Development of a biomechanical orthotic device

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***Abstract* — The proposed work treat about the analysis and development of an orthotic device for people suffering Radian Nerve Palsy known as wrist drop. This disability impairs the correct functionality of the human wrist, shirking the fingers. For the development of the device the main anthropometric measurements has been done as well as the wrist anatomy has been studied in order to develop a more adaptive and identic device. The device design is based on the ergonomic design of the products, and user requirements. One DC actuator realizes the extension of the wrist, through a simple mobile application. Silicone and ABS materials were used for the development of the orthotic device. The experimental results of the extension function show that the device is able to extend the human wrist in a natural way.**

***Index Terms* — orthotic device, development, actuators, ergonomic design**

I. INTRODUCTION

The human body is one of the most complex mechanisms up to date. From electronic and mechanic point of view, the human body is reproducible, with the adequate and advanced technology.

From the prehistory, over 5000 years B. C., Egyptians used prosthetic and orthotic devices. The first prosthetics was discovered in an Egyptian mummy. The aim of the development of such devices was to reinforce the bone structure or helping osseous tears. First orthotic and prosthesis devices were made from fiber, wood and/or leather.

About 300 B.C. the prosthetic limbs were made from bronze and iron.

The outhouses provide effective rehabilitation of the treatment of injuries. Numerous research studied demonstrated a success rate is between 50% and 90%.

Actual dynamic orthotic devices are aimed to assist the people with different disabilities in everyday life as for rehabilitation [1]. Due to the orthotic devices people can have a more comfortable life.

People with muscular diseases or Radial Nerve Palsy, are unable to control wrist movements as grasp or extend the fingers. Active orthotic devices are able to control the joints of the device when the passives ones are just simple mechanical devices. The active orthotic devices such for upper limbs as for lower limbs are designed to realize the movement more naturally and efficiently. With the increasing the development of new technologies, the orthotic devices is every time more sophisticated that are used for rehabilitation, and as assistance and therapy [2], [3], [4], [5]. Usually, orthotic devices used for therapy are not portable. Nerveless, there are devices for rehabilitation purposes after stroke more sophisticated and portable [6]. The improvements made in the last decade are focused o n the control bandwidth [7] and workspace.

The hand orthotic devices are classified by using various criteria: Degrees Of Freedom (DOF) [8], [9]. Intention Sensing and Control Method (ISCM), and Actuator Time (AT). Also the devices can be classified by their approaches as: single phalanx orthotic devices and multi-phalanx orthotic devices. The single-phalanx orthotic devices are able to control one single part of the hand, when the multi-phalanx orthotic devices are able to control each phalanx of the hand. The multi-phalanx orthotic devices/hand exoskeleton are inspirited into the human hand [10].

Enriquez describes the development of dynamic orthotic device for rehabilitation for people suffered Cerebral Vascular Accidents (CVA) that affects over 3,5 million people. The device they purpose have one freedom degree in the Phalangeal metacarpal articulation for each one of the fingers and one freedom degree in the distal inter phalangeal articulation.

Recent developments on human hand orthotic devices began more sophisticated and portable [11], [12], [13], [14].

In this work, we focus on the research and development of an active orthotic device that might allow people with lost hand mobility due to the Radian Nerve Palsy or known as wrist drop, to move their fingers and hand.

The posterior interosseous nerve that is a branch of the radial nerve supplies the extensor muscle of the forearm. When this nerve is affected or is not working, as they should be, then occur the wrist drop.

The work purposes the improvement of the device design by using soft materials as polymers and adaptive ergonomic design. The improvements applied to the device improve user quality of life and make the movement more naturally. As the purpose of the system is for straighten the human hand and fingers, the device does not cover the human palm.

II. HUMAN ANATOMY

The human hand is a complex anatomic structure. Its function consists as a rigid support for the muscle and tendons, and movement realization. The human upper limb consists of the upper-arm, forearm and hand or wrist. The hand, thumb and the fingers work intensively and repeated.

