USING THE PLANAR 3-RRR PARALLEL MANIPULATOR FOR REHABILITATION OF HUMAN HAND

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Abstract. *This paper presents the 3-RRR parallel manipulator used to the rehabilitation of the fingers and wrist of the human hand, which has to justify the large amount of people who suffered any type of brain injury and/or accidents that limit the movements of the hand. This structure should allow the achievement of movement rehabilitation/ recovery of the fingers and wrist according to the kinesiology of the hand. So first robotic structures applied to rehabilitation of the hand and kinesiology/size of the finger and wrist are presented. Then the mathematical model of the finger and your workspace are presented. Following the proposed structure is described in this paper. Finally graphic simulations and experimental tests are presented showing the feasibility of applying the robotic structure proposal.*

Keywords: *human hand, rehabilitation, robotic, control system.*

1. INTRODUCTION

One of the robotics applications in medicine is the development of devices to assist in the rehabilitation of the human hand, because sensory disabilities after a stroke change the perception of touch, pressure, tweezers, shape, position, pain and more. Devices rehabilitation for upper limbs had a major breakthrough in recent years, but the development of these that faithfully reproduces the movements of the human hand is a complex task due to the fact of the human hand is composed of twenty-seven bones, seventeen joints, nineteen muscles and nerve endings (Silva, 2011).

The objective of rehabilitation of the upper limbs through devices, is not substitute health professionals, but assists in the tasks of rehabilitation and maximizes residual function of a patient who was submitted to a surgery or had an injury or illness on the hand.

Thus, the health professional performs the movement of the finger coupled to the equipment and then these will be reproduced by the equipment in a certain amount of cycles. The data of physiotherapy of the patient will be stored allowing the quantification of this improvement. The strength and muscular resistance should be increased gradually. The patient needs to have almost full range of motion and be relatively painlessly before starting a strengthening program. The manual resistance exercises are important in the initial strengthening. Gradual increases in the number of repetitions of the exercise increase resistance to fatigue, similarly slow increases in resistance can increase strength. The patient can perform activities of daily living or functional special activities, gradually expanding the time spent on them, however, the activity or exercise should not cause pain, unusual muscle discomfort or signs of overuse (Delisa and Gans, 2000). Thus, robotic equipment for rehabilitation can help improve these parameters.

This paper proposes the use of a 3-RRR parallel robotic structure aiming to provide the fingers rehabilitation, since these movements are essential for the execution of daily tasks. This structure will perform the main movements needed for the recovery of the fingers.

In this way, first this paper presented the robotics structures applied to rehabilitation of the hand. After the hand kinesiology and the mathematical model of the finger and your workspace are presented. In function of the finger workspace was projected the 3-RRR parallel manipulator proposed. Finally graphic simulations and experimental tests in an anthropometric and anthropomorphic wooden puppet hand showed the feasibility of applying this structure in hand rehabilitation.

1.1 Robotics structures applied to hand rehabilitation

The existing devices for rehabilitation of the human hand can be classified into: serial robotic structures; articulated mechanisms; parallel robotic structures and parallel structures actuated by cables (Gonçalves and Carvalho, 2012). There are also "wearable" robotic structures that from the drive cables can promote the movement of the fingers. Some devices for hand rehabilitation are described next.

HWARD (Hand Wrist Assistive Rehabilitation Device) is a robotic device with three degrees of freedom, limited only flexion, extension of the fingers and wrist, which operates through pneumatic actuators that make all the control of hand movements. This device also includes graphical interface, where the patient operates a virtual hand to simulate the movements of grasping objects in a virtual environment (Ho et al., 2011).

Another structure used for rehabilitation has been proposed by (Chen et al, 2009) that makes movements of flexion and extension. The patient, when using the equipment, have to sit and your arm positioned in a horizontal position, with the wrist angle at 0 °. Each finger of the hand is set in an adapter that has one linear actuator and force sensor. The data are shown on a screen and then archived by the robot system (Chen et al., 2009).

