Research, Design & Development Project

Myoelectric Prosthesis of Upper Limb

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Abstract. A Research Design and Development Project was developed of a myoelectric prosthesis for a pediatric patient presenting congenital amputation of the left forearm below the elbow. A multidisciplinary work-team was formed for this goal, in order to solve the several (various) aspects regarding this project (mechanical, ergonomics, electronics, physical). The prosthesis as an electromechanical device was divided in several blocks, trying to achieve a focused development for each stage, according to requisites. A mechanical prototype of the prosthesis was designed and built along with the circuitry needed for EMG acquisition, control logic and drivers. Having accomplished the previous stages, the project is now dealing with the definitions of the interface between the prosthesis and the patient, with promising perspectives.

Key words: myoelectric prosthesis, upper limb, pediatric patient

1. Introduction
The congenital malformations of upper limbs are not a very frequent condition, for they affect less than 0.2% of born babies. Many of these malformations are not severe, have a minor functional impact and may be surgically treated.
The embryologic development of the upper limb takes place in the early stages, presenting a complete differentiation at week 7 of gestation [1]. Usually, if malformation occurs, it may already be present by the time the mother confirms her pregnancy.
There are many classifications to categorize the various forms of congenital amputation. According the International Federation of Societies for Surgery of the Hand [2][3][4], there are 7 groups of malformations:
• failure of formation of parts,
• failure of differentiation (separation) of parts,
• duplication,
• overgrowth,
• undergrowth,
• congenital constriction band syndrome,
• generalized skeletal abnormalities
Malformations of the first group result in congenital amputations, being the hand and the forearm the most frequent affected. According with the level of malformation they are denominated as:

- **Amelia**: total absence of upper limb
- **Hemimelia**: absence of forearm and hand.
- **Acheiria**: absence of hand.
- **Adactilia**: absence of metacarpus and phalanges
- **Aphalangia**: absence of all phalanges

These conditions are treated with protheses, because they usually have no surgical indication. Regardless of the cause of amputation, there are six prosthetic options for the upper limb amputee, namely:

### Cosmetic prosthesis
Also called passive prosthesis, it replaces the missing part or limb, and looks quite similar the remaining one. They are usually made of PVC, latex or silicon. They do not provide functionality, are lighter than other prosthetic options, and require very little maintenance.

### Body actioned prosthesis
They are actuated and controlled by movements of the amputee's body, usually the shoulder, the arm or the chest. They use a harness system and have a hook or clamp at the end. They have an easy design, do not have problems with water or other external elements and require very little maintenance. On the other side, the harness system represents a restriction on the amputee movements which causes discomfort.

### Electrical prosthesis
They are actuated through small electrical motors. These are controlled by the EMG signal that can be registered using superficial electrodes placed on the remaining muscles of the limb (or on other location). The prosthesis is controlled at will by the patient. They use a battery system for energizing the electrical components, and require more maintenance and careful use.

### Hybrid prosthesis
It combines the body actuated prosthesis with electrical prosthesis. They are usually used in transhumeral amputees (amputation over the elbow).

### Specific prosthesis
They are devised for specific activities of the patient, such as playing a musical instrument, practicing a specific sport, etc.

### No prosthesis
It is considered that only half the number of upper limb amputees receive prosthetics services, and only half of these continue using their prosthesis after the first year of implementation. Not all the amputation cases can receive prosthetic service; besides the patient may decide not to use them due to bad experiences, discomfort, etc.

In the market, various international manufacturing companies and suppliers offer an ample range of prosthesis for any kind of amputation. We can mention Animated Prosthetics, Hosmer, Otto Bock, Pepp, UtahArm and others [5][6][7][8][9]. The approximated cost of a myoelectric prosthesis for the upper limb is above u$s15000. The orthopedist implements them on the patient, placing the electrodes over the remaining muscles and manufacturing the structure representing the forearm. It is usual to perform a periodic follow-up of pediatric patients, with increased-size prosthesis change-over as needed during the patient’s growing-up phases, implementing a bigger size prosthesis along with the
natural growing of the patient. Usually, the above-mentioned companies present several models of prosthesis with different sizes for pediatric, young, women and men patients. Each model replaced according to the natural growth of the pediatric and/or young patient.