The wrist joins are represented in the Figure 1. The wrist bones can be structured into three groups: the fingers, composed by the proximal, media and distal phalanges; the carpus bones and metacarpal bones.

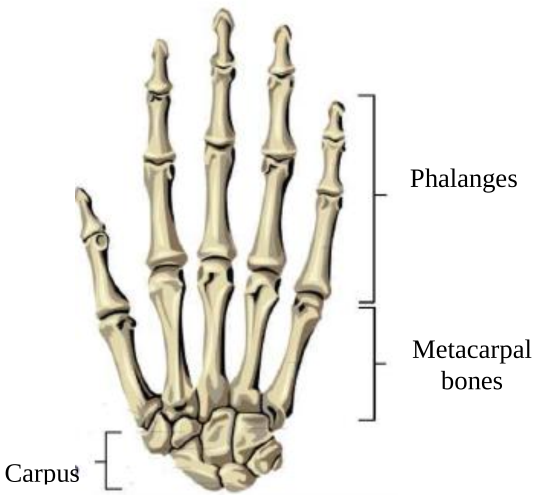
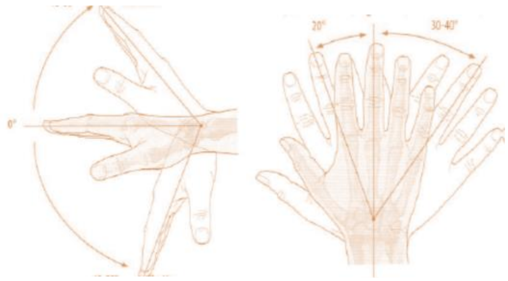


Figure 1. Wrist anatomic structure

The wrist contains the radiocarpal joint, the intercarpal joins and carpometacarpal joins. Generally, the wrist join have two Degrees Of Freedom (DOF). One DOF is the extension and flexion and one DOF for ulnar and radial deviation.

Regarding to the axis of the wrist movement from the Figure 2, can be observed that the axes pass through the carpal bones. The carpal bones have more small movements around instantaneous centers. These movements have various centers of rotations. Although the movements are so small, that are ignored and is considered that the wrist have just two DOF.



a) b)

Figure 2. The wrist Degree Of Freedom. a) DOF of flexion/extension, b) DOF of ulnar deviation and radial deviation.

The wrist extension/flexion movements are generated through a series of joins between the proximal, medial and distal phalanges, the metacarpal bones and three articulations (the metacarpal phalange, proximal interphalangeal and distal interphalangeal).

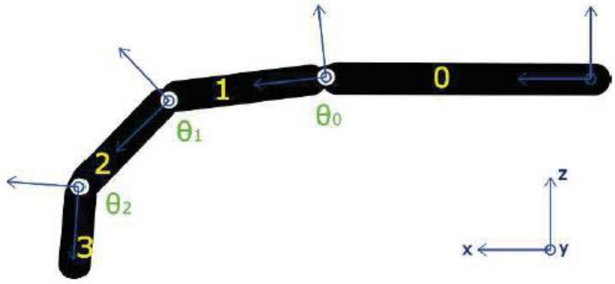


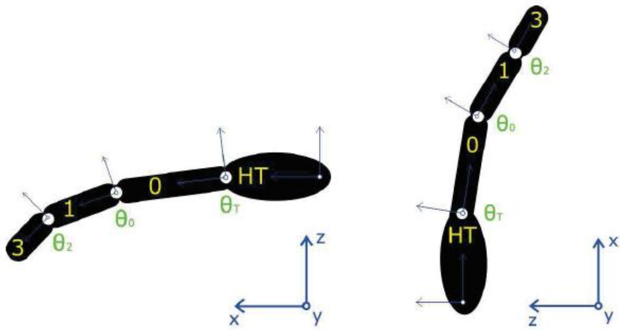
Figure 3. The wrist extension and flexion.

