DEVELOPMENT OF A PROSTHETIC HAND WITH ADAPTIVE GRIP

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Abstract: The aim of this paper was to make a study in the field of prosthesis, to present the long history of prostheses and the impact they have had on people with disabilities, to explain the anatomy of the skeleton of the hand and its properties. The most important aspect was by far the CAD design of a functional hand prosthesis using the Creo Parametric 5.0 program. so that it respects the aesthetic similarities with a real hand, but to ensure a space in the body of the hand for the mechanisms that will operate the fingers in compliance with the necessary calculations.
Keywords*:* prosthetic arm, CAD design - Creo, biomechanics

1. Introduction

Today's world is becoming more and more influenced by robotics and the possibilities of this field of research and production. As a widely applied scientific field, an important contribution to the support and progress of medicine is medical robotics, implicitly the component of medical prosthesis.

Starting from the science-fiction literature and descending into reality, current medical research sometimes talks about the goal of making prostheses that not only serve to replace an amputated organ, but would amplify or complete the functions of a healthy organ, but the morality and necessity of such of prosthesis is controversial.

However, there is archaeological evidence to support the hypothesis that limb amputations have been performed since prehistory, then from antiquity and the Middle Ages to the present day. These amputations were initially performed in order to save the life of the individual, by sacrificing some limbs, following accidents or wars. However, until the twentieth century, amputations rarely had good results, due to the massive hemorrhage they generated and the subsequent septic shock [1], [2]. Early surgeons could only hope for improved speed and surgical technique to improve outcomes and minimize pain.

Surgical robotics is an evolving field, with major advances in the last decade. The origin of robotics was in the science fiction literature and came to be brought into reality by industrial applications and, more recently, by surgical robotic devices made. Microprocessor-controlled prostheses have been available since 1993, especially smart knee prostheses. There are several microprocessor-controlled prostheses today, predominantly for prostheses of the knee, hands and exoskeletons [1].

2. Discussion

Flexion-extension is performed around a transverse axis, which passes through the condyles of the metacarpals, and the lateral inclination is made in the frontal plane around an antero-posterior axis, which passes through the center of the condyles of the metacarpals. The flexion-extension movements of the last four fingers are performed either in isolation or simultaneously, at the three articular levels of the fingers: metacarpiano-phalangeal, proximal and distal interphalangeal. The movements of the thumb are wider due to the radio-scaphoid, scapho-trapezoid, trapezoid-metacarpal, metacarpo-pollex and interphalangeal joints of the thumb. The movements performed are flexion-extension, abduction-adduction, circumduction and opposition.

The opposition stems from a combination of two moves [13]:

- angular movement, through which the tip of the thumb describes an arc of 120° between the point furthest from the vertical axis of the hand
- concomitant 90° rotational movement of the thumb around a longitudinal axis.

The anatomical-functional structural study of the hand can be used successfully to model its movements with prosthetic devices.

2.1. Elements of Biomechanics

"The hand is where the mind meets the world." [10]. The reason why people can use their hands for so many things is explained by their extraordinary anatomy. The hand, the terminal segment of the upper limb, is an improved organ of movement and indispensable for the processes of grasping and work. Under the skin, the hands have an intricate network of tissues. The thumb is alone controlled by nine separate muscles. Some are anchored to the bones in the hand, while others make their way to the arm.

The anthropomorphism coefficient (α) can be defined as the ratio between the functions of the prosthesis and the biological functions, it being responsible for the correlation between the possibilities of modeling the shape and structure of real movements.

$$\alpha = \frac{Zp}{Zb} \cdot 100$$

Zp - prosthesis functions
Zb - biological functions

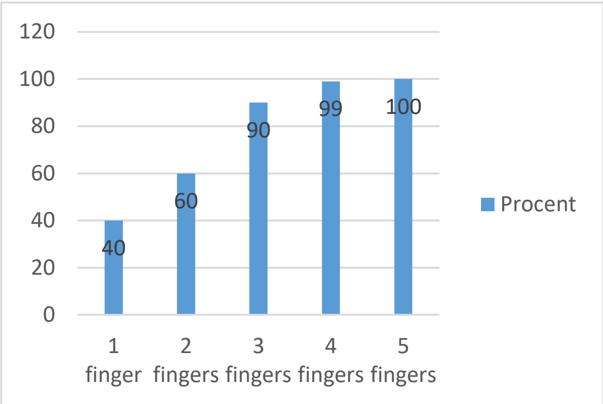

Fig. 1. The anthropomorphism coefficient

With the help of the anthropomorphism coefficient, the minimum number of artificial elements to be fulfilled by the maximum number of functions of the organic member is established. Normally, a five-fingered hand will have an anthropomorphism coefficient of 100%, as shown in Fig. 1, but studies show that three fingers are enough to reach a coefficient of 90% [5].