The Haptic Knob is a parallel robotic structure with a compact terminal element that facilitates the use in rehabilitation centers or in the patient's own home. Individuals who use, control movement of the robot and interact with the forces of the structure adapted to your level of commitment. To increase the level of motivation, games are presented with increased level of difficulty in a simple visual interactive feedback. The Haptic Knob is a robotic system of two degrees of freedom, one linear degree of freedom to open and close the hand and another degree of freedom for rotation, pronation and supination of the forearm in relation to the axis through the forearm (Lambercy et al., 2009).

The AMADEO is a device that performs flexion and extension of the fingers through a graphical interface. The flexion causes the target balloon move up and down and during extension patients are instructed to avoid contact with the ground or other balloons. This device has been used in patients where the performance was monitored by health professionals, and the task was gradually increased throughout the course of training (Stein et al., 2011).

Handcare is a rehabilitation device actuated by cables, in which each finger is attached to a part connected to cables that allows control of force and linear displacement predominantly. The device is based on biomechanical measurements which may assist in opening and closing movements of the hand and can be adapted to accommodate various shapes and sizes of fingers (Dovat, 2008).

For rehabilitation may be used devices with "haptic" interface, as proposed in (Hioki and Kawasaki, 2010). The mechanical structure is formed by five serial robotic structures that mimic human fingers. The movements of the fingers are obtained by electromyography and after these movements are repeated by the equipment.

In the hand rehabilitation can be used parallel robotic structures, as proposed in (Daud et al., 2010). This work uses the mechanism 5R which is a five-bar mechanism with two degrees of freedom. This mechanism is designed to cover the reachable workspace of the human finger.

Other devices for hand rehabilitation use gloves that wear the patient's hand called wearable robotic structures. These mechanisms generally use cables that are triggered allowing the movement of the fingers (In et al., 2011).

2. HUMAN HAND

The hand movements can be divided in (Silva, 2011; Kapandji, 2000):

a) Flexion: indicates an angular range towards closing the hand;

b) Extension: indicates an angular variation in the opposite direction of the closing of the hand. The extension of a limb or part of it beyond the anatomical position is called hyperextension;

c) Abduction: movement away of the fingers relative to third finger (middle) in a neutral position. The third finger abducts medially or laterally in relation to the neutral position;

d) Adduction: movement of rapprochement of the fingers apart or movement of other fingers toward the neutral position of the third finger. The finger abducted, medial or lateral is adducted back to the neutral position;

e) Opposition: movement by which the pulp of first finger (thumb) is approximated to the another finger pulp. The repositioning describes the return movement of the first finger of the position of opposition to its anatomical position.

One can observe these movements in Fig. 1.

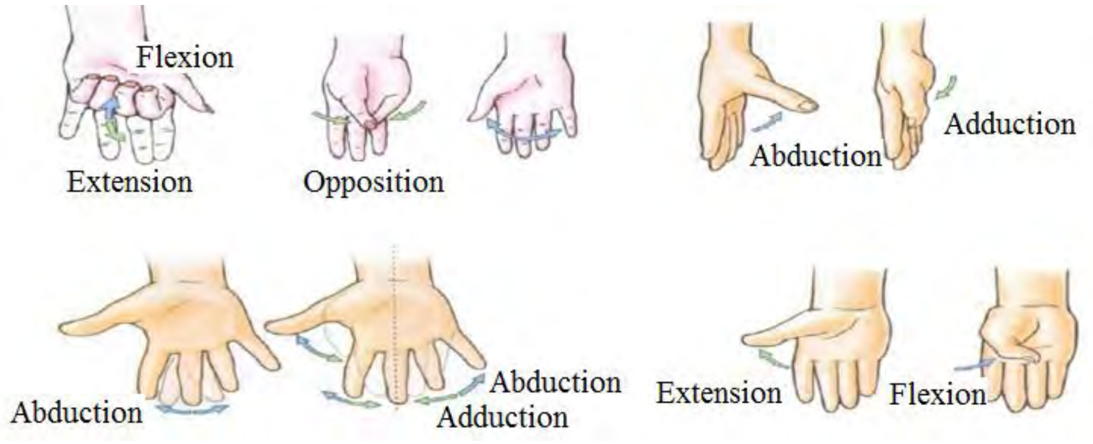


Figure 1. The fingers movements (Moore and Dalley, 2007).