The rotation through transversal axis generates the movement of the flexion/extension in each articulation or joins, see the TABLE 1.

TABLE I. THE WRIST EXTENSION/FLEXION MOVEMENTS

Element	Description	Abr.	Degree	
			flexion	extension
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

The PIPJ is different from the MPJ. The MPJ is a condyloid articulation and have 3DOF, when PIPA have the structure of a simple hinge that have a bicondylar anatomy. The MPJ allow the radial and ulnar deviation and rotation. Due to “cam effect” of the aspherical metacarpal head, the collateral ligaments become tight in the MPA. This allows little abduction or adduction of the fingers during grasp.



a) *b)*

Figure 4. Thumb movements. a) Represents the flexion/extension and b) represent the adduction/abduction movements.

The thumb have different characteristic than all fingers. The MPJ have two DOF as in other fingers, the flexion/extension and adduction/abduction and two DOF in the zone of the metacarpal and the trapezoid bone that realize the flexion/extension and addiction/abduction movements.

The maximum flexion/extension and adduction and abduction on the thumb [15] are represented in the TABLE 2.

TABLE II. THE THUMB EXTENSION/FLEXION AND ADDUCTION/ABDUCTION MOVEMENTS

Nº	Description	Abr.	Degree			
			flexion	extension	adduction	abduction
0	Metacarpal	MET	-	-	-	-
1	Proximal phalanxes	PP	-	-	-	-
3	Distal Phalanxes	DP	-	-	-	-
Θ_0	Interphalangeal Join	IPJ	90	45	-	-
Θ_1	Metatarsophalangeal Join	MCPJ	70	15	-	-
Θ_2	Carpometacarpal Join	CMCJ	71	38	71	20

III. ORTHOTIC DESIGN

Materials and components

An Arduino Uno, an Arduino IDE, one Microdrive, Adafruit Motor-Shield V1 electronics, a Bluetooth HC-06 and a Smartphone, compose the core electronics. The software under running the orthotic device is Android Studio and Android OS, C/C++.

The Arduino Uno with a microcontroller AVR with 8 Bits is able to realize the logic process of the device as well as to control the periphery electronics. Through the USB connector the Arduino Uno is connected to the Computer. The Arduino IDE (Integrated Development Environment) is used for the microcontroller process. The Bluetooth HC-06 module is used for the communication between the Smartphone with the orthotic device. The Microdrive is a small 5V DC motor. The Adafruit Motor-Shield V1 controller is used to control the actuator during the device process. The Android software was selected in order to create the mobile application for orthotic device control.

The orthotic device has been designed with Autodesk Inventor tool and printed with a 3D printing machine.

Development process

Before starting designing the orthotic device, the anthropometric measurements of the hand have been measured.

The orthotic device design is based on the ergonomic principle of the product design. Those involve the end user requirements, functionality and esthetic design. The end user requirements are based especially on the anthropomorphic measurements (See Figure 5), which are carefully analyzed and processed in order to develop the most adjusted orthotic device. Due to the importance of the development of a portable device, the expectations are to be lightweight, adjustable and confortable, secure and easy to use.

Likewise, in the orthotic device design, apart of the anthropometric measurements of the user hand, the biomechanical and physiological aspects have been analyzed.

All measurements are not sufficient if on the design are not taken into consideration the tactile feeling of the device. From this point of view, the characteristic of the applied materials plays an important role on the design. The materials applied on the orthotic device may be hard enough to be withstand the pressure and adjustment of the electronic and mechanical elements; soft on the inside so as not be annoying to the user as well as to easy grasp the hand tissue; elastic to fit the shape of the hand.

Figure 5. Anthropometric measurements

The novel design features, ensures the adjustment and adaptation to different hand sizes, as well as the easy placement and remove.

From climatic point of view, the orthotic device should be water resistant as well as having a temperature range wide enough to withstand heat and cold wind, etc.

Another aspect of the ergonomic accessible design of the orthotic devise consists on the ventilation. For that, the device design has the honeycomb aspect.

