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Prototype of a mechanical assistance device for the wrists' flexion-extension movement

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Abstract. Using CMU actuators, a Prototype of Mechanical Assistance Device for the Wrist's Flexion Movement (PMA) was developed and probed in a mechanical model, in order to be implemented in a future as a dynamic powered orthosis or as a rehabilitation assistant instrument. Two Mayor Actuators conformed by three CMU actuators arranged in a series configuration, allows to an artificial hand to be placed in four predefined positions: 0º, 20º, 40º and 60º. The synchronism and control of the actuators is achieved with the Programmable Control Module (PCM). It is capable to drive up to six CMU actuators, and possess two different modes of execution: a Manual mode and an Exercise mode. In the Manual Mode, the position of the hand responds directly to the commands of the keyboard of the front panel, and in the Exercise mode, the hand realizes a repetitive and programmed movement. The prototype was tested in 100 positions in the Manual Mode and for 225 works cycles in the Exercise Mode. The relative repetition error was less than 5% for both test. This prototype only consumes 4,15W, which makes it possible to be powered by small rechargeable batteries, allowing its use as a portable device.

1. Introduction

Nowadays exists pathologies such as hemiplexy and muscular dystrophy among others, that come up with the incapacity to control the limb's movement and the impossibility of realize forces. Usually, patients that suffer of these pathologies require a device that control and/or assist the movement mechanically. Even when there are some commercial passive dynamic orthoses [1],[2], that assist to the patient to realize forces and movements, these devices are not able to doing it in a continuous and controlled way. Even though there are some developed powered orthosis which are not commercially available and the ones that are in their prototype phase, all of them are actuated with pneumatic pistons and electro-actuator [3]-[5], which makes them bulky, rigid and noisy, producing a negative emotional impact to the patient.

Besides, there are some articular dysfunctions that results from trauma, illness or other causes that requires rehabilitation therapies, which involves the realization of movements and/or forces exercises. Generally, these exercises are realized under the supervision of a professional, which means that the session's time and frequency is limited. Although, exist automatic equipments that could assist in the rehabilitation therapy [6]-[10], these are too big and expensive, though they are only available in clinics and rehabilitation's room therapies.

Recently, the research team from the Laboratorio de Biomecánica DBI-UNT, have developed a planar actuator named Contractile Metallic Unit (CMU), using Niquel-Titanium (NiTi) wires [11], (patent pending [12]), whose electrical and mechanical characteristics are adequate to be employed in a mechanic assistance device: it is small, low weight, silent, low power consumption, flexible and can be coupled among them.

Based on the characteristics of the wrist's Flexo-Extension movement, two Mayor Actuator (MA) were designed using three CMU coupled in series. They have been arranged so that they work antagonistically on a wrist's Mechanical Model. The control of the movement is achieved with Programmable Control Module (PCM), which allows positioning the artificial hand in four predefined positions: 0º, 20º, 40º, 60º with respect to the direction of the longitudinal axis of the forearm. The hand's position can be carried out manually using the PCM's keyboard (Manual Mode), or automatically (Exercises Mode), setting certain associated parameters. These Modes of work pretend to simulate the behavior of a dynamic powered orthosis and/or an instrument for the assisted rehabilitation therapy, respectively.

2. Materials and Methods

2.1. Contractile Metallic Unit (CMU)

The CMU (figure 1), is a planar electromechanical actuator, capable of to stretch when it is put under the traction of a force, and to recover its original length when an adequate electric current is applied. Its characteristics are:

- Dimensions: 35mm x 10 mm x 5mm.
- Maximum pulling weight: 1600gr
- Maximum deformation recommended: 1mm
- Current needed to achieve a full contraction (at room temperature): 250mA
- Approximate electrical resistance: 13Ω.
- Power consumption: less than 0,8w
- Contraction time: 1s
- Relaxation time: 5s (can be reduced to 1,2s if an external cooling system is used).
- Flexibility
- Can be coupled with others CMU, in series or parallel disposition, when either more strength or displacement is needed, respectively.

