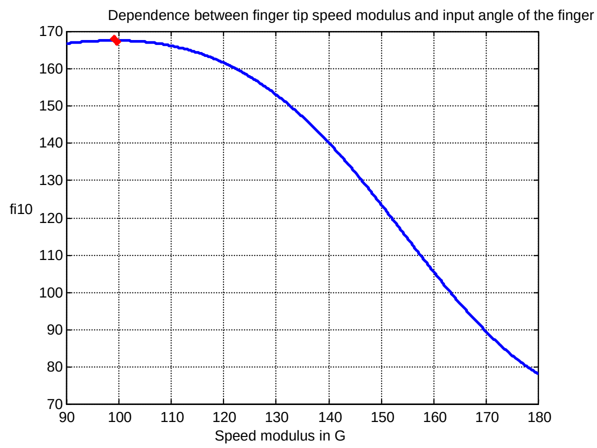


Figure 6 Variation of finger tip speed modulus and the input angle

It could be underlined that the maxim value of the speed is obtained for an input angle around 90^{o} (more precisely $99,5^{o}$) – the point on the diagram.

Input force of the finger

Considering that the force on the finger tip has a variation between 65 N (precise grasp) and 400

N (power grasp) and the joints speed are those determined above, one can determine the power needed as input of the finger. This power is, in fact, the output of the power transmission mechanism. So, after is determined this power, one is able to calculate the power needed to the driving motor so, is able to chose the appropriate motor for the prosthesis.
In figure 7 is shown the dependence between the input power of the finger and the input angle of the finger for two values of the grasping force: 65N and, respectively 400N.

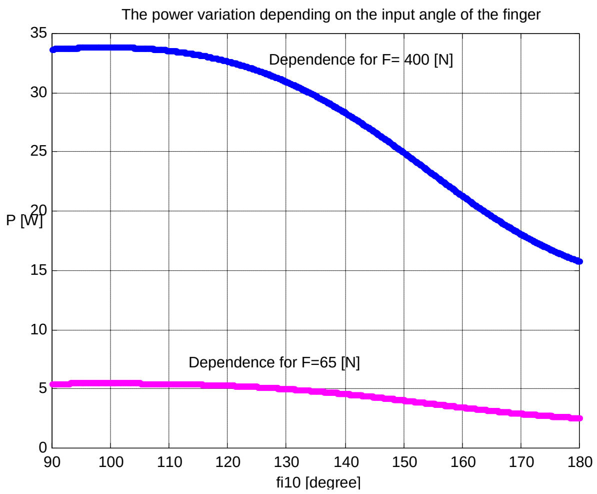


Figure 7. Dependence between input power of the finger and the input angle of the finger

Conclusion

The mathematical modeling of a system is a very important step for control. The paper presented the design of a finger for hand prosthesis. After one finger is designed, one is able to model the whole hand (the fingers, the power transmission, the motors and the sensors). After the models are created the simulation diagram might be done.

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