

METHODOLOGY PROPOSEL FOR GEOMETRIC MODELING FROM THE MEDICAL IMAGES IN THE CAD SYSTEM

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***Abstract.** This paper discusses the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Individually tailored prosthesis designed to fit particular patient requirements as accurately as possible should result in more successful reconstruction, enable better planning before surgery and consequently fewer complications during surgery. Fast and accurate design and manufacture of personalized prosthesis for surgical use in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies, which are each at different stages of maturity. Initial case study experiments have been undertaken to validate the research concepts by making dimensional comparisons between a bone and a virtual model produced using the proposed methodology. Future research directions are discussed in the final section of this paper.*

***Keywords:** Geometric modeling, CAD, human prostheses, image processing, medical information, tomography examination*

1. INTRODUCTION

Advances in manufacturing technology accompanied by accelerated design techniques that are enabled through electronic information exchange and management are increasing the feasibility of very fast and accurate production of individually tailored or personalized products. There are many potential benefits to be gained through these approaches particularly in the context of medical applications. This paper discusses the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Individually tailored prosthesis designed to fit particular patient requirements as accurately as possible should result in more successful reconstruction, enable better planning before surgery and consequently fewer complications during surgery.

2. CONTEXT

There are very substantial, international requirements for reconstructive or replacement surgery. In Brazil, it is estimated that 12% of the people are physically disabled, i.e. approximately 19 million people. The reasons for their deformities are varied, but the main reasons include car accidents, accidents at the work, radical sports, genetically-based malformation and pathological and degenerative illness D'URSO (1998).

In the UK, bone reconstruction and replacement is successfully undertaken by surgeons in many types of routine and elective surgery. This is a major area of expenditure within the health service, since for example 147,000 knee and hip treatments were carried out in UK in 2007 (Website of the UK National Joint Registry - NJR). Bones from hips, knees, shoulders, ankle and elbows can all be routinely replaced and typically last for approximately 15 years. There are also many more difficult and challenging cases of bone reconstruction (e.g. jaw and skull) due to congenital or traumatic conditions as well as for elective cases.

The current method in which a prosthesis is produced for bone replacement is either by choosing an approximate prosthesis (using the experience of the Surgeon) from a pre-formed selection (typically made from metal, high density polyethylene or ceramics) or by hand-making an appropriate prosthesis, or by performing reconstructive surgery whilst the patient is in theatre. These methods have consequences on quality and on operational costs, since normally the prosthesis are geometrically irregular obligating the surgeon to make adjusts during the surgery process. These adjustments can increase substantially the surgery time and costs and, also can cause, in certain cases, traumas to the patient.

3. BACKGROUND TECHNOLOGIES

Fast and accurate design and manufacture of personalized prosthesis for surgical use in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies,

which are each at different stages of maturity (COCQUEREZ and PHILIPP, 1995; BROGDON, 2000; CORDEIRO, 2002; BAZAN, 2004; GRANDO, 2005; OHNISHI, 2005; STATELLA, 2008.).

3.1. Three Dimensional (3D) Processing of Images

The discovery of X Rays, which allow indirect access to the human body, enabled diagnostics to be made from images. However, the incorporation of the computerized tomography in the 1970's and subsequent advances in the processing of three dimensional images have vastly improved capabilities in human body visualization, providing valuable tools for diagnosis and treatment of many conditions. Data from tomography scans can be captured and extracted in the DICOM - Digital Imaging and Communications in Medicine format (2004). However, before this data can be used in the design of prosthesis, it needs to be converted, "cleaned" and pre-processed into a form suitable for transfer to a computer aided design (CAD) system (BAZAN, 2004; FRANCESCONI, 2008).

3.2. Geometrical 3D models in CAD systems

These days CAD systems are very valuable tools in the design of most (if not all) products. An aim of this research therefore is to determine a feasible methodology for the creation of virtual models of human prosthesis in a CAD/CAM system. However, despite their common usage, existing CAD systems still have several limitations that must be addressed if they are to be used in this context. The main problems for the complex three dimensional reconstruction that is required for the design of personalized prosthesis (based on individual patient's bone and body shapes) are bifurcation and open borders problems, as existing CAD software systems cannot solve these problems automatically.

The problems are largely due to the geometrical complexity of the individual human bones, indeed, they are so complex that it is hard to find mechanic components with such complexity. In the several CAD systems with solid and surface modellers that currently exist on the market, there are several common functions (e.g. loft, swept, rule, through curve, and others) that are utilized to generate the surface of the borders and produce a 3D model. As the geometry stays totally closed, the union of these surfaces can be transformed into a solid geometry. In short, the essence of this environment is to create surfaces or solids from parallel borders. The surfaces are obtained by the interpolation of a built curves sequence, most of them, in a parallel plane. Thus the following constraints exist which restrict our use of CAD in this application area:

- Limitation of only one border by plane;
- The border/curve must be closed;
- Some systems may not have the superposition of the borders/curves.