In relation to range of fingers motion, the measures of them, and the force required for execution of tasks performed by the hands, the bibliographies are diverse, but most of them are not complete in their individual analyzes (Silva, 2011).

The human finger has four degrees of freedom and consists of three joints: metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP). Each joint has one degree of freedom to perform flexion / extension, and articulation MCP has one more degree of freedom to perform movements of abduction / adduction (lateral movement of the finger).

Thus, a finger can be viewed as a serial robotic structure where the base can be regarded as the hand and terminal element, the fingertip, according to the scheme of Fig. 2.

The schematic positions of the finger joints and proximal phalanges (Lp), medium (Lm) and distal (Ld) are shown in Fig. 2.

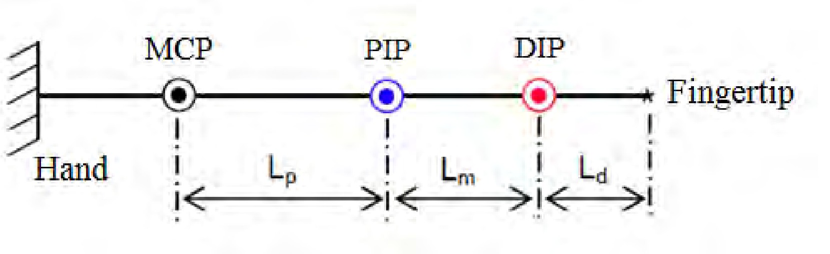


Figure 2. Schematic positions of the finger generic phalanges joints (Silva, 2011).

In this way, the analysis of finger, except the thumb, is similar, being selected the index finger for the definition and modeling of the structure of the robotic device.

For the modeling of the proposed device, the parameters of force were based on the work (Fu et al, 2008) and the amplitudes of movement in (Kapandji, 2000), (Floyd and Thompson, 2002) and (Levangie and Norkin, 2005), as shown in Tab. 1. The dimensions of the phalanges were obtained in (Wu et al, 2009), shown in Tab. 2.

Table 1. Range of motion and force of motion for flexion.

		Joint	*MCP*	*PIP*	*DIP*
Forefinger	**Motion (degrees)**	Flexion	0 – 90	0 – 110	0 – 80
		Hyperextension	0 – 40	nonexistent	0 – 5
	Driving Force (N)	Maxim	35.0	20.0	16.1
		Minimum	11.0	9.0	7.0
		Average	23.0	14.5	11.5

Table 2. Dimensions of the phalanges sections of the index finger in [mm].

Phalange	*Proximal*	*Average*	*Distal*
Length	43.4	25.3	17.0
Width	17.8	16.8	15.2
Thickeness	17.4	14.8	12.6

The external border of all points that the finger can reach with its tip defines your workspace. This space depends only on the lengths of the finger phalanges and the amplitudes of motion of each joint.

For determine the workspace of the finger analyzed, was considered in a plane, in other words, flexion and extension for the three joints. Figure 3 shows a schematic of a generic finger to establish the location of the finger tip, defined by point P, and the referential Cartesians associated with each joint. The axis MCP-X0 represents the finger in the anatomical position.