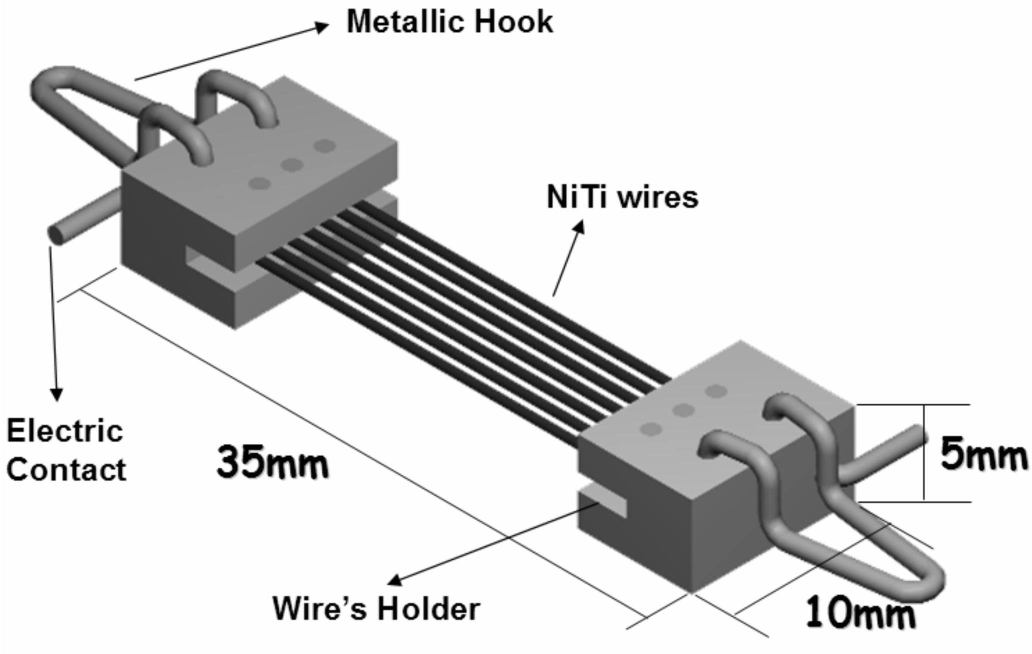

Figure1: CAD design of the CMU.

2.2. Wrist's Mechanical Model

The objective of the wrist's Mechanical Model is to simulate the wrist's Flexo-Extension movement. In order to achieve it, the hand's dimensions and weight, and the wrist's angular displacement for an average person of 1,70m tall and 70kg of weight, was considered [13][14]. The proposed model (figure 2), is composed basically by three elements:

- Aluminium Forearm: the CMU actuators are placed over it. Its dimensions are: 25cm x 5cm x 1cm.
- Mechanic Wrist: composed by two high density PVC pieces, a revolution joint, an angular resistive transducer and two holders made of steel.
- Artificial hand: made of silicon. It has the weight and the dimensions of an average person (350gr and 20cm from the tip of the large finger to the wrist).