Shape adaptability is the possibility of the artificial organ to deform under the action of an external force, which acts on the mechanisms of the prosthesis. For example, in the hand, the finger joint can be continuous or discrete.

Finger movement coordination can be:

- rigid coordination (e.g. with a sliding mechanism or a roller),
- flexible or adaptive coordination (with a double rocker mechanism or with a pneumatic one),
- independent or voluntary, passive coordination (with the help of forces external to the prosthesis).

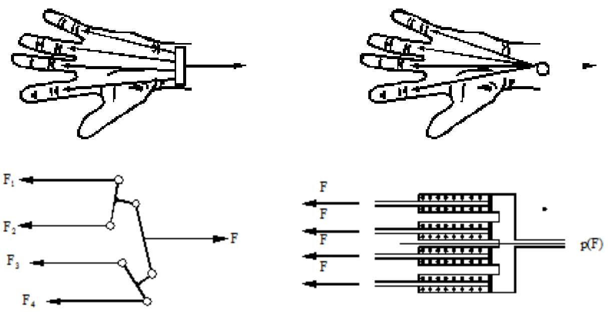

Fig. 2. Rigid coordination and flexible coordination [6].

2.2. Current Solutions in Prosthetic Technology

Federica's hand requires only one actuator to operate all five fingers in an attempt to further reduce the complexity of the control. In particular, a specific set of pulleys were placed on the body of the palm. All drive tendons are connected to this pulley set. An external traction force is applied to the large pulleys with the help of a single external tendon. Then, the specific dimensions and the location of the other pulleys allow the distribution of the external firing force [4], [11].

An example of a hand prosthesis is the i-limb [12] (Touch Bionics), the first commercially available hand prosthesis with five fingers connected to the individual motor, controlled by myoelectric signals generated by the muscles in the remaining portion of the patient's limb. The electronic rotating finger, with manual cancellation, automatically switches between the side and opposition positions. Muscle control uses specific muscle signals called triggers to instruct the hand to activate a specific grip. 18 different automatic clamping options are available.

BeBionic has 14 different grip and hand position models, the BeBionic artificial hand is designed to handle almost any type of everyday wear and tear of the wearer: from eating and carrying bags, to opening doors, turning on lights and typing. The individual motors in each finger allow the hand to move and grip in a natural, coordinated way. Proportional speed control provides precise control over delicate tasks. The hand is available in three different sizes and has multiple wrist options to suit individual requirements. Selectable thumb positions and a built-in sensor allow you to complete a large number of tasks [14].

3. Results

3.1. Positional Kinematic Analysis

The translational moving rocker system that allows adaptive gripping is shown in Fig.3. The system contains 4 rockers, each of them being articulated along a guide. The rocker arm has two branches, one connected to the wire that acts on one of the fingers and the other to the next rocker. The last rocker arm has both branches connected to the ring finger and the little finger.

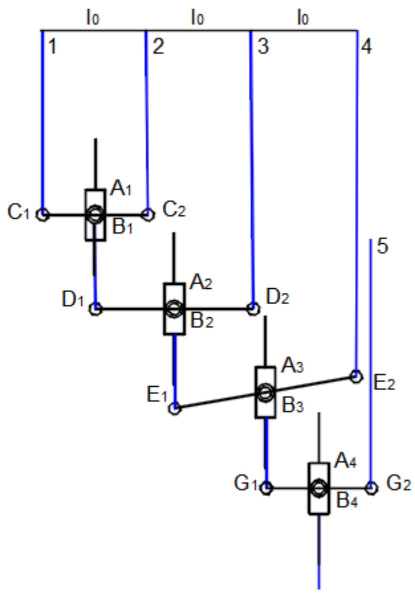

Fig. 3. Kinematc scheme of the adaptative coordination

In order to analyze the whole oscillating swings mechanism, we will consider the guides in turn when the successive movement of the fingers is blocked, due to the prehension of a tronconic object.