2. Objectives
Given the scope of the project the general and specific objectives were defined:

- General objective
  RDD of an active upper limb prosthesis for pediatric patient with congenital amputation.

- Specific objectives
  - Prosthesis design according with the anthropometric characteristics of the patient.
  - Use of biocompatible materials.
  - Provide electrical and mechanical safeness of the design.
  - The prosthesis will have an open and close movement of the fingers, which will be controlled by the EMG signal acquired using superficial electrodes.
  - Stetic accordingly design.
  - Assure proper autonomy of the device for its use.
  - Conventional and easy to use power supply system.
  - The vinculation between the limb and the prosthesis will avoid use of harness.

3. Development
For the developing of the project, the constitutive elements of the myoelectric prosthesis were divided according with the following criteria

\textbf{Electrode:} The EMG signal is generated by voltage variations at the membrane of the muscle cells during muscle contraction. It has a signal strength in the range of uV to few mV and a frequency spectrum of 0 to 500Hz aproximately, having the major energy range at 50 to 150Hz [10][11].

In order to detect EMG, a superficial "dry type" (in direct contact with skin) electrode was designed and developed. Thus, the electrode can be mounted directly on the structure of the prosthesis, making contact with the skin of the limb.

The electrode as a transducer of ionic currents (generated in the muscle), into electronic currents (handled by a circuit) was built with two 99% purity silver bars, of 1cm long, 1mm width and separated by 1cm.
An integrated instrumentation amplifier was implemented, using the INA121 from Texas Instruments. This device has a high RRMC (above 100dB), a high input impedance (FET like) and a very low bias current (4pA). These properties make it ideal for its use in biopotential detection applications. In order to obtain maximum signal detection the location of the electrode is a very important factor as much as its electronic properties. The neighbor muscles EMG interferences must be avoided (crosstalk), along with movements in the skin-electrode interface (movement artifacts) [12].

**Conditioning:** this block essentially receives output from electrode and transforms it in a logical signal (0/1) indicating presence or absence of EMG. It has an external adjustable level comparator that allows variations of the sensibility threshold of the system. Thus, it can be adapted to different patients with different EMG signals.

**Control:** Is implemented with a MSP430 Texas Instruments microcontroller [13]. It is responsible of monitoring presence and source of the EMG signal and with this information comands motion and direction of the motor. It also controls the limits of the open and close movement and in case of an overcurrent on the motor windings (indicating excessive effort), it stop motion.

**Motor Driver:** The motor is driven by a transistors H-bridge integrated on chip 2919 from Allegro [14]. This component allows to select the direction motor winding current flows (phase selection) and has three different speeds. It also has an externally configurable PWM module.

**Power Distribution:** This block receives battery voltage and delivers +/-5V to the entire system.

**Battery:** A conventional and easy to get power supply was required so a rechargable Ni-M 9V battery was chosen for feeding the system. It has a good capacity (in terms of mAh) and size relationship and can be replaced easily [15]. It is intended to migrate to Li-Ion batteries on future versions, since they have greater capacities and reduced dimensions.

All this blocks were designed and implemented using a low power criteria, in hardware and software, in order to seize battery charge at its maximum.

**Clamp:** Regarding the design of the mechanical hand, measures of the size and weight of the patient were taken in order to find the position on the growth charts and determine the percentile. Having determined a 50 percentile, charts of weights and measures of segments of the body were then used for the dimensioning the constitutives elements of the hand (length of fingers and maximum opening, wrist perimeter, length and thickness of the carpus, weights of the hand and forearm, etc).

In the meantime, the mechanism that traduces the motion of the motor in the gesture of opening and closing the fingers was designed. It was proposed a chain of gears shared in common to an endless crown and screw (in the end of the motor) and to a geared arc (in the end of the forefingers), whereas an articulated pivot makes the opposite movement (in the thumb).