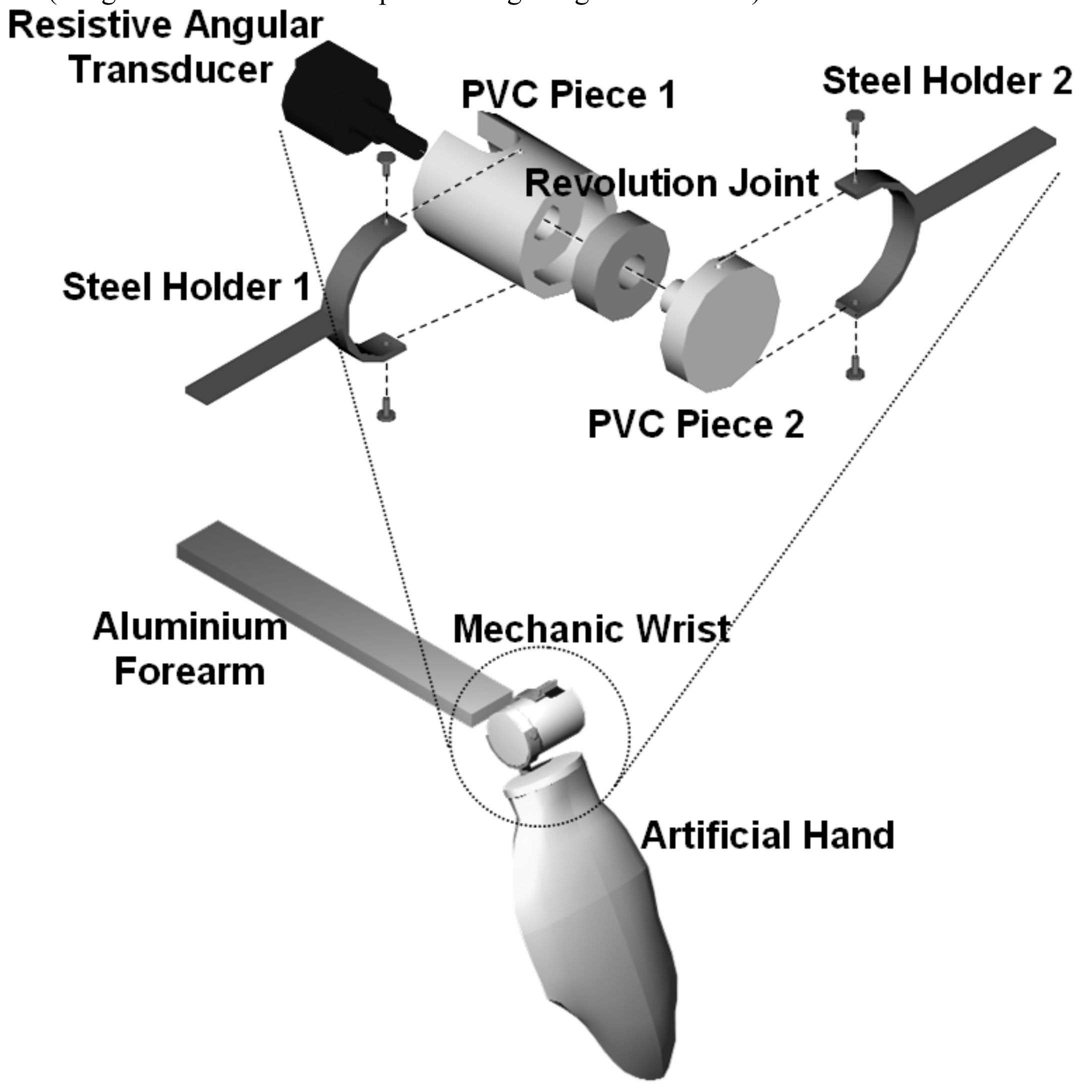

Figure 2: CAD design of the Mechanical Model.

Three CMU actuators arranged in an electrical-series and mechanical-parallel disposition form the Mayor Actuator (MA) (figure 3a). With its 105mm x 10mm x 5mm, it is capable to achieve 3mm maximum contraction with a maximum mechanical load of 1600gr, and a maximum consumption of 750mA (~3W). Each CMU is individually actuated. Thus 0, 1, 2, and 3mm contraction are possible, depending of the quantity of actuator activated simultaneously.

Two MA were used in order to give movement to the Mechanical Model, one of them was placed left side of the aluminum forearm and the other on the right side. This configuration makes them work in a manner that the contraction of a MA occurs during the relaxation of the other. The MAs are held to the forearm by guitars tuning pegs, which give them the appropriate initial pretension (figure 3.b). Because the maximum contraction produced by the MA is 3mm, a movable pulley was used to duplicate this linear displacement.