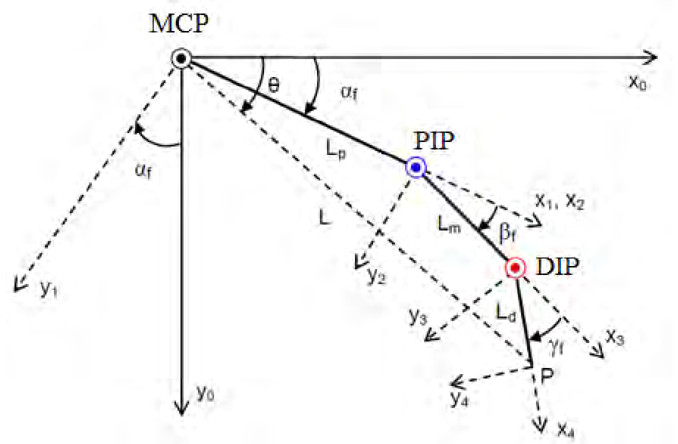


Figure 3. Generic finger flexion (Silva, 2011).

Using the homogenous transformation matrices (Tsai, 1999), can be obtained *x* and *y* coordinates relating to the finger tip, point P, from the metacarpophalangeal joint. The angles of each phalange are given by α_1, β_1 and γ_1 respectively.

$$x = L_p \cos(\alpha_1) + L_m \cos(\alpha_1 + \beta_1) + L_d \cos(\alpha_1 + \beta_1 + \gamma_1) \quad (1)$$

$$y = L_p \sin(\alpha_1) + L_m \sin(\alpha_1 + \beta_1) + L_d \sin(\alpha_1 + \beta_1 + \gamma_1) \quad (2)$$

Utilizing the data in Tab. 1 and Tab. 2 and Eq. (1) and Eq. (2) is obtained the finger workspace shown in Fig. 4.

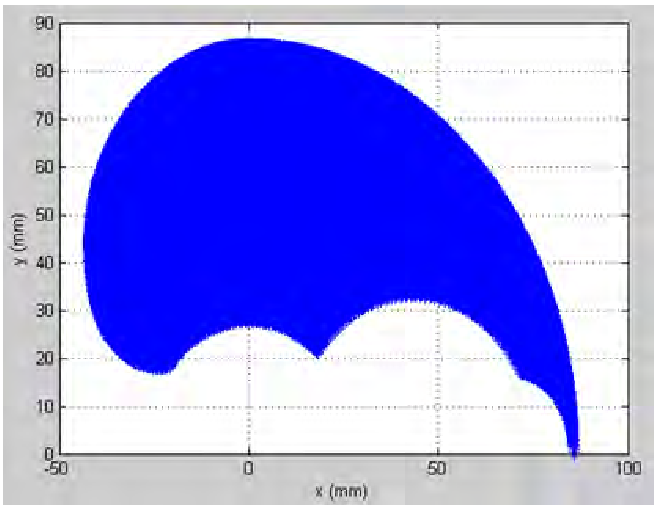


Figure 4. Index finger workspace.

3. THE PLANAR 3RRR PARALLEL MANIPULATOR FOR REHABILITATION OF THE HUMAN HAND

From various types of articulated mechanisms, their capacity of handling and transmission of efforts, taking into account the constraints and simplicity of assembly, in other words, few components, it was determined that each phalange will be moved using a planar 3-RRR robotic parallel manipulator, Fig. 5.

The structure of 3-RRR robotic parallel manipulator has three degrees of freedom allowing movement in the *xy* plane and a rotation around the *z* axis. The mathematical equation of this structure can be found in (Tsai, 1999).

Due to the workspace of the human finger, Fig. 4, were determined the dimensions of the robotic parallel structure 3-RRR avoiding the singularities loci.

