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Modeling and development of a prosthesis inspired by the anthropometry of the hand

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Abstract

The present article describes the design, modeling and development of a mechanical hand prosthesis driven by myocardial impulses. The design of the prosthesis is based on the anthropometry of the hand, taking into account the skeletal shape of the phalanges and metacarpals, the mechanisms of connection between phalanges, the system of flexor tendons and extension, ligaments and muscles. Through signals from the muscles, the control system performs the operations of grip, rotation, etc. The control system consists of nano wreck, a motor controller, DC motors and the muscle sensor system.

Keywords: hand prosthesis, myoelectric impulses, modelling, and anthropometry.

1 Introduction

Actually the usage of the robotics, EEG and myoelectric signal acquisition devices in the development of the prosthetic devices are highly involved. The prosthetic devices objectives is to substitute the missing or damaged part of the human body. In the last decades the usage of the prosthetic devices are not only used in order to substitute the missing parts of the human body, but also are used in the rehabilitation centers in order to facilitate the rehabilitation of the damaged extremities. The damaged extremities as lower limb and upper limbs are often lost through trauma, vascular brain diseases or craneoencephalic disease. The prosthetic devices also known as robots are designed in order to strengthen the lower or upper limbs during large training sessions.

The prosthetic devices are dated from Ancient Egypt over 950-700 years B.C. Their objective was to reinforce the bone structure or helping osseous tears or simply for cosmetic appearance [1]. In Persia, 484 years B.C. solders amputate one of his legs to escape imprisonment and replaced it with a wooden prosthesis [2].

From 60^{th} the improvement of the mobility and to increase the force of the patients became a necessity. Prosthesis was introduced in the military training with the idea of the improvement of the solders force during different programs as DARPA, etc. [3, 4].

The upper limb prosthesis are classified due to the:

1. degree of amputation
    - transhumeral
    - transradial
2. integration
    - osseointegration
    - suspension
3. functional
    - Cosmetic
    - Body powered
    - Myoelectric

The osseointegration prosthesis are the invasive devices integrated in the human body that is subcutaneous and in contact with the bone. The suspension prosthesis are the devices are suspended to the human body through belts, harness, etc.

The present work describe the design and development of a suspended myoelectric transradial (hand) prosthesis.

In the era of new technology the 3D printing and the advances in computer-aided design (CAD) provide designers and manufacturers great freedom on the product design [x]. This advances make easy the development of upper limb hand prosthetic device [x1, 25]. The [x2 25] describe the development of a flexible and more anthropomorphic design of the human prosthesis. Despite the antropometric design of the prosthetic hand / robotic hand an important role plays the functionality and the mechanism. Most usual prosthetic hands are based on tendon simulation working mechanism [x5 x6]

2 Human anatomy

Human hand have complex anatomic structure. The hand or wrist is composed by 14 phalanges 5 metacarpal bones and the carpus see Fig. 1. The hand bones are structured as:

1. Fingers

    - Proximal phalanges
    - Media phalanges
    - Distal phalanges
2. Metacarpal bones
3. Carpus bones

Between each phalanges and bones are radiocarpal joins, carpometacarpal joins and intercarpal joins. The joins contains two Degrees of Freedom: extension and flexion. The carpus bones realize small movements around instantaneous centers. As well as these movements are very small, this movements are ignored and considered that the hand or wrist have only two DoF [5].

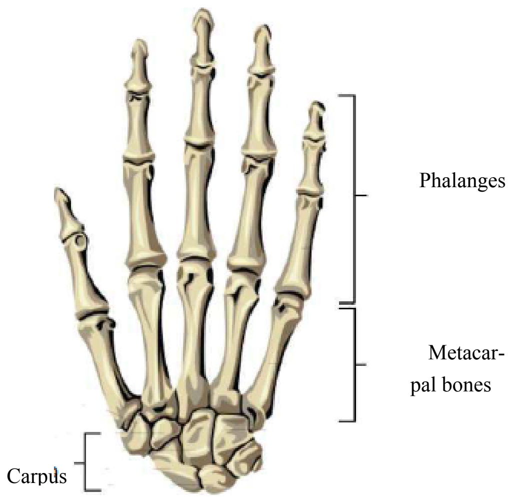


Fig. 1. Hand anatomic structure.

In the Fig.2 b, and c, as well as in the Table 2 can be seen the flexion/extension and abduction/adduction movements of the thumb [6].

Table 1. Wrist extension/flexion movement.