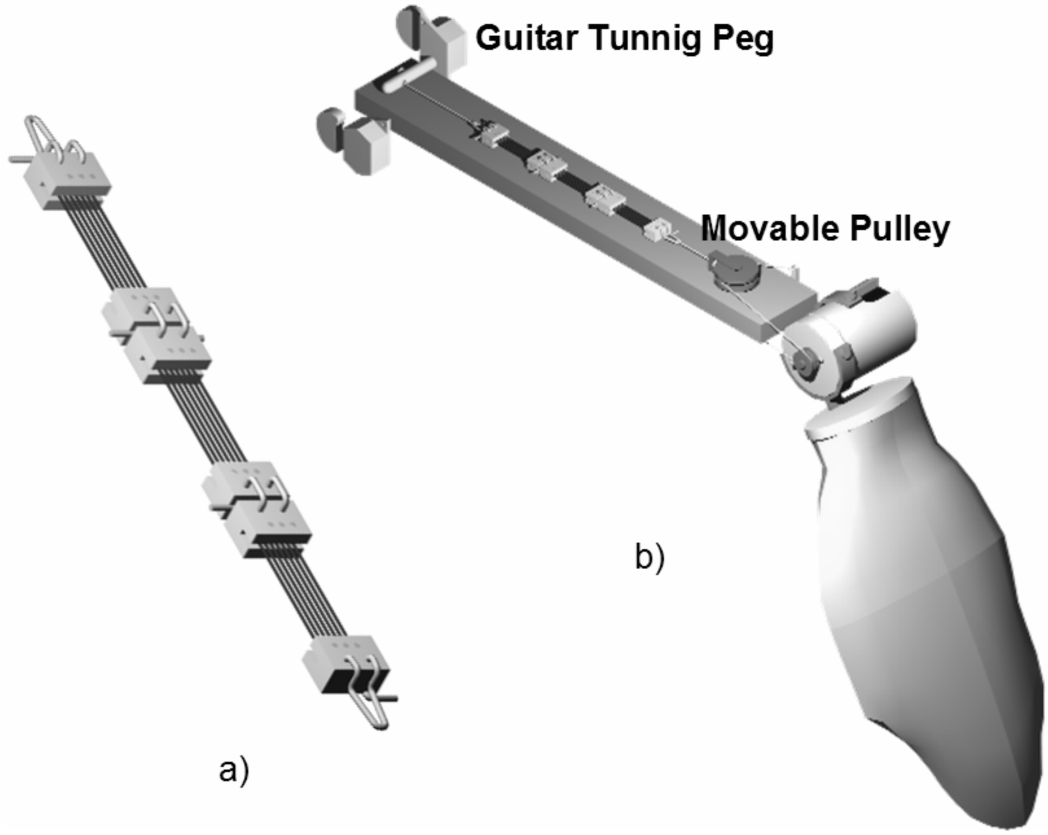

Figure 3: a)- CAD Design of the Mayor Actuator.b)- CAD design of the Prototype of Mechanical Assistant for the wrist's flexo-extension movement.

2.3. Programmable Control Module (PCM)

The control and synchronization of the actuators that form the PMA is achieved with the Programmable Control Module (PCM) (figure 4). Basically, it is composed by four well defined blocks (figure 5):

- Visual Interface: conformed by a four button keyboard (Up, Down, OK, Reset) and a LCD display.
- Control Block: a 8bit Freescale™ microcontroller (MC68HC908JL3), is the core of the PCM. The software that controls all the modules of the PCM is loaded in its internal 4KB Flash memory.
- Power Block: conformed by a variable power tension (0-30V, 3A) and six power HEXFET® IRFZ22 transistor. It is capable to drive up to six CMU.
- Input/Output Block:
  - ✓ DB9 Input: this connector is used in order to load the program from a PC.
  - ✓ Six tension output: the CMU actuators are connected here. Each one of them can deliver up to 30V – 3A.
  - ✓ Analogical input (0-5V): this input is connected to the internal 8bits ADC of the microcontroller, and can be used to achieve a feedback control.