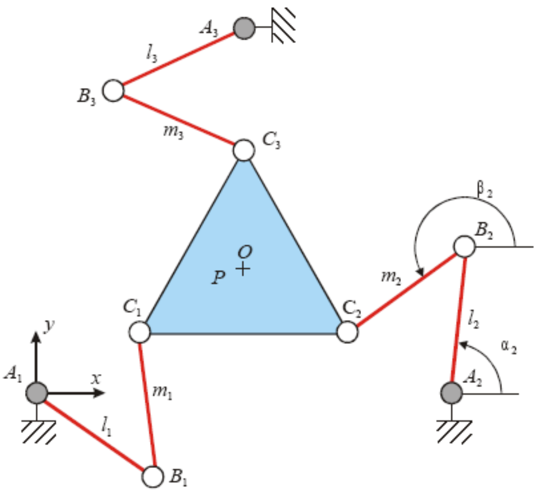


Figure 5. 3-RRR robotic parallel structure (Chablat and Wenger, 2004).

Simulations were conducted in which the workspace of the finger to be contemplated within the limits of movement of the robotic parallel structure 3-RRR, as Fig. 6.

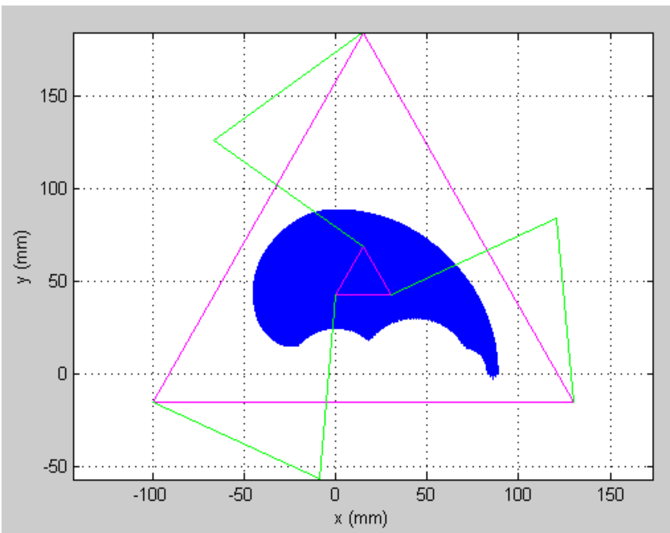


Figure 6. Workspace of human finger and the proposed 3-RRR robotic parallel manipulator.

Figure 7 shows the simulated structure.

The finger phalange of the patient will be fixed to the structure 3-RRR through a rod. Simulations were performed using three-dimensional graphics software SolidWorks® and could confirm the feasibility of proposed structure.

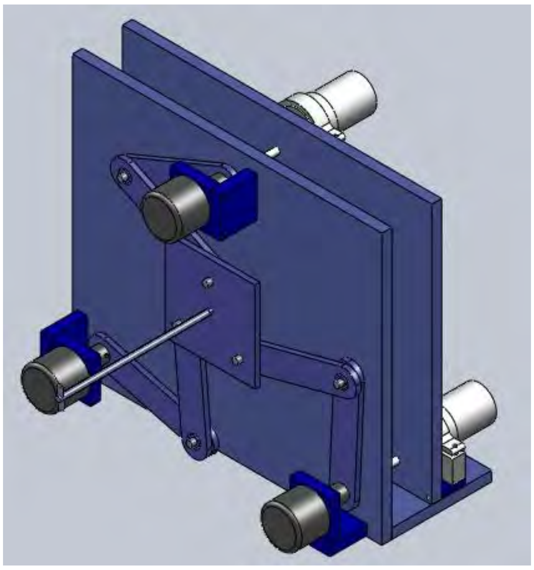
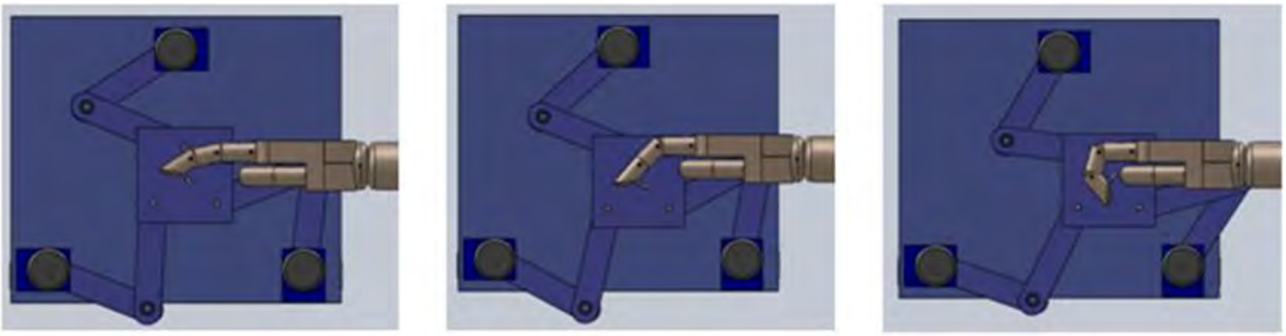