Element	*Description*	*Abbrevia-tion*	*Flexion, º*	*Extension, º*
0	Metacarpal	MET	-	-
1	Proximal phalanxes	PP	-	-
2	Media Phalanxes	MP	-	-
3	Distal Phalanxes	DP	-	-
Θ_0	Metatarsophalangeal Join	MPJ	90	45
Θ_1	Proximal Interphalangeal Join	PIPJ	105	5
Θ_2	Distal Interphalangeal Join	DIPJ	90	10

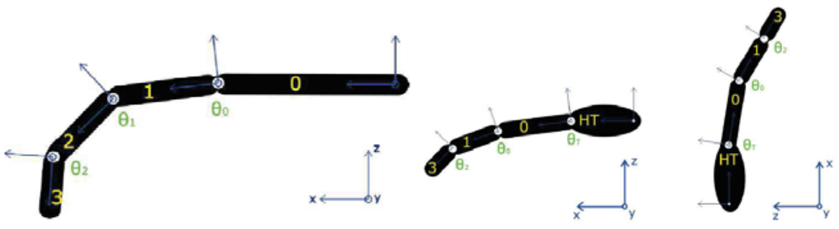


Fig. 2. a) The wrist extension and flexion. b) Thumb flexion/extension and c) Thumb adduction/abduction movements.

Table 2. Thumb extension/flexion, adduction and abduction movement.

Element	*Description*	*Abbreviation*	*Flexion, º*	*Extension,º*	*Adduction, º*	*Abduction, º*
0	Metacarpal	MET	-	-	-	-
1	Proximal phalanxes	PP	-	-	-	-
2	Distal Phalanxes	DP	-	-	-	-
3	Interphalangeal Join	IPJ	90	45	-	-
Θ_0	Metatarsophalangeal Join	MCPJ	70	15	-	-
Θ_1	Carpometacarpal Join	CMCJ	71	38	71	20
Θ_2	Metacarpal	MET	-	-	-	-

3 Materials and methods

An Arduino Nano has been used as processing unit, five DC step by step servomotors, one external battery, one muscle Sensor Kit and an Analog-to Digital Converter.

For the robotic hand design the anthropometric measurements of the human hand have been measured. Each phalange has been modelled with a three dimensional drawing tool, see the Fig. 3. In total have been modelled 14 phalanges and 5 metacarpal bones with their measurements, as well as the artificial carpus and the processing unit support.

The processing unit support is composed by five servomotors, the Arduino processing unit and the Analog-to Digital Converter, that is fixed to the hand with a harness. The contact with the human hand is made by silicone in order to reduce the friction.

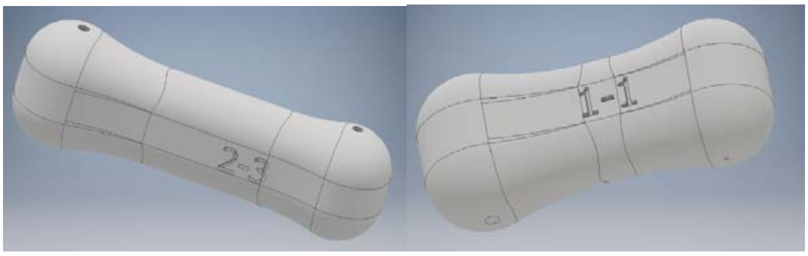


Fig. 3. Modeling of the hand phalanges.

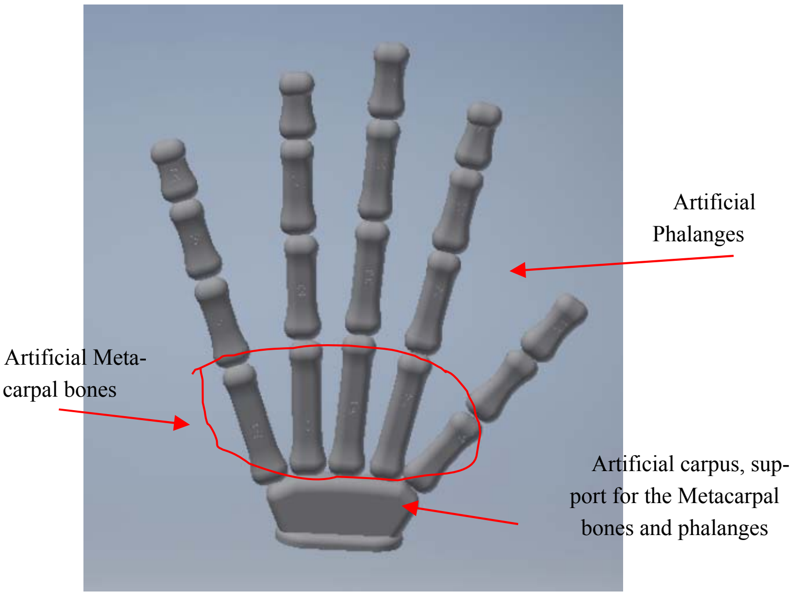


Fig. 4. Integration if the artificial Phalanges, Metacarpal bones on the campus.