✓ Excitation level: presents the tension delivered through the tension output and can be set using the front panel knob.

Figure 4: Photograph of the front panel of the Programmable Control Module (PCM).

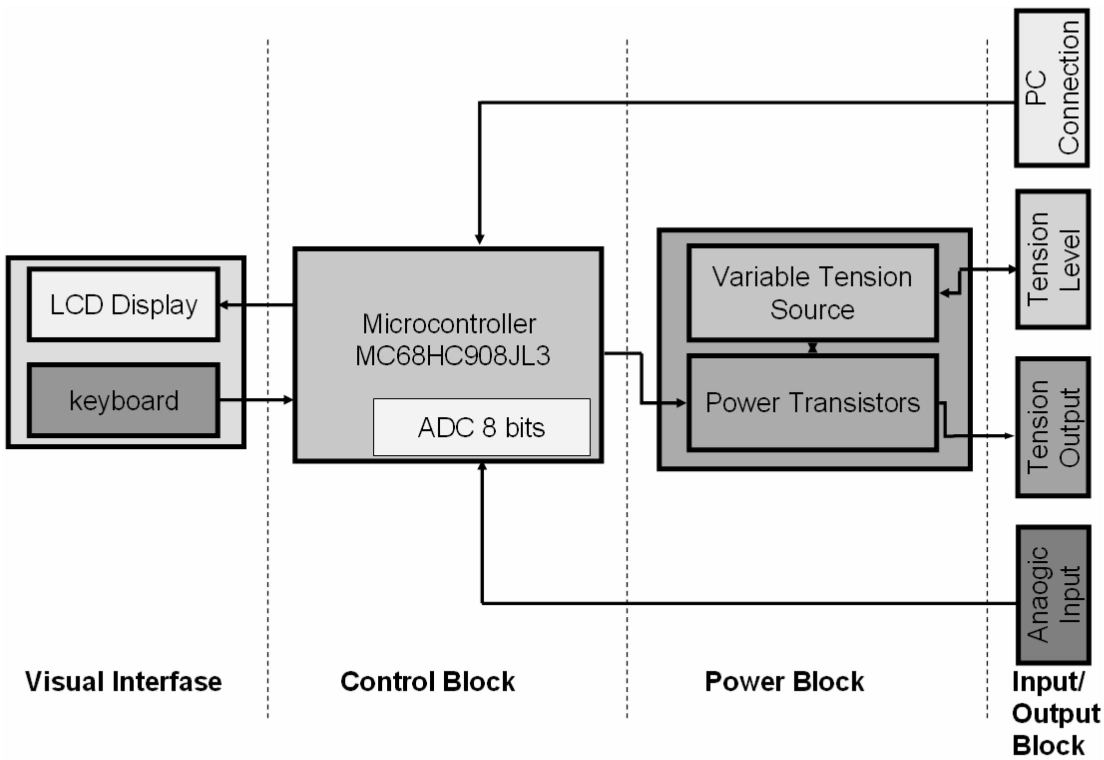

Figure 5: Schematic block diagram of the PMC.

2.4. Prototype of Mechanical Assistance Movement (PMA)
A 60º angular displacement is considered for the wrist's flexion-extension movement. It would allow the user to place the artificial hand in four predefined positions: 0º, 20º, 40º, 60º or rest (figure 6).