With all this schemes a virtual model was made, on wich was able to study the vinculation between parts, the aproximated dimensions, the position of the transmision mechanism, and even an estimation of the final weight of the system.

The next step was to manufacture the first on scale prototype, using elements easy to find and work with. Acrylic was used for the fingers, aluminum for the chassis (corresponding to the carpus), bronze for the gears, etc. This model allowed to evaluate the whole system, revalidate previous calculations regarding strength (or torque), speed of opening and closing of the fingers, total weight of the system, noise generated by the mechanism during motion, etc.

For the manufacture of the final model the structural design of the prototype was conserved and some improvements were added. The transmission ratio of the gears was modified to reduce the force generated at the end of the fingers thus increasing the speed of opening and closing. Microswitches
were added to limit the open-close movements. In addition, the connector ring that ties the prosthesis with the structure of the forearm (made by the orthopedist) was designed and manufactured. The used materials were carbon fiber for the fingers, duraluminio (an alloy more resistant than conventional aluminum) for the chassis and the gears were made in steel.

4. Results

As it can be seen on the nature of the project, it has two well defined aspects; electronics and mechanics.

From the electronic aspect the requirements aimed to fulfill functionality, low power consumption and reduced size.

In the first place the circuit had to be able to gather the EMG signal in the remaining extremity of a pediatric patient with congenital amputation. According to this, the circuit evolved through several versions, detecting in adult individuals without amputation initially and after successive tests and modifications the EMG signal could be detected properly on the patient, as was required. A myoelectric signal in the order of 150uV could be determined (by indirect calculations).

On the other hand, the circuit was designed with a low power consumption philosophy to prolong life utility of the battery between charges. Hardware and software strategies were used to obtain a base consumption of few mAmps, reaching up to 250mAmp in the case of maximum motor effort. Performance evaluations were made using a conventional Ni-MH 9V battery obtaining over 300 open-close cycles, considered normal for a day of use.

Finally, special care was taken during the selection of components (with SMD packaging) and in the design of the pcb boards in order to reduce its size as much as possible.

Regarding the mechanical aspects, functionality and stetics criteria were imposed. The prosthetic hand was designed to look as human hand in a finger clamp gesture. Dimensions were defined considering anthropometric charts and measuring directly over the patient.

The same criteria was applied to the weight of the system. A careful selection of materials was done, always looking for an optimal relation between weight and mechanical resistance, so that the final weight of the prosthesis would not exceed the weight of the segment hand-forearm.

The weight of the final model is of 185g, to which 45g of the weight of the battery and 15g corresponding to the electronics must be added. All this gives a gross weight of the prosthesis of 245g, acceptable considering that the segments forearm and hand represents 350g in a young percentile 50 of four years old.

The calculation of the chain of transmission was made having in consideration that the force made at the end of the prosthetics fingers was not greater to the one that can developed by the patient in natural form. This was verified by lifting tests of calibrated weights.

In addition an effort was done to diminish the noise produced by the movement of the mechanism (motor, gears, etc.), mounting housings that offer protection as well.

All these requirements were defined as objectives of the design process and were fulfilled, at least in this stage, being pending the relative ones to the stage of final assembling of the prosthesis on behalf of the orthopedist.

These are the results, on images, of each block:
Figure 2. Current version of electrode and conditioning.

Figure 3. Microcontroller.  
Figure 4. Motor driver.

Figure 5. Power distribution.  
Figure 6. Battery holding.

Figure 7. Prosthesis virtual model.  
Figure 8. Prototype.
5. Conclusions
At this point of the project the great majority of the proposed objectives has been fulfilled satisfactorily. The obtained results, as outputs of the design and development process are acceptable and promissory in view of the future definitive implementation. At the moment, operation tests are being made on the patient, in a way of training and familiarisation in the use of the prosthesis. It remains the manufacture of the structure that conforms the forearm and contains all the elements (prosthetic hand, electrodes, electronics and battery).

6. References

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