ELECTRONIC VARIATION OF A MECHANICAL 3D SCANNER FOR THE READING OF RESIDUAL LIMBS GEOMETRY

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Abstract. *Due to advances in the manufacturing process of orthopedic prostheses, the need for better quality shape reading techniques (i.e. with less uncertainty) of the residual limb of amputees became a challenge. To overcome these problems means to be able in obtaining accurate geometry information of the limb and, consequently, better manufacturing processes of both transfemural and transtibial prosthetic sockets. The key point for this task is to customize these readings trying to be as faithful as possible to the real profile of each patient. Within this context, firstly two prototype versions (α and β) of a 3D mechanical scanner for reading residual limbs shape based on reverse engineering techniques were designed. Prototype β is an improved version of prototype α, despite remaining to work in analogical mode. Both prototypes are capable of producing a CAD representation of the limb via appropriated graphical sheets and were conceived to work purely by mechanical means. The first results were encouraging as they were able to achieve a great decrease concerning the degree of uncertainty of measurements when compared to traditional methods that are very inaccurate and outdated. For instance, it's not unusual to see these archaic methods in action by making use of ordinary home kind measure-tapes for exploring the limb's shape. Although prototype β improved the readings, it still required someone to input the plotted points (i.e. those marked in disk shape graphical sheets) to an academic CAD software called OrtoCAD. This task is performed by manual typing which is time consuming and carries very limited reliability. Furthermore, the number of coordinates obtained from the purely mechanical system is limited to sub-divisions of the graphical sheet (it records a point every 10 degrees with a resolution of one millimeter). These drawbacks were overcome by designing the second release of prototype β in which it was developed an electronic variation of the reading table components now capable of performing an automatic reading (i.e. no human intervention in digital mode). An interface software (i.e. drive) was built to facilitate data transfer. Much better results were obtained meaning less degree of uncertainty (it records a point every 2 degrees with a resolution of 1/10 mm). Additionally, it was proposed an algorithm to convert the CAD geometry, used by OrtoCAD, to an appropriate format and enabling the use of rapid prototyping equipment aiming future automation of the manufacturing process of prosthetic sockets.*

Keywords*: 3D Scanners, CAD, prosthetic sockets*

1. INTRODUCTION

As far as high technology is concerned, the state-of-art in the field of prosthetic socket points towards the latest limb prosthetic designs that have been incorporated with **D**ynamic **E**lastic **R**esponse (DER) (Lee, 2006). Unsurprisingly, the scientific literature shows that a properly designed monolimb may potentially offer similar functional advantages to the relatively expensive DER feet. A cheaper alternative is to use the simple conventional **S**olid **A**nkle **C**ushioned **H**eel (SACH) designs.

In Brazil, the majority of low income patients, particularly those assisted by the National Health Service (S.U.S), are still employing traditional rigid-shank prostheses. A good literature review on orthopedic prostheses models, used around the world, can be found in (Queiroz, 2008).

Due to advances in the manufacturing process of orthopedic prostheses, the need for better quality shape reading techniques (i.e. with less uncertainty) of the residual limb of amputees became a challenge. To overcome these problems means to be able in obtaining accurate geometry information of the limb and, consequently, better manufacturing processes of both transfemural and transtibial prosthetic sockets. The key point for this task is to customize these readings trying to be as faithful as possible to the actual limb profile of each amputee.

Since early 90´s some researches have been working on the development 3D **o**ptical **s**urface **s**canners (OSS) and have made interesting evaluation of several others measurements techniques such as x-ray **c**omputed **t**omography (X-ray CT), electromagnetic digitizer and calipers (Smith,1996, Commean,1998).

Within this context, the multidisciplinary research group on computational mechanics at UFRN University worked on the design of a low cost Electro-Mechanic 3D scanner for reading residual limbs´ shape based on reverse engineering techniques. Firstly, two prototypes of the equipment (versions α and β) were conceived and manufactured (Queiroz, 2008).

Prototype β is an improved version of prototype α, despite remaining to work in analogical mode. Both mentioned prototypes are capable of producing a CAD representation of the limb via appropriated graphical sheets and were conceived to work purely by mechanical means.