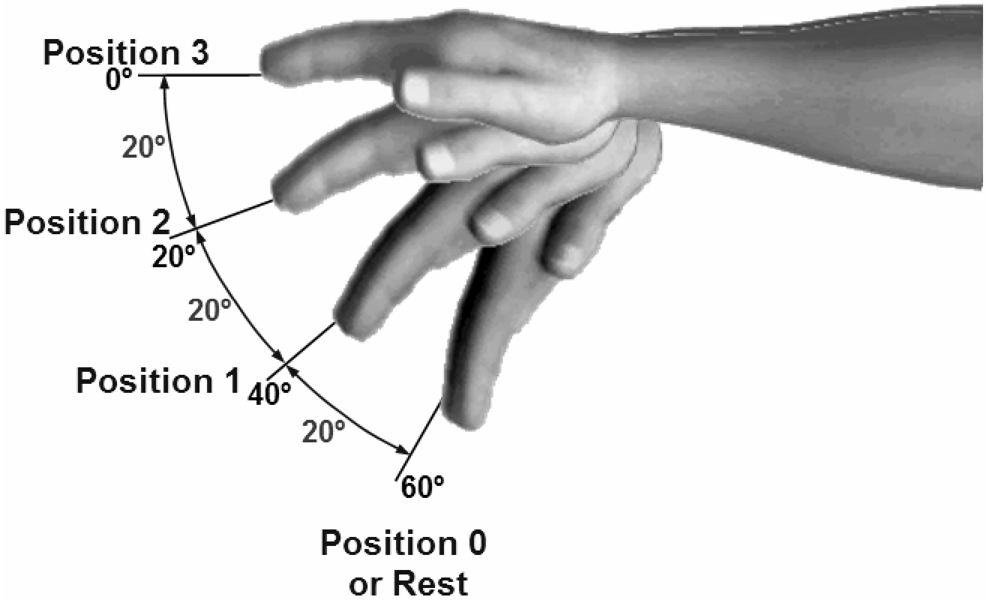

Figure 6: PMA movement description. Superior view.

2.5. Programmable Control Module(PCM) Implementation
The software resident in the PCM was developed in Assembler language and loaded in the microcontroller's Flash memory using the Codewarrior Development Studio for Freescale HC(S)08 Microcontroler v5.0. This software generates a sequence of screens denominated Interactive Menu (IM), (figure 7). This last one together with the keyboard and the LCD display conform an Interactive Visual Interfase (IVI).

The PCM has two modes of operation: Manual Mode and Exercise Mode.

The Manual Mode pretends to simulate the behaviour of a dynamic powered orthosis, in which the hand's position responds to the commands of the keyboard. The keys "Up" and "Down" allow to move the artificial hand through four prefixed positions 0º, 20º, 40º and 60º. It is considered as an action to all the answer of the PMA to a keyboard command. In the execution screen (P2), the hand's actual position and the amount of actions that were carried out are shown. The movement initiates in the rest position.

The Exercise Mode pretends to simulate the behaviour of an assistance rehabilitation instrument, in which the movement is programmed so that, it executes during an established time with a speed and determined intensity. The user must program the position (P): 0, 1, 2 or 3; and the Time of Action (T) in screen P3; these parameters are stored in the temporary RAM memory of the microcontroller. The movement leaves from Position 0 (60º) (figure 6), takes the hand to the programmed position P and returns to the starting point (60º). This cycle is referred to as an Action Cycle, and the time that it takes is referred to as Time of Action Cycle (T). This cycle is repeated until the user presses the OK button from the front panel, and the system returns to the initial screen P1. The time of transition between the intermediate positions depends on the time of action T and the programmed position P, this implies that the actuators that compose the MA are activated or deactivate every time "t=T/2P". In the screen of execution of this mode (P4), the programmed time, the actual hand's position and the amount of actions realized are shown.