When one finger „i”, i=5-1 closer to the actuator is locked, the corresponding kinematic diagram is shown in Fig. 4. According to the diagram, the stroke of the wire is blocked and the rocker arm rotates in a trigonometric direction, acting at the same time as the guide of the next rocker arm. The equation for closing the polygonal contour of the resulting equivalent mechanism is given by the following relation (s. Fig.4):

$$l_{i-1}e^{i\varphi_{i-1}} + l_{fi}e^{i\vartheta_{i-1}} = -(s_0 + s(\varphi_i) - l_i cos\varphi_i) + i \cdot l_{i-1}, \quad (1)$$

After regrouping the terms, the equation will become:

$$l_{fi}e^{i\vartheta_{i-1}} = -(s_0 + s(\varphi_i) - l_i cos\varphi_i) + i \cdot l_{i-1} - l_{i-1}e^{i\varphi_{i-1}}, \quad (2)$$

The new equation will be multiplied by its complex conjugate equation:

$$l_{fi}e^{-i\vartheta_{i-1}} = -(s_0 + s(\varphi_i) - l_i cos\varphi_i) - i \cdot l_{i-1} - -l_{i-1}e^{-i\varphi_{i-1}}, \quad (3)$$

to obtain the transmission equation, be written in the form:

$$0 = C_{i-1} + A_{i-1} \cdot cos\varphi_{i-1} + B_{i-1} \cdot sin\varphi_{i-1} \quad (4)$$

where:

$$\begin{aligned} A_{i-1} &= 2 \cdot l_{i-1} \cdot ((s_0 + s(\varphi_i)) - l_i \cdot cos\varphi_i) \\ B_{i-1} &= -2 \cdot {l_{i-1}}^2 \\ C_{i-1} &= (s_0 + s(\varphi_i) - l_i \cdot cos\varphi_1)^2 + {l_{i-1}}^2 - {l_{fi}}^2, \end{aligned} \quad (5)$$

from which the angle φ_{i-1} can be determined, namely:

$$\varphi_{i-1} = \arctan \frac{B_{i-1} \mp \sqrt{A_{i-1}^2 + B_{i-1}^2 - C_{i-1}^2}}{A_{i-1} - C_{i-1}}. \quad (6)$$

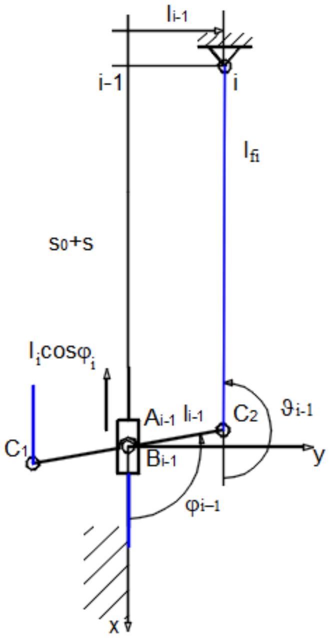

Fig. 4. Kinematic analysis of the mechanism

The computation of all rokers rotation angle φ_4, φ_3, φ_2 and φ_1 folows with the relationship (6).

3.2. Kinetostatic Analysis

As can be seen in Fig. 5, each finger is assigned a certain force. These are distributed from the smallest forces in the little finger and the ring finger, then the next fingers being in turn equal to the sum of the forefingers.

$$\begin{aligned} T_1 &= F_1 + F_2 \\ T_2 &= T_1 + F_3 = F_1 + F_2 + F_3 \\ T_3 &= T_2 + F_4 = F_1 + F_2 + F_3 + F_4 \\ T_4 &= T_2 + F_5 = F_1 + F_2 + F_3 + F_4 + F_5 \end{aligned} \quad (7)$$

By considering the equilibrium condition of the rockers, when all the fingers are in contact with the tronconic object are given as sum of the finger contact forces:

$$F = \sum_{i=1}^{5} F_i = 16 \cdot F \quad (8)$$

where: F is the contact force of the littel and ring finger.

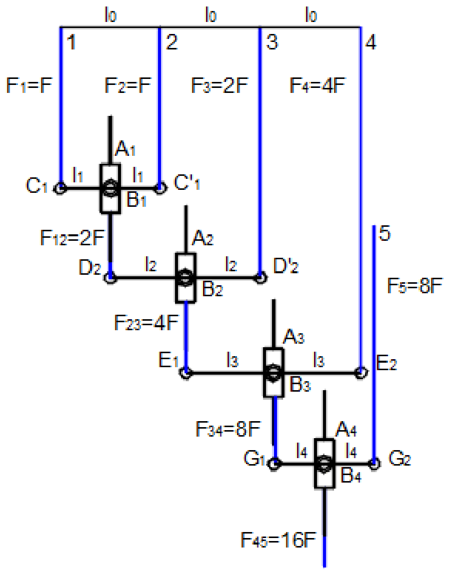

Fig. 5. Kinetostatic analysis of the mechanism

4. Numerical Example

The considered geometrical parameters of the adaptive prosthesis mechanism are given in Tab. 1.

