Manufacture of a myoelectric prosthesis for transradial amputation

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Abstract. Losing a part of a body is a traumatic situation for any human being. The hand allows us to grasp things, touch, and help us to communicate with others. Therefore, it is very important for an amputee to replace this essential part of the body. This study was motivated for giving a better life to a person with this disability. A 45-year-old man was the patient for who was designed a hand-held myoelectric prosthesis for a transradial amputation and it has focused on generating the processes required for the construction of a first. The design process was divided into two subsystems: mechanical and control. A novel manufacturing process is proposed to make a thin cover for the forearm. Freudentstein equations was used to simulate the movement of the fingers by means of mechanical linkages. This study sought not only to improve the life of patient but to apply the engineering knowledge for solving problems in biomechanics area and give an idea for more autonomous prostheses.

1. Introduction

The loss of a part of the body in human beings has been an inevitable fact in the history of humanity. It causes personal difficulties that result in an emotional detriment of those who suffer from it and difficulties in their performance and daily tasks. Dealing with this adverse and historically inevitable situation, it has been necessary to create devices to supply these deficiencies. In addition, biomedical engineering has become more and more specialized with technological development and now provides a diversity of manufactured products tailored to the needs of each patient. Despite the progress reached by various countries in this area, there are many more improvements and things to do. One of the greatest difficulties faced by a patient who requires a prosthesis is its high cost. Therefore, it is worth to improve this field of engineering in such a way that increase the development of bionic prostheses [1-4].

This study sought to design and manufacture a hand-held myoelectric prosthesis for trans radial amputation. A patient who presents a right forearm amputation due to a work accident was the person to help on the manufacture of a prosthesis that has required the generation of manufacturing processes to make each of the components of the prosthesis feasible [1-4]. At the beginning it was used 3D printing to manufacture the hand but after it was employed thermo forming [5]. A special requirement is that the socket must be very thin to allow enough space to other components of the prosthesis. Forearm manufacture employed a novel method unlike the forearm palm which was 3D printed [6-8]. On the other hand, it was employed a Myoware sensor to capture the EMG signals [9-14].

This project was the result of weekly meetings with the students of Universidad Industrial de Santander in Barbosa, specifically from the hotbed of research in robotics LABbionic group, now it
intends to continue advancing until obtaining the expected product in such a way that it can be used by the specifically patient (see Figure 1).

2. Methodology
The following stages have been proposed in order to achieve the development of the prototype of the prosthesis under consideration: geometric design, instrumentation, control design, drive and validation algorithms. These stages are arranged in such a way that part of the design of the external components or brackets of the prototype are made to ensure the fit of the prosthesis to the patient's measurements and secondly to ensure an appropriate design the internal components are adapted to the supports of the prosthesis such as is shown in Figure 2 and Figure 3.

Figure 1. 45 years old man patient with a transradial amputation in his dominant right arm.

Figure 2. Methodology which was employed in the manufacturing process.

Figure 3. Methodology employed in geometric design.

2.1. Geometric design
For the geometric design stage, the sub-stages shown in the graph below have been proposed to guarantee an adequate adjustment of the prosthesis to the patient beginning with the drawing of planes and the construction of the molds to obtain right patient’s measures. Finally, it was necessary to choose the materials to build the socket and after it’s necessary to probe the right adjust to patient’s stump.

2.2. Biometry
The main objective of biometrics is to establish the geometric characteristics that the prosthesis must satisfy in such a way that they adapt to the ergonomics of the patient. In this aspect the design of the prosthesis has identified three main components: the socket, the forearm and the hand (see Figure 4 and Figure 5).
It was necessary to use measuring instruments in order to guarantee good biometrics among the tape measure and goniometer. On the other hand, the molds of the stump and the hand were generated using plaster bands as a molding element. To generate the molds of the missing hand, someone who volunteers and had similar measures in height and size of the patient's limbs under consideration was used. It was necessary to generate two instruments to record the biometric information: a plane for capturing the measurements of both the stump Figure 4(a) and the palm of the hand and a format for recording the lengths of the phalanges and angle of rotation of each finger.