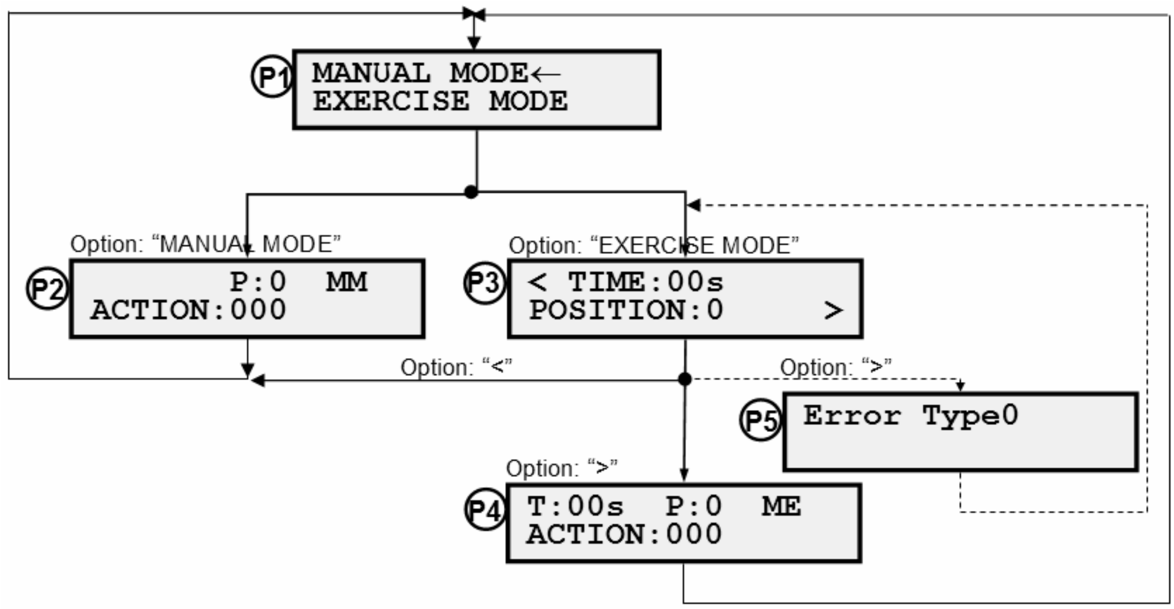

Figure 7: Schematic diagram of the screen sequences that conforms the Interactive Menu.

Because the contraction and relaxation velocities of the actuators are not equal (1s for complete contraction and 7s for complete relaxation), both MAs work in a antagonistic manner, and a delay of 200ms between the relaxation and contraction actions is set, in order to prevent any damage of them.

In order to guarantee an even wear away of the actuators, a sequence algorithm was developed, which uses a stack of turns of three levels. As a MA requires of greater contraction, more active actuators will be needed, therefore more levels of the stack will be used. When an actuator is deactivated, the stack is updated causing that the first turn moves to third, and all the levels move to the inferior immediate level.

All the actuators are activated using a pulse excitation at 10Hz with 80ms width.

2.6. Assembly and Test

The MM is placed so that the thumb of the artificial hand is aiming upwards, in this way the movement will be due only to the action of the actuators and not of external causes, such as its weight (figure 8). The actuators of the MA disposed upon the forearm, are connected in the three first output of the PCM, the actuators of the antagonistic MA are connected to the three remaining output.

In order to quantify the performance of the PMA, the following tests were carried out with the PCM:

- ✓ **Test in Manual Mode of execution**: the hand position is taken from rest to position 3, passing trough the intermediate positions, and then return to rest. The transitions are carried out every 5 seconds. This was repeated for 100 different positions.
- ✓ **Test in Exercise Mode**: using the, a repetitive movement is taken account. The parameters are set with the following values: P=3 and T=40s. This was repeated for 225 cycles of work.

To guarantee a current of 250mA during the tests in all the actuators, the level of tension in the outputs of the PCM is set to 4V. The variation of resistance of the angular transducer in the mechanical wrist is registered with a digital multimeter Wavetek® 38XR.