Table 1. Geometrical parameters of the adaptive prosthesis mechanism

No.	Parameter	Dimension
1	Lenth between the finger joints	l_0 = 20 mm
2	Length of rocker 1	l_1 = 10 mm
3	Length of rocker 2	l_2 = 15 mm
4	Length of rocker 3	l_3 = 17.5 mm
5	Length of rocker 4	l_4 = 10 mm
6	Initial lenght of the wire 1	l_{f1} = 41 mm
7	Initial lenght of the wire 2	l_{f2} = 41 mm
8	Initial lenght of the wire 3	l_{f3} = 67 mm
9	Initial lenght of the wire 4	l_{f4} = 80 mm
10	Initial lenght of the wire 5	l_{f5} = 30 mm

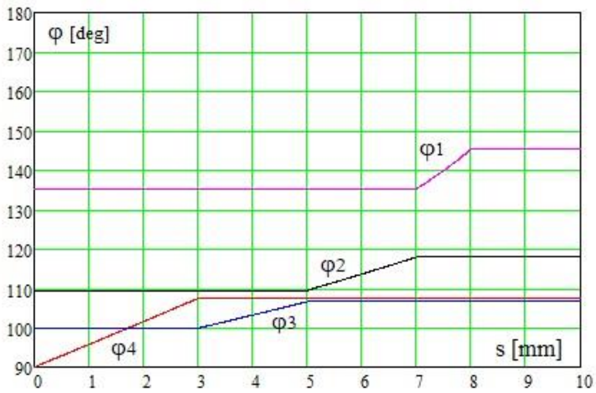

Fig. 6. Succesive finger motion of the prosthesis

Considering the fingers motion as succesiv by linear actuation of the slider 4, with the total stroke of 8 mm, the rotation angles of the rockers is given in Fig. 6. This stroke correspond for maximum rotation of the all the fingers by gripping an object.

It can be seen that the index finger rocker finished the rotation motion for the total stroke s = 3 mm, the thumb finger rocker for the total stroke s = 5 mm, the ring finger rocker for the total stroke s = 7 mm and the littel finger rocker for the total stroke s = 8 mm. By finishing the rotation motion of the rockers the fingers are in contact with the tronconic object.

5. CAD Model for the Prosthetic Arm

A conical shape was chosen for the shape of the phalanges, with rounded ends to allow rotational movement in the joints. As can be seen bellow in the Fig. 7, a stop has been added to the base of the phalanges to prevent excessive finger rotation.

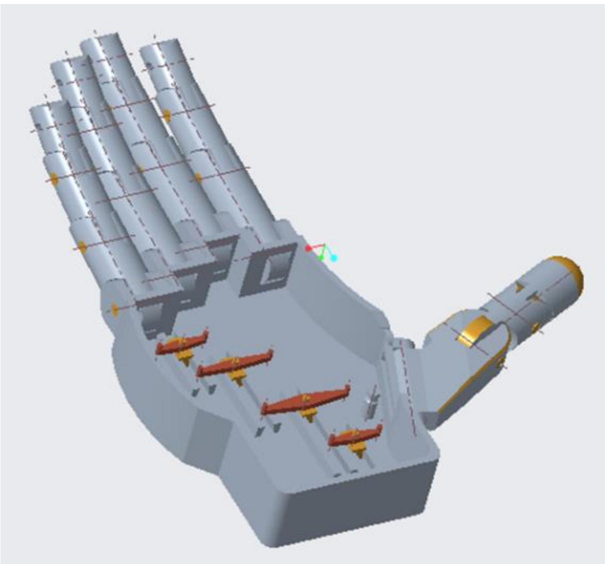

Fig. 7. CAD model for hand assembly with open palm.

In order to model the reality as much as possible, the diameter of the cylinders from which the modeling of a phalanx was started was modified so that it is with the diameters in regression from the proximal to the distal phalanges. This will make the fingers thinner towards the tip.

Another measure that had to be taken was to have slightly different diameters inside the joints between the rounded ends of the phalanges to reduce friction between them. Also, the proximal phalanx of the little finger is shorter than the others, also to better shape reality.

As can be seen from the images below, the components of the thumb were chosen differently from the other fingers for a better grip of the objects, but also partly for aesthetic reasons.

A conical shape was chosen for the phalanges, with rounded ends to allow rotational movement in the joints. As can be seen below in Fig. 8, a pawl has been added to the base of the phalanges to prevent excessive finger rotation.