In order to guarantee the automation and quality of the reading procedure, efforts have been made to design an electronic variation of the equipment by adapting a 3DPS device (3D **P**erception **S**ystem) based on 2D electro-mechanical sensors. Therefore, in this paper it is proposed a new release of prototype β that provides facilities to produce a CAD representation of the limb either via appropriated graphical sheets (analogical mode) or by storing input data fed from an USB (Universal Serial Bus) connection (digital mode).

Some important design requirements were taken into account. Firstly, special attention was given to ergonomics accessibility of the amputee to make sure that he/she would fit comfortably in the equipment and not be exposed to avoidable safety risks (particularly accidental falls). The design should also consider a combination of raw material availability, low cost of production and access to a regional market. Finally the equipment should enable the automation of the measuring process.

Good results were obtained meaning less degree of uncertainty for the reading procedure when compared to the traditional methods carried out by the National Health Service (S.U.S) (i.e. ordinary measuring tapes, wood vernier calipers, ballpoint pen, etc.).The developed equipment resolution is of 1mm while running in analogical mode and of 1/10 mm if operating in digital mode. Furthermore, a 3D visualization software (OrtoCAD) was developed to display the reading results and to allow finite element analysis of the prosthetic socket being manufactured.

2. THE OPERATION OF THE ELECTRO-MECHANIC 3D SCANNER

Current traditional measuring procedures are still very inaccurate and outdated. For instance, the measurements of the residual limb are made by using ordinary home kind measure-tapes or wood vernier calipers (resolution of 1cm) in steps of 5cm in length from the low end (figure 1). This procedure may end up providing geometry data which carry a very high degree of dimensional uncertainty and, therefore, is passed on downstream to the final product (Pereira, 2007). More serious problems may also happen due to risk of pressure sore and, sometimes, reamputation.

Figure 1. Conventional Measuring of Below-knee Residual Limb (ordinary tape)

In contrast, the proposed equipment works as an electro-mechanical reader for measuring the cross sections of residual limbs of amputees to help on the design of prosthetic sockets which are fitted in either transtibial or femoral prostheses (Figure 2).

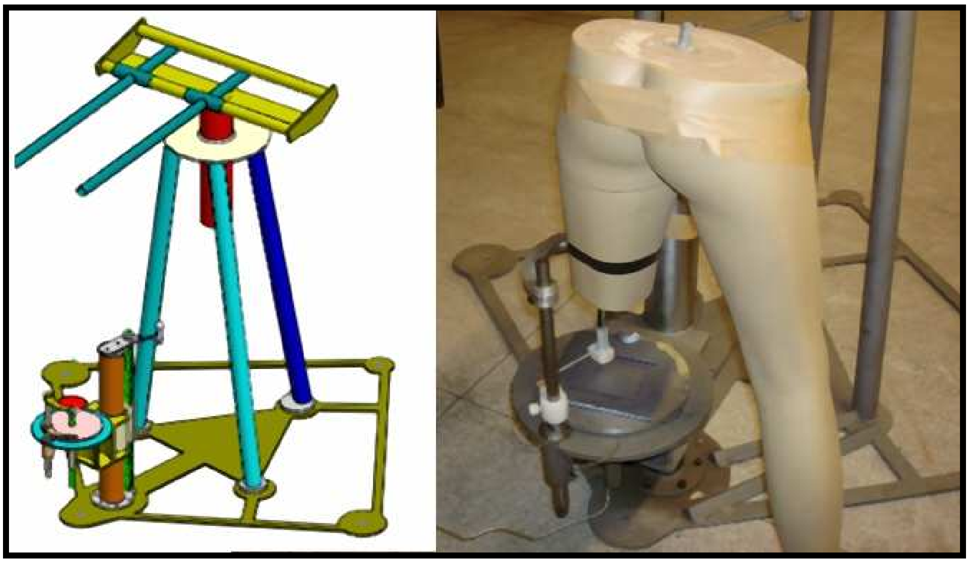

Figure 2. The Electro-Mechanic 3D Scanner (CAD model /Left and Real Device plus Mannequin /Right)

The Electro-Mechanic 3D Scanner was able overcome several of the above mentioned problems. It works, firstly, by capturing the residual limb's geometric surface information via reverse engineering techniques (Figure 3). This is done by reading upwards and storing several cross sections (Figure 4) of the amputee residual limb or his/her healthy leg (if any). In this illustration a mannequin is used to simulate an above knee amputation using the Pen Tablet. Next, a CAD software named "OrtoCAD" takes action to automatic reconstruct the anatomic 3D representation of the residual limb, as well as, the virtual model of its corresponding plaster positive cast of the socket part. The software OrtoCAD is an academic application and was developed by our research group at UFRN (Silva, 2007). It also provides an interface with a CAE module allowing finite element analysis to be performed.