![Figure 4](image1.png)  
**Figure 4.** Measure of the stump (a) and building of the negative mold (b).

![Figure 5](image2.png)  
**Figure 5.** Negative (a) and positive (b) molds of the stump.

Three products were obtained as a result of this stage of biometrics: a plane that records the patient's measurements, a format for recording the palm measurements along with the lengths and angles of rotation of each of the phalanges of the existing hand and finally a positive mold of the stump Figure 5(b).

3. Results
To make possible the construction of each component in the prosthesis, it had been necessary to employ a lot of tools, define several manufacturing processes, build a thermo forming machine an employ a 3D printer to obtain the final product as it is showing below.

3.1. Socket
The socket is the connecting element between the stump and the prosthesis and requires a constructive process that guarantees the fidelity of the shape between the stump and the socket. For the elaboration of this component it was necessary to use the thermoformed sheet of high impact polystyrene, it was proposed by Camelo [5]. Because of the thermoformed service is not available at the company level for the processing of a single element, the design and construction of the thermoforming machine was necessary. Polystyrene sheets of 1 mm and 3 mm were obtained, getting better results with the 3 mm sheets to set up it, Figures 6(a) and 6(b). Figure 6(c) shows a first socket that failed because of it was used a 1 mm sheet but in the Figure 6(d) it was employed a 3 mm polystyrene sheet producing a better result.
3.2. Forearm
This component is fundamental for the prosthesis since it defines one of the external components of the prosthesis and works as support to house the internal components such as: microprocessor, battery, sensor and wiring. For its elaboration the thermoformed was used, being necessary the preliminary elaboration of the mold.

3.3. Forearm mold
For the elaboration of this component it was necessary to devise a novel process that starts from three profiles: a circular profile that starts from the transversal portion near the elbow, an elliptical profile towards the transversal portion of the stump and a longitudinal profile that adapts smoothly to the measurements of the forearm. Starting from these premises, a process was devised which begins with the grouping of four blocks of balsa Figure 7(a); they were joined by screws through two metal sheets arranged at their ends, it is shown in the photographic record: a sheet with circular profile, a sheet with elliptical profile and a sheet with smoothed longitudinal profile that adapts to the patient's recorded measurements Figure 7(b) and Figure 7(c). Once assembled the set proceeded to the roughing of this by means of rotary tool and head for roughing of wood. This process required progressive slabs until the final form was obtained, with multiple stages of roughing required to obtain the result as it is seen in Figure 7(d). Then, it is proceeded to carve a profile to improve the external presentation of the forearm. Additionally, the box was designed to house the battery Figure 7(e), Figure 7(f) and Figure 7 (g). Once the mold in wood was finished, the thermoformed was obtained, obtaining very good finishes. The two resulting pieces of the forearm are joined by screws Figure 7(h).

![Figure 6. Building of the socket. (a) machine for generating the forearm socket, (b) 3 mm polystyrene sheets forearm socket (c) a failed 1 mm sheet forearm socket (d) patient with the socket.](image)

![Figure 7. Detailed stages for the forearm mold. (a) to (d) construction stages of the forearm mold from balsa blocks. (e) to (h) construction stages for battery box.](image)
3.4. Palm
To obtain the palm, two plaster molds were generated Figures 8(a) and (b): one upper mold and one lower mold. To ensure an adequate shape during the thermoforming, it was necessary to create a hole in each of the fingers of the mold to improve the suction effect at the fingertips. The result of the palm can be seen in the following photographic record Figures 8(c) and (d).

3.5. Palm forearm connector
An adequate union between the forearm and the palm is needed, therefore, the following process is proposed to guarantee an appropriate measurement of the internal parts between the forearm and the palm, plaster cast was poured over the whole and the casting cast Figures 9(a) and (b). From plaster cast casting, the required measurements were obtained, and the joining piece was designed in Solid works software Figures 9(c) and (d) and the piece was then manufactured in 3D printing as it is shown below Figures 9(e) and (f). Finally, the final prototype was obtained of the prosthesis like can be shown in the Figures 9(g) and 9(h).