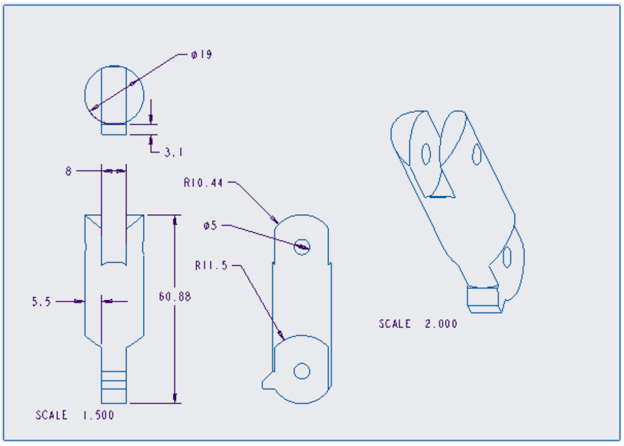

Fig. 8. CAD model of the phalanges

In order to be shaped as close to reality as possible, the diameter of the cylinders closest to the base of the hand was done so as to have a diameter in regression from the proximal to the distal phalanges. This will make the fingers thinner towards the tip.

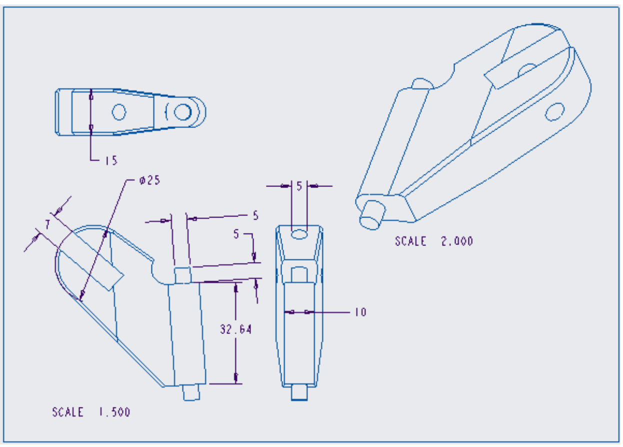

Fig. 9. CAD model of thumb base

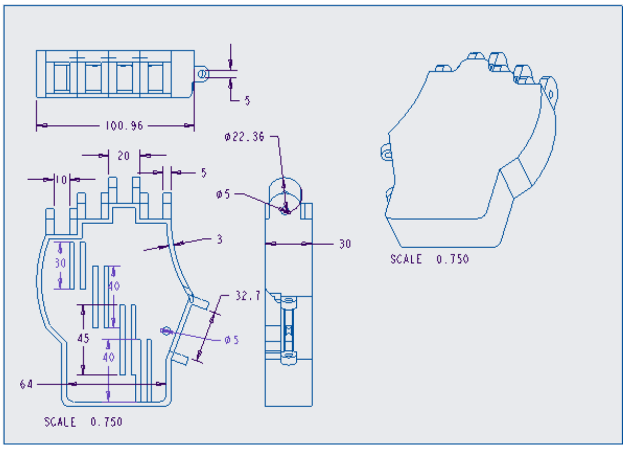

Fig. 10. CAD model of the hand casing

Another measure taken was to have slightly different diameters inside the joints between the rounded ends of the phalanges to reduce friction between them. Also, the proximal phalanx of the little finger is shorter than the others, also to better take after reality.

As can be seen in Fig. 9, the components of the thumb were chosen differently from the other fingers for a better grip of the objects, but also partly for aesthetic reasons.

The hand casing is shown in Fig. 10, with the positions of the slider guides.

6. Conclusions

The aim of this paper was to realise a study in the field of adaptive prosthesis. The study presents the long history of prostheses and the impact they have had on people with disabilities, to explain the anatomy of the skeleton of the hand and its properties. The most important aspect was by far the CAD design of a functional hand prosthesis using the Creo Parametric 5.0 program, so that it respects the aesthetic similarities of a real hand, but also to ensure a space in the body of the hand for the mechanisms that will operate the fingers in compliance with the necessary calculations.

The effort made to make this prosthesis came mainly from the many changes that had to be made to the CAD model and to the calculations that correlate with the results. Initially, more emphasis was placed on the aesthetic side of the prosthesis so that later, once the calculations started, they could be adjusted according to the constructive and functional possibilities. In the end, the results of the calculations could be materialized in the CAD model, so that the prosthesis would work properly.

The calculation of the prosthesis mechanism was in itself an important part of this project. The main contribution of this paper is the development of the four-guide sliders system with rotational rockers, that allows adaptive gripping of objects with irregular outer surfaces. The rocking system operates in a differential mode of motion, which allows a gripping by shape of objects.

In conclusion, if any attempt to bring an innovation in the field of prosthetics through this work thought me anything, is that this effort shows how impressive the properties of a biological hand and how many innovations are needed for people to make artificial organs equal to or better than the original.

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