In Figure 4 are presented the integration of the carpus, metacarpal bones and phalanges.

It have to be mentioned that the design of the prosthetic hand is based on the real anthropometric measurements of a young human hand. The idea of the anthropometric measurements is to model and develop an adaptable personalized robotic hand.

The mechanical movement of the prosthetic hand is based on the human biomechanics. The Artificial carpus is a designed with 1 DoM that realize the movement of rotation. The artificial metacarpal bones are divided in two groups: the group of the fingers are fixed to the carpus. Doe to the small degree of movement of the metacarpal bones with the carpus, the movement is considered null. The second group is composed by the thumb metacarpal bone. Its movement consist on the flexion/extension and adduction /abduction movement, which can be seen in Figure 5.

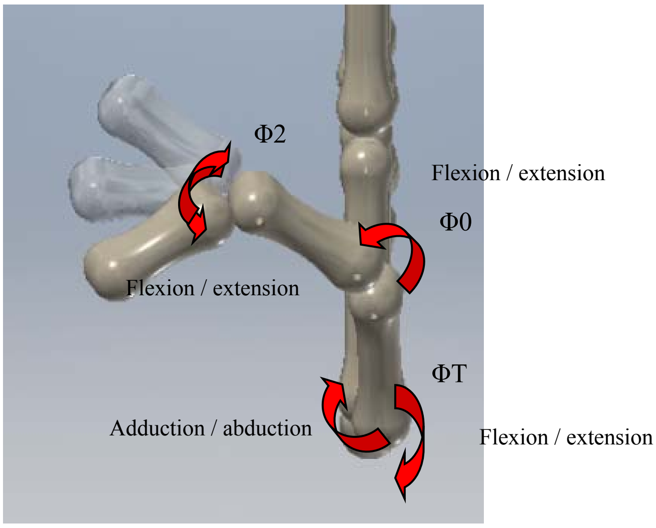
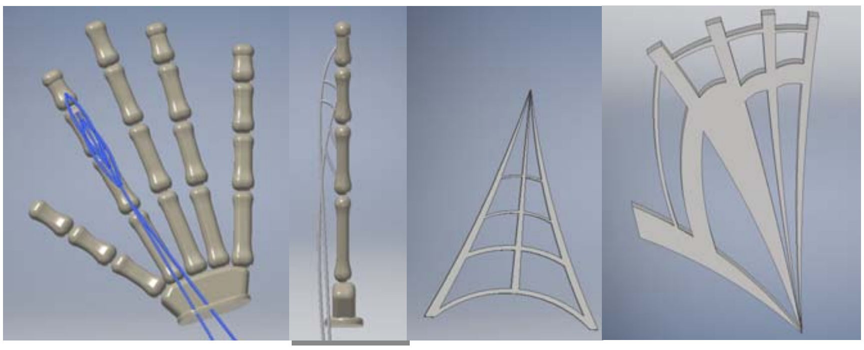


Fig. 5. Phalange movement of the thumb the flexion, extension, adduction and abduction.

The main fixing system of the prosthetic hand are the tendons and the muscles. The extensor tendons are placed on the dorsal area named opisthenar area, see Figure 6 a, b, c and d).

The flexor tendon is situates in the palmar area of the phalanges that realize the flexion of the phalanges and make possible the grasp, it is represented in the Figure 6 b).



a) b) c) d)