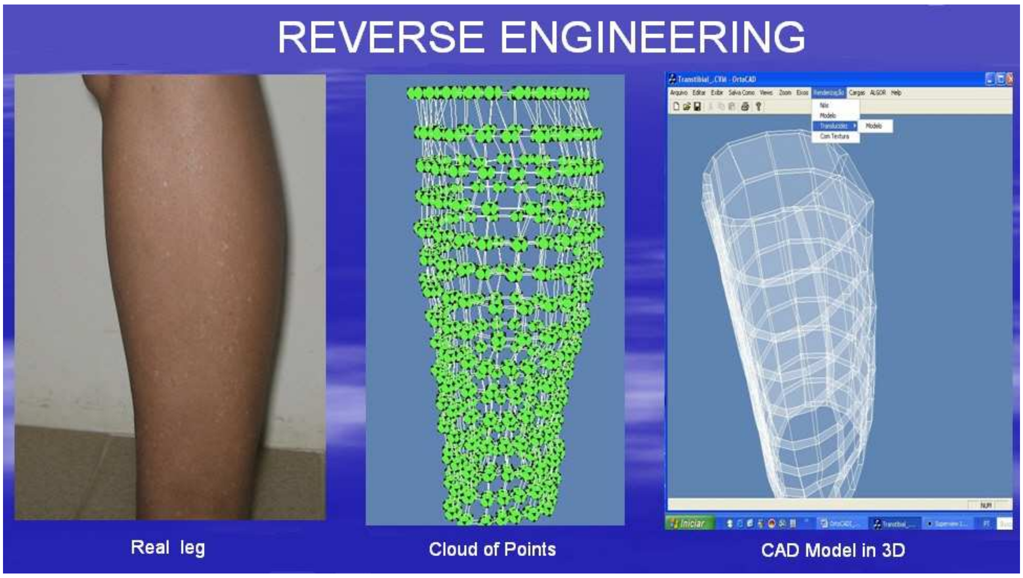

Figure 3. Applying Reverse Engineering through the Electro-Mechanic 3D Scanner and OrtoCAD (Pereira, 2007)