Figure 7. Simulated parallel structure 3-RRR.

Figure 8 shown the simulate sequence of finger flexion movements coupled to the proposed structure.

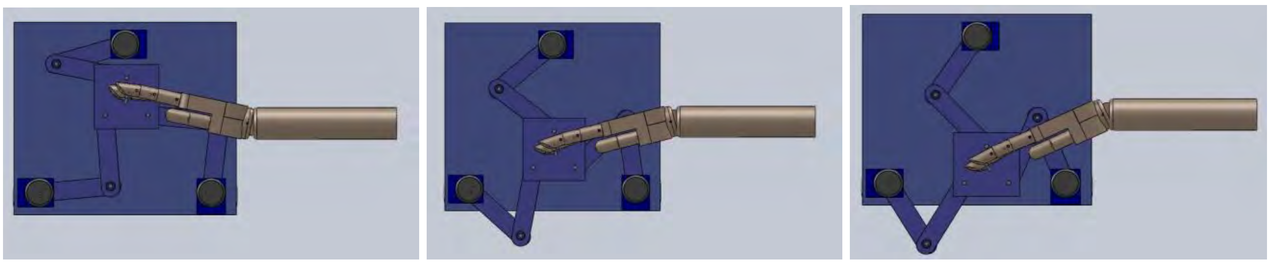


(a) (b) (c)

Figure 8. Flexing the index finger.

The structure proposed herein will permit individual movement of each phalange, for fixing other, or the coupled movement of all phalanges, Fig. 8.

This device can also be used for rehabilitation of the wrist, since the same movements of flexion and extension are performed for the rehabilitation. The simulation of these movements is show in the Fig. 9.



(a) (b) (c)

Figure 9. (a) Wrist extension; (b-c) Wrist flexion.

4. CONTROL SYSTEM AND EXPERIMENTAL TESTS

This work aims to provide people with some difficulty to fingers movements obtaining this rehabilitation, since these movements are essential to the execution of daily tasks.

This proposed structure performs the principal movements necessary for the recovery of the fingers by means of a control system that is performed by a microcontroller BIOLOID ROBOTIS CM-5 that controls three servomotors

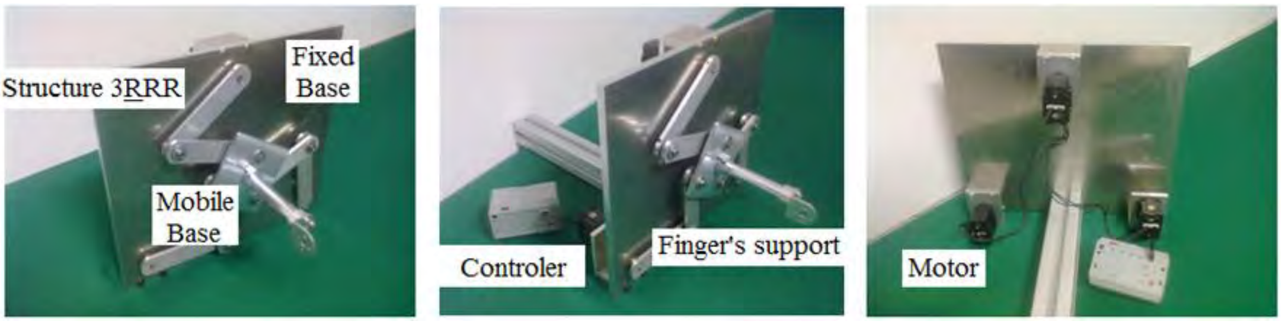
Dynamixel AX 12A. This microcontroller is designed to store and run programs to control structures that use servomotors Dynamixel AX series. It is based on Atmel Atmega128, and its features include four serial ports, programmable control buttons and status LEDs.