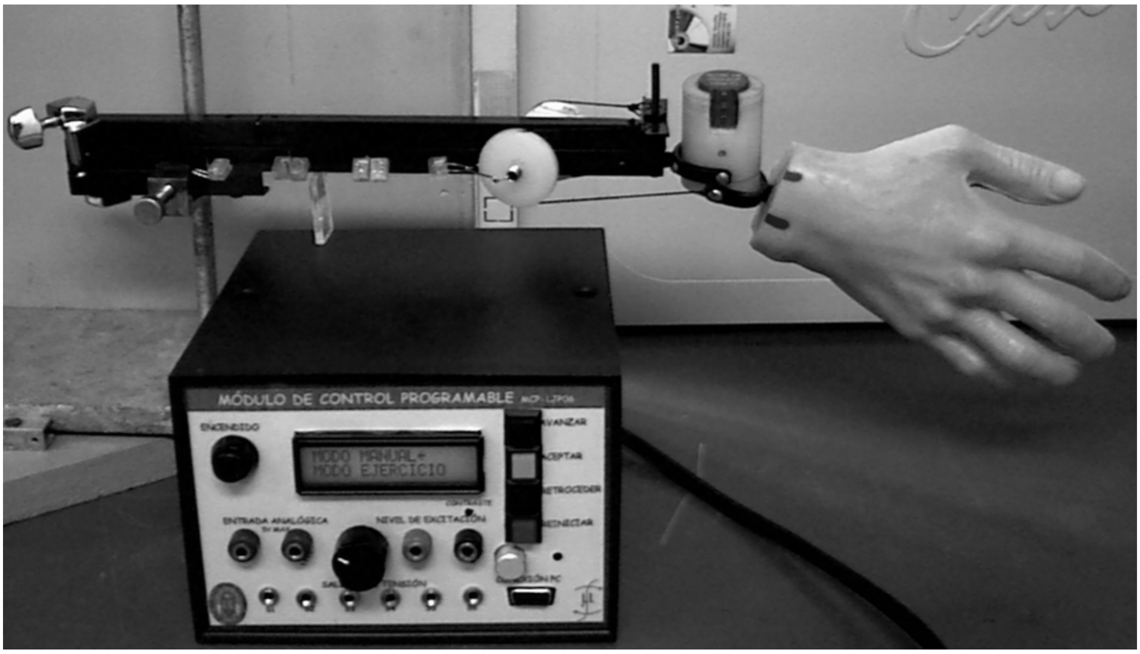

Figure 8: Photograph of the PMC.

3. Results

It was verified that a delay time of 200ms is adequate to produce the antagonistic work of the MAs without damaging the CMU actuators, and that the algorithm of sequence of individual action of the actuators worked correctly, avoiding the existence of an actuator that works more than others.

During the tests using the Manual and Exercise Modes of operation, the maximum excursion registered was 37º, with intermediate positions averages of 0º, 12º, 24º and 36º, marking a great repeatability with a relative error smaller than 5% for each position.

During the tests using the Manual Mode, the PMA, always responded to the commands of the keyboard. Using the Exercise Mode, 225 cycles of work were made during 180 minutes of continuous work, with a relative error smaller to 5% in all the positions.

The power consumption of the PMA was approximately 4,15W, in which 3W (750mA – 4V) corresponds to the AM.

4. Conclusions and Future Works

The preliminary design of PMA, has demonstrated that CMU actuators are adequate to be used in dynamic powered orthosis and/or assistant rehabilitation instruments.

The antagonistic work of the MAs, makes possible to reduce the time of relaxation of the typical 7seconds of the actuator to approximately 1,2 seconds.

However the limited excursion obtained of 37º has not fulfilled our expectation, can be easily improved by replacing the hand made pieces that conform the structure of PMA, with machined pieces and an adequate mechanism.

The repeatability of the system makes possible its use as a mechanical assistance instrument.

The low consumption of the MA, makes possible their use in portable instruments using small rechargeable batteries.

Future works includes, the improvement of the rotation system so that the PMA could perform a greater excursion angle of the wrist's flexo-extension movement. Integrate more CMU actuators within a MA in order to achieve more predefined positions, making possible a more continuous and human like motion. Design a glove or polyurethane structure, and assemble the PMA over it, making the PMA wearable. Test the performance of this PMA in normal as well as unable persons.

5. Acknowledgement
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