TABLE III. MATERIAL PROPERTIES

Abr.	Material properties	
	Silicone	ABS
Hardness	40	R105
Tensile strength (psi)	850	6,100
Tear strength (ppi)	125	7540
Density g/cm3	1,07	0,25
Color	Translucent	White

Each part of the orthotic device has been fabricated with a Three-Dimensional (3D) printer.

The orthotic device is distributed into 4 parts: the processing unit, the actuation unit the wrist unit and fingers units.

The processing unit composed by the Arduino UNO and the HC-06 Module is introduced into a flexible box.

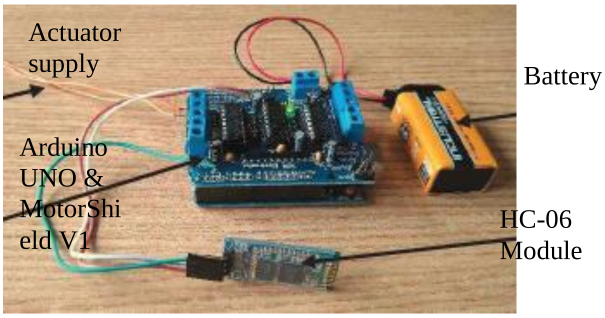


Figure 6. Processing unit of the orthotic device.

The used battery is a rechargeable battery of 5V and 5600 mAh is used for the electronics and one battery of 9V is used for the motor. The battery working time is as minimum 6 hours in a continuous working.

The processing unit is controlled by an Android based smartphone through a simple interactive interface.

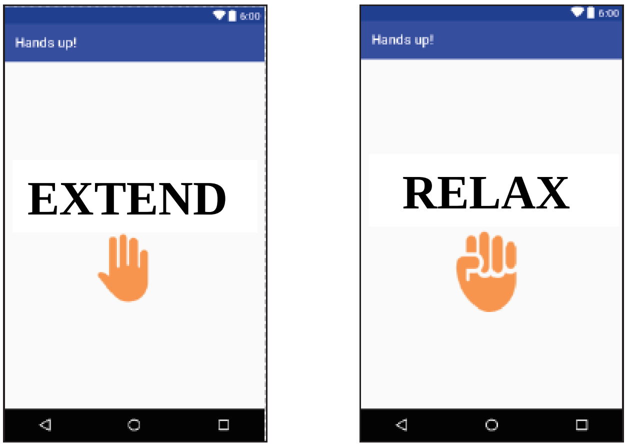


Figure 7. User interface of the mobile control application of the orthotic device.

"Extend" and "relax" are the two device functions. The extend function is in charge to extend the wrist and fingers, when "relax" function is in charge to leave the actuators OFF. When "relax" function is selected, the user can easily to move the wrist, realizing all activities as moving fingers and grasping. When the "extend" function is selected, the actuators start and smoothly the wrist and the fingers of the user.

The Actuators unit is designed to fit one actuator DC motor of 5V and two pulleys. The motor realizes the "extend" function for the whole wrist. Pushing and pulling the wire, the actuator realizes the extension/flexion function.

The actuation unit consists of several mountable elements see Figure 8. Each element has been printed in ABS material.

The inside of the actuator holder unit contains a silicone surface. The silicon surface provides a more secure and fine grip with the skin. Two Velcro strips fix the support to the hand.