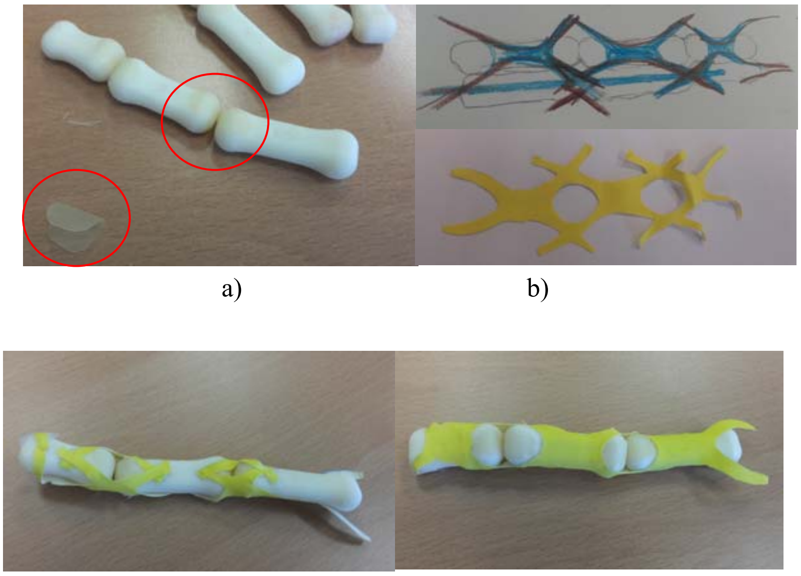
Fig. 6. a) Example of the extensor tendon. b) Example of the flexor tendon. c) Intrinsic muscle modeling. d) Example of the palmar tendon connection

Once all elements are designed they are printed with a 3D printer with different resistance materials. The phalanges and the metacarpal bones as well as the carpal and principal support are printed in ABS hard material, when the tendons and muscles are printed with elastic silicone material, described in the Table 3.

Table 3. Printing material properties.

Abbreviation	*Silicone*	*ABS*
Hardness	40	R105
Tensile strength (psi)	850	6,100
Tear strength (ppi)	125	75400
Density g/cm3	1,07	0,25
Color	Translucent	Beige

Between each phalange, a rubber pad has been inserted in order to avoid the friction, see Figure 7 a). Each pad is designed individually for each connection surface of the robotic hand phalanges. The Figure 7 b) describes the sketches and the developed from silicone fibrous sheath over flexor tendon sheaths.



a) b)

c) d)

Fig. 7. Silicone elements of the human robotic hand. a) The silicone pad example, b) the silicone fibrous sheath, c) example of the adjustments of the fibrous sheath in the palmar side, and d) represent the adjustment of the fibrous sheath over flexor tendon sheaths in the dorsal side of the hand.

The phalanges are covered with silicone glove.

The grasping is controlled by the Arduino Nano electronics and the pressure sensors placed in the distal phalanges, see Figure 8.

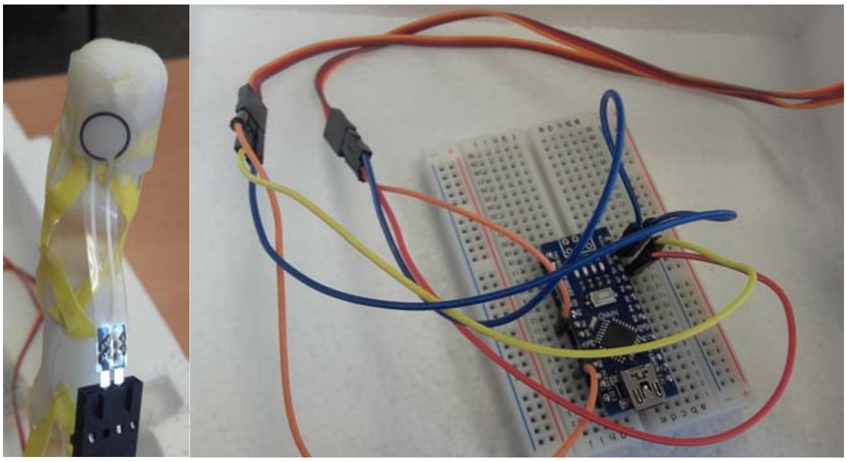


Fig. 8. A) Pressure sensor inserted in each distal phalanges. b) Electronic board.

4 Conclussions

The paper describe the design and development of an intelligent mechanical hand prosthesis able to realize the grasping and extension of the fingers as well as taking objects due to the pressure sensors. Based on the human hand anthropometry, the presented robotic hand is an adaptable to the user requirements. The phalanges and carpal bones have been carefully measured and designed in order to be able to adapt to different sizes. All elements of the prosthesis as pads between phalanges, the tendons, ligaments and bones have been designed and integrated one by one. The control system consist of an Arduino nano board, DC motors, motor controller and the muscle sensor system.

The work is presented in the experimental prototype. In the future, the work will be improved with temperature sensors, improvement of the design of the adjustable housing to the arm, as well as testing and validation in real environment.

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