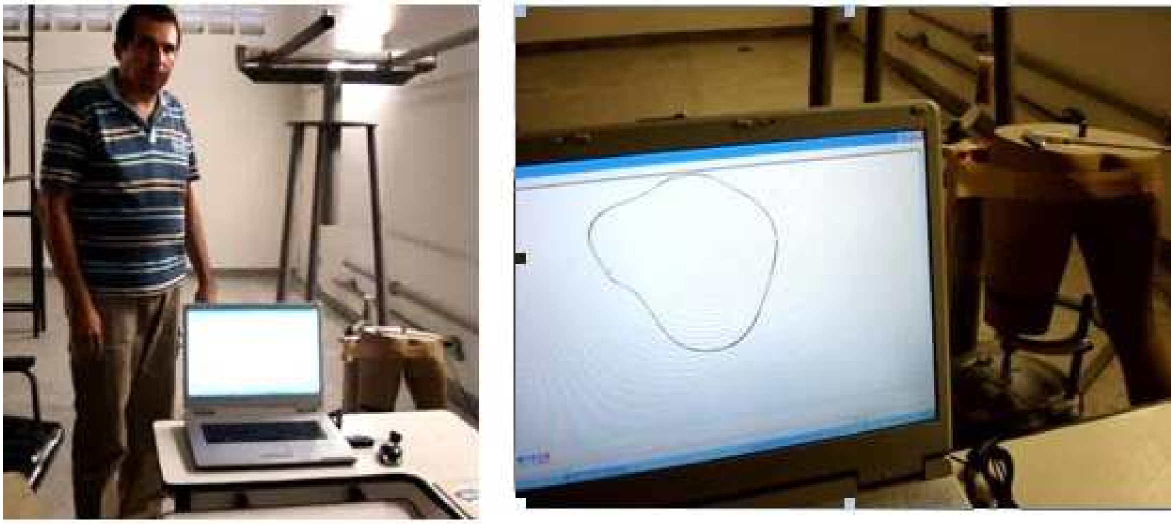

Figure 4. Capturing a Cross Section of a Mannequin's Residual Limb via Pen Tablet to Test the Electronic Interface

This new procedure for sure reduces the uncertainty for measuring and capturing the residual limb shape. If one uses an ordinary measuring tape (resolution of 1cm) as show in figure 1, the above same cross section would become a perfect circle instead. It is than clear that the real cross section presents a shape far different from a simple circle. Figure 5 illustrates a comparison between the perfect circle obtained by using an ordinary measuring tape and the real profile obtained by using the second release of prototype β (in digital mode). Although this figure shows only a single section of the residual limb, one can easily note that there is a gain related to the areas of regions A, B, and C.

The higher is the number of cross sections measured, the higher it will be the total area for all these regions. No further research has been done so far to determine the percentage of the areas illustrated here. This will be an interesting topic for future work that will help in a deep evaluation of the equipment performance (accuracy, degree of uncertainty, etc). For now, it can only be qualitatively stated that the proposed Electro-Mechanic 3D Scanner offers better results and therefore can achieve good accuracy and good-fitting prosthesis.

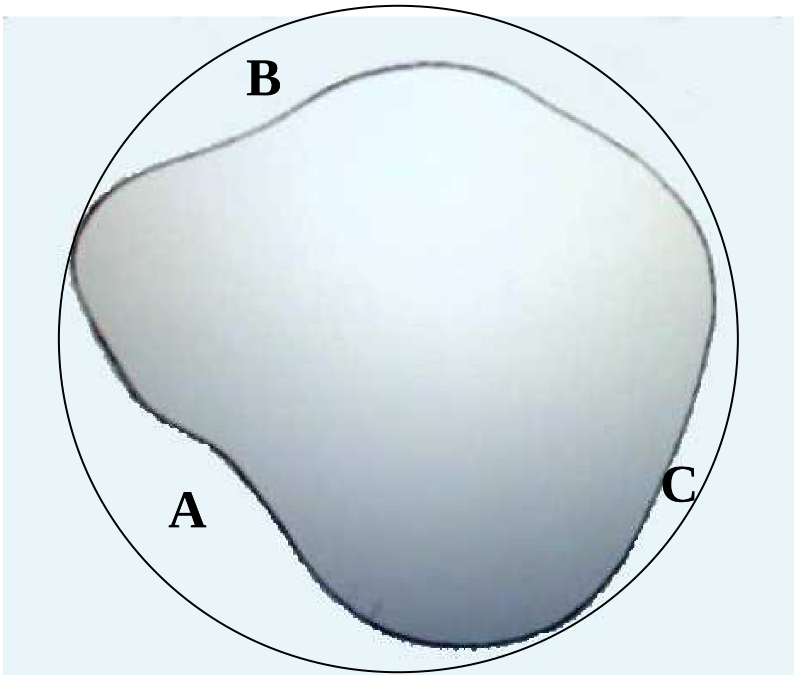

Figure 5. Comparison between a circle obtained by using ordinary tape and the profile from the developed equipment

The equipment consists of a mechanical system in which a mechanism named "feeler follower," is capable of performing movements of rotation and translation on the axis of the limb, which enables it to obtain a wide variation of measurements (Queiroz, 2008). This assembly set is called the Planetarium and is illustrated in Figure 6. The Planetarium is fitted with two arms (Figure 7) that move in synchronism.