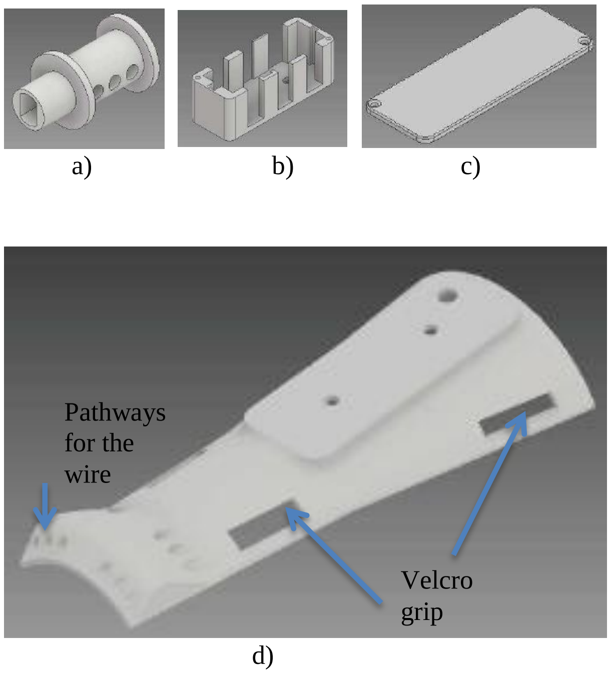


Figure 8. Actuator support of the orthotic device. A) Represent the pulley designed for the device adapted to the selected actuator; b) represent the actuator box and c) represent the upper actuator box top; d) represent the support of the actuation unit.

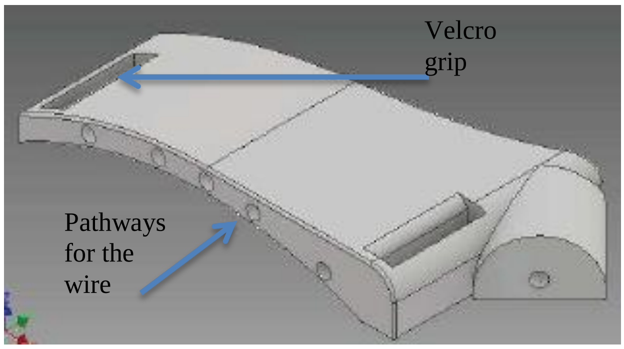


Figure 9. The dorsal are of the hand element.

The wrist part of the orthotic device is composed by the element for the dorsal area of the hand, see Figure 9.

Through small channels pass the wires from the actuators to the fingers elements. The support have wire small channels for the five phalanges and one for the extend function of the metacarpal zone.

Phalanges elements consist by two elements for four

fingers and one element for the thumb, See Figure 10.
The actual orthotic device is designed to extend the human wrist for patients with lost hand mobility due to the Radian Nerve Palsy, known as wrist drop.

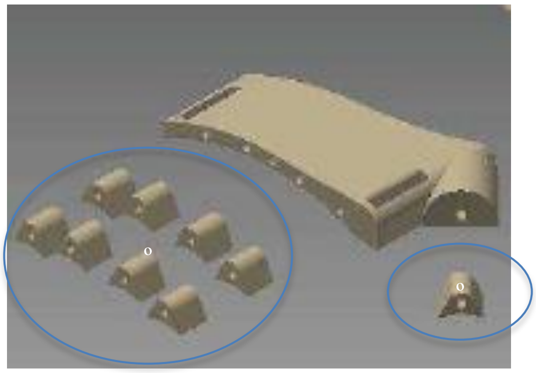


Figure 10. Phalangeal elements of the orthotic device

In the Figure 11 is presented the orthotic device.

Figure 11. The orthotic device

IV. CONCLUSION

The present work treat about the design and development of a orthotic device for people suffering Radian Nerve Palsy, known as wrist drop. The development of the device has been analyzed and implemented the esthetic and ergonomic aspects of the product design in order to adapt the device to the user requirements and functionality. The functional elements consist by applying a DC actuator of 5V, and Arduino UNO, Adafruit Motor-Shield V1 electronics, a Bluetooth HC-06 and a Smartphone. The software under running the orthotic device is Android Studio and Android OS, C/C++. The mechanical performances of the orthotic device were analyzed through extension experiments. The results showed that the orthotic device is able to extend the hand softly and carefully. The main objectives of the user requirements that include being lightweight, compact, ergonomic has been successfully reached. Future work on the project includes improving the electronic equipment, making them more compact and wearable, to improve the device design.

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