The series Dynamixel AX-12, Fig. 10 is an intelligent modular actuator that incorporates a reducer, a precision DC motor and control circuit with networking functionality. Despite its compact size, it can produce the torque and support the external forces necessary to the built prototype.

The purpose of the proposed device is to assist health professionals in rehabilitation exercises of the human hand and not replace them. Thus health professionals will put the patient finger or the hand and teach the movement for the structure. Thus, is sent to the microcontroller program, positions of the motors, whose data are stored for later repeated at a number of cycles, by the control of robotic parallel structure 3-RRR.

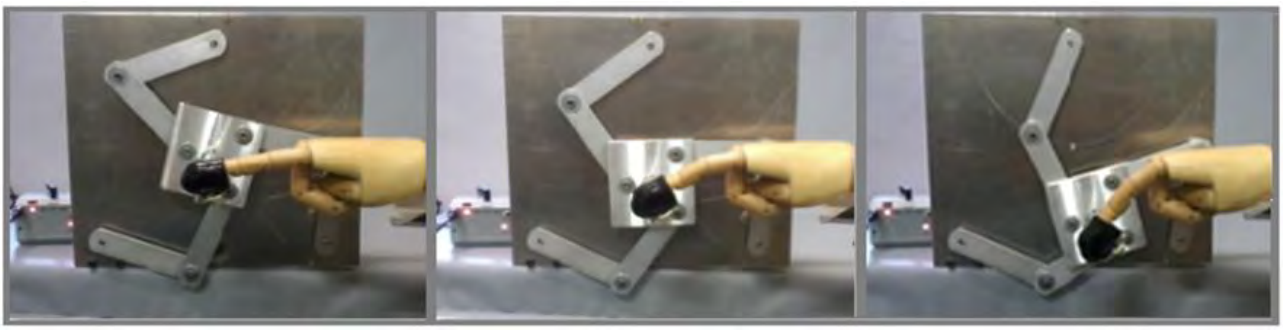
The Fig. 10 shows the built prototype 3-RRR structure together with the motors and the microcontroller used to the control system.

The Fig. 11 shows the finger coupled to structure and repeat the flexion teach movement. The experimental test was realized using a wooden puppet anthropometric hand.



(a) (b) (c)

Figure 10. Built prototype.



(a) (b) (c)

Figure 11. Finger flexion.

5. CONCLUSIONS

This paper presents a device that uses a planar robotic 3-RRR parallel manipulator to be applied in the rehabilitation of the human hand.

The proposed mechanism aims to provide the fingers rehabilitation, since these movements are essential to the execution of daily tasks.

The purpose of this structure is to assist health professionals in rehabilitation. This will guide the movements necessary for rehabilitation and the proposed structure will reproduce the movements.

This study was conducted taking into consideration the care not to further injure the patient fingers. A study was made of all the movements that fingers perform and movement type suitable for rehabilitation start, the degrees of freedom and the finger workspace.

This device allows the rehabilitation of each phalange separately considering other fixed, or finger rehabilitation with movements combined of the phalanges.

The proposed structure also allows the movements of the wrist rehabilitation.

From simulations and experimental tests, it was possible to demonstrate the applicability of this device.

The next steps involve the improvement of the robotic structure 3-RRR and testing in patients.

6. ACKNOWLEDGMENTS

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