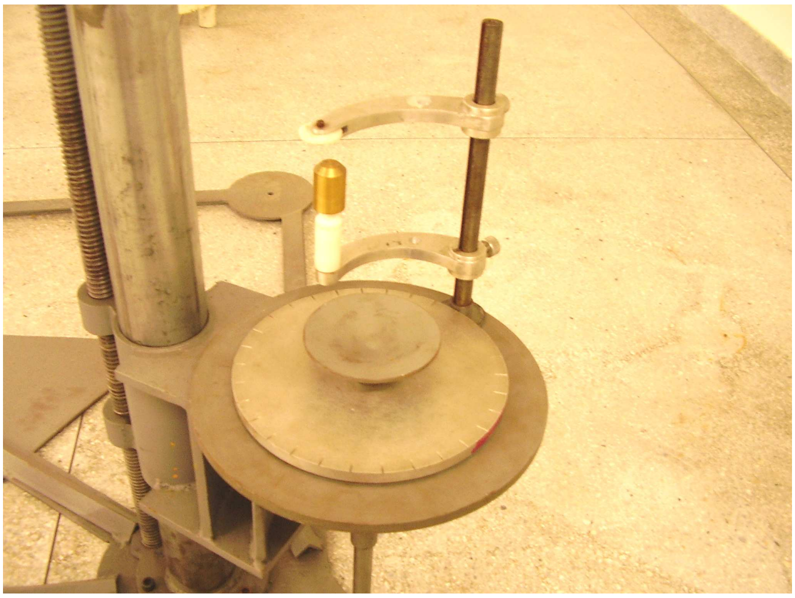

Figure 6. The Planetarium

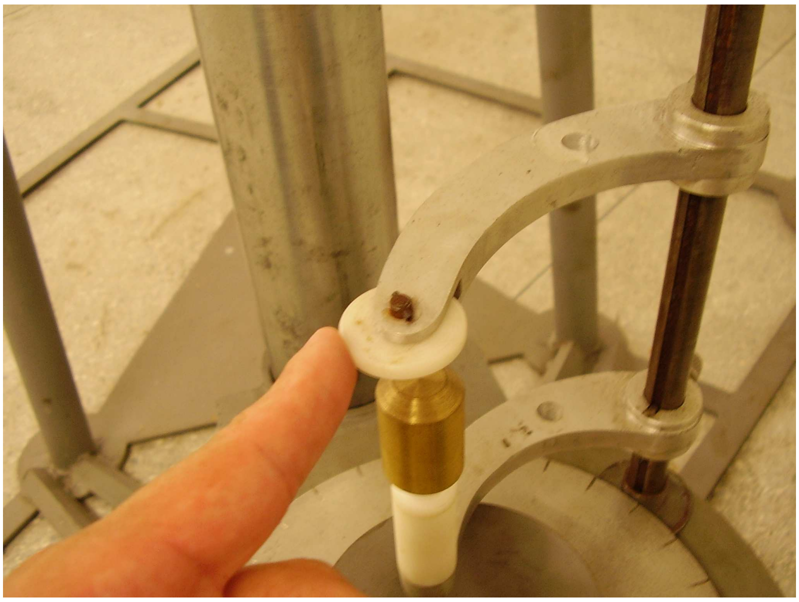

Figure 7. The upper arm of the planetarium is fitted with a wheel

The upper arm is fitted with a wheel that circumvents the limb of the patient (Figure 8) while the lower arm includes a record device to register the coordinates of each section of the limb. This task is accomplished either with the help of appropriate graphical sheets (analogical mode)(see Figure 9) or via Pen Tablet (digital mode) (see Figures 4 and 10).