![Figure 8. Manufacturing process of the palm. (a) and (b) mold for the palm, (c) and (d) 3mm polystyrene palm mold.](image)

![Figure 9. Construction detail of palm forearm connector. (a)–(f) forearm connector design and construction, (g), (h) forearm connector installed in the prosthesis.](image)
3.6. Instrumentation
Considering that during the voluntary process related to the intension of movement, signals are generated from the central nervous system and these travel through the axons. These signals are directed towards the muscle groups that are innervated and can be measured from the surface of the patient's skin [11]. These electrical signals known as EMG signals that are of the order of millivolts or micro volts may be amplified to the order of volts by using surface electrodes for them. Electrodes for electrocardiography were used in this project because they are the most common commercially available and additionally, analogue operational amplifiers were needed, which increase the output gain of the signals. An inherent difficulty during the process of amplification of the EMG signals is the presence of noise in these signals and consequently they require the use of filters and signal conditioners [11-13]. The above situations and the instrumentation systems to condition the surface EMG signals require the use of two stages: an amplification stage and a second filtering stage to eliminate undesirable signals. For this project muscle sensors called Myoware were used, available at low cost in the market and with the miniaturization required for this type of prosthesis [9-15].

The tests performed on the patient regarding the uptake of the EMG signals by means of the Myoware sensor were satisfactory since the signal was easily captured and the servomotors responded effectively to the intention of the patient's movement Figure 10(a) and Figure (b) [9-14].

3.7. Drive system
Micro motors with electronic driver including which have micro gears with 50 to 1 ratio have been used Figure 11(a) to drive each of the fingers of the prosthesis. The control of rotation of the engines is done by PWM pulses since they have a circuit embedded electronic that responds to modulated width pulse signals. The alternative of micro motors has been chosen instead of the servomotors for size reasons to transmit the controlled rotation of each of the five fingers a total of five micro motors have been used, which have a coupling with each micro motor through an endless screw Figures 11(b) and (c) that communicates with the proximal phalanx of each finger. Each of the five fingers of the prosthesis will be activated by a micro motor, the movement of each of the phalanges was coordinated by means of links using the Freudstein equations as proposed by Dorador [16,17].

![Figure 10](image1.png) **Figure 10.** Capture tests of the EMG signals and corresponding activation of test servomotors.

![Figure 11](image2.png) **Figure 11.** Detailed mechanisms that allow the movement of the fingers.

3.8. Control system
The controller is the electronic component in charge of managing the information of the prosthesis and it is responsible for receiving the signals from both the EMG signal sensor and the rotation angle sensor of each of the fingers that in this case corresponds to flexible resistance additionally it has the process instructions required to generate the output signals that will be sent to each of the micro motors. The entire control system is performed in closed loop [18] to maintain the supervision and control of the patient's movement intentions Figure 12.
The control algorithm generally employs different strategies and are the fundamental nucleus that give orders to the prosthesis from the controller itself. On the other hand, control strategies used are listed: threshold algorithms, algorithms based on the temporal domain, multi-resolution algorithms based on the time domain and the frequency that use the wavelet transform, algorithms and based on neural networks among others. It has been decided to opt for a simple threshold detector algorithm since the preliminary stage of this project.

4. Conclusions
This project has focused on the manufacture of a prototype of a myoelectric prosthesis for trans radial amputation and has allowed to identify the minimum technologies required and the necessary materials. Although in the beginning 3D printing was used for manufacturing the prosthesis, later thermo technology was used, especially in the manufacture of the forearm, because it was concluded that printing in three dimensions despite having excellent manufacturing potential; the low resistance to forces of the components printed in three dimensions makes them undesirable.

A relevant aspect is that the patient could see the decrease in muscle volume in the affected limb because of muscle atrophy but despite this muscular atrophy, the myoelectric signals remain intact, being able to capture these signals and easily operate the servomotors test.

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