Figure 8. The wheel that circumvents the residual limb

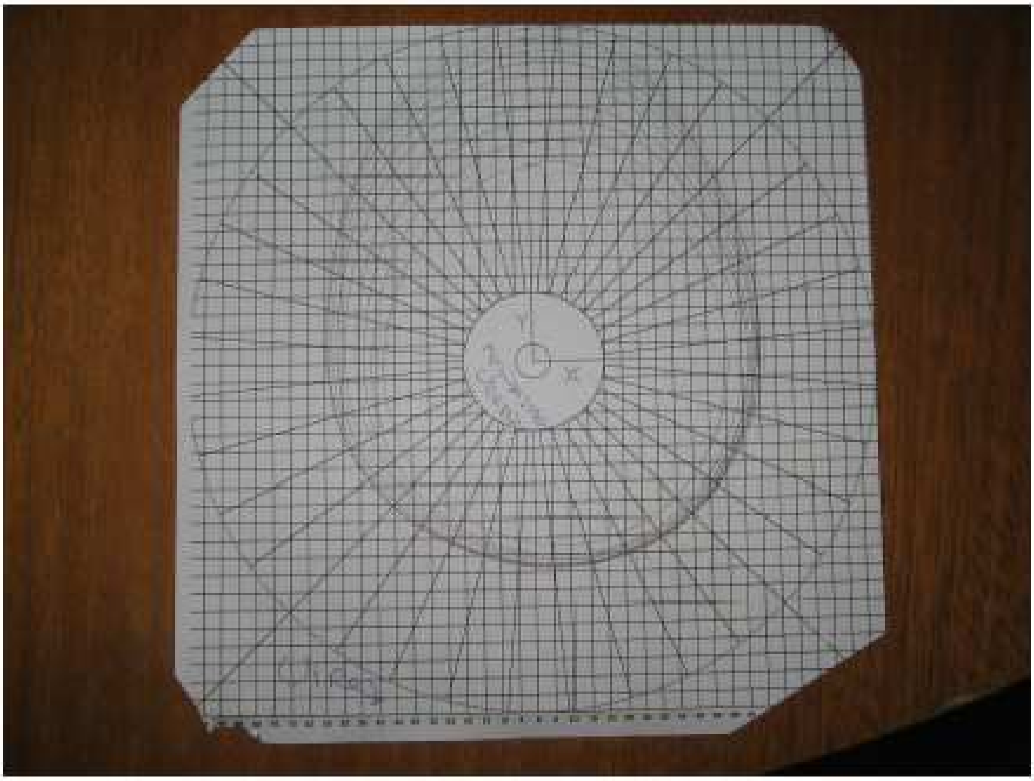

Figure 9-Several Profiles of a Limb Plotted in Graphical Sheets (Analogical Mode)

Figure 10 - The Pen Tablet being used to record a mannequin's residual limb (Digital Mode)

The coordinates of the profile curve of each section of the residual limb are passed to a computer through an USB connection (Universal Serial Bus). To receive and process these coordinates a driver was developed (i.e. interface). The functions of the software are, beyond receiving the coordinates X and Y, to calculate the Z coordinate and generate an specific file format of extension .LEM (Silva, 2007) supported by OrtoCAD. Finally, the Z coordinate is calculated based on the distance between the several cross sections read.

3. DISCUSSION AND CONCLUSIONS

There is no doubt that the prototype of the Electro-Mechanic 3D Scanner focus of this work represents an improvement on measurements accuracy and quality of the final socket of the prosthesis. It also means a step forward improved prosthetic fit assessment.

Although different approaches may be used for reducing the manufacturing steps of prosthetic sockets, the developed equipment here has shown capable of by-passing 2 or 3 steps downstream this job.

As far as some construction need are concerned, it would be useful if a particular type of pen-tablet could be designed following the same circular shape of the planetarium's table. Current commercial pen-tablets are rectangular shaped and are descentred with respect to their external boarder. This had to be adjusted during assembly of the equipment. Furthermore a wireless version would make the system more versatile.

The authors believe that in a near future perhaps Rapid Prototyping may be used to achieve a prototype of a socket that also works as a final product to meet infant prostheses type needs.

The methodology of Reverse Engineering has proved to be an efficient and feasible mean to achieve less uncertainty while reading data for reconstructing a 3D virtual representation of a residual limb. Therefore it helps to improve the quality of the prosthetic sockets manufacturing process.

Future work has to be done to improve the CAE model of this system in order to overcome some well known difficulties of commercial packages concerning composite material analyses. Most of them use metal based strength criteria such as Von Misses or Tresca. Instead non-metal criteria should be applied for simulating new materials (i.e. composite like).

Another interesting work would be to study the errors induced by the flaccidity of the limb tissue and to determine how its deformation (produced by the spring force applied via the mechanical probe against the leg) can interfere in the final measurements.

Finally, the authors also suggest a research aiming perform a deep metrological evaluation of the developed equipment.

4. ACKOWLEGMENTS

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6. RESPONSIBILITY NOTICE

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