These problems largely have to be addressed in the cleaning and pre-processing stages, prior to importation of the data to the CAD system. It may also be necessary to simplify the region to be built. The image data must also be converted into an appropriate format before importing it into the CAD system to model the surfaces, since the CAD/CAM systems work in polygonal format (vector) and not in the matrix format (raster).

3.3. Model Virtual Machining CAM

Assuming that a solid geometry can be generated by the CAD system, based on the tomography image, the dimensions of the raw material needed for the CAM process (machining) can be determined. The virtual machining process can then be defined by dividing the model basically into two parts: external surface, for the representation of the external part of the bones; and internal surface for the representation of the internal part of the bones. Each part can then be defined in the software using the geometry of the model, the dimensions of the raw material and a definition of a point of reference (zero point).

With the defined geometry, to generate the trajectory of the machining, it is necessary to select the suitable tools, to obtain the most suitable surface finishing quality and the machining strategies. After these steps, a simulation is realized and if all elements are visually correct, the code CNC can be sent to the machining tool via DNC.

3.4. Summary of Methodology

Figure 1 shows the whole methodology divided in two main functions: i) the acquiring and conversion of the tomography image and the creation of the geometrical model in CAD; and ii) the virtual machining of the model.

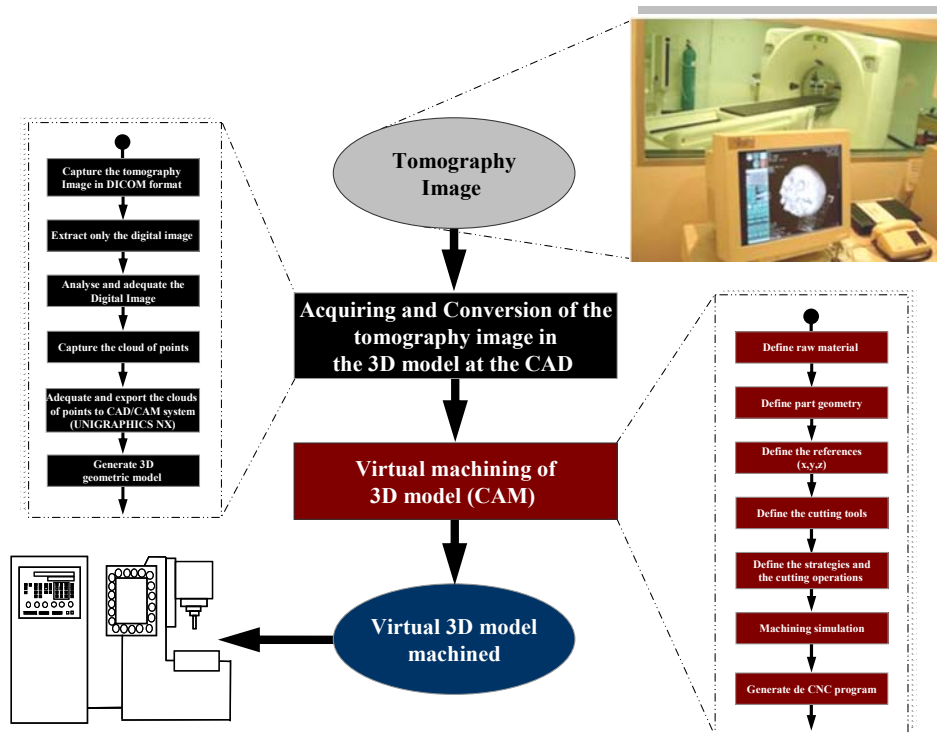


Figure 1 – Conception and manufacturing of prosthesis models.

4. INITIAL CASE STUDY WORK

In order to test the concepts of this research, initial case study work has been carried out at Pontifical Catholic University of Paraná (PUCPR), in Brazil. The case study experiments aimed to validate the research theories by making dimensional comparisons between a bone and a virtual model produced using the above methodology. In this initial experimentation, a femur bone from a cow was used, as it was easily purchased from a specialist supplier. See figure 2.

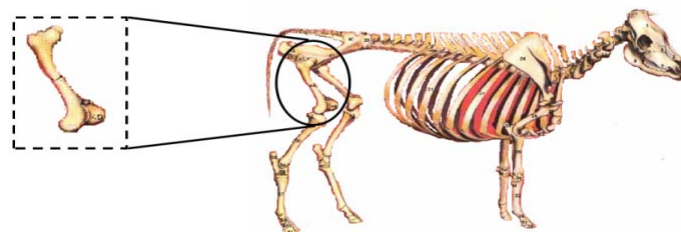


Figure 2 – Part used in the case study.

To demonstrate the feasibility of creating a virtual model for the reconstruction of only part of the femur, a section of the bone was selected for the experiments. The chosen part was near to the intermediate part, and large enough for about 40 tomography cuts to be taken. The part of the bone studied is shown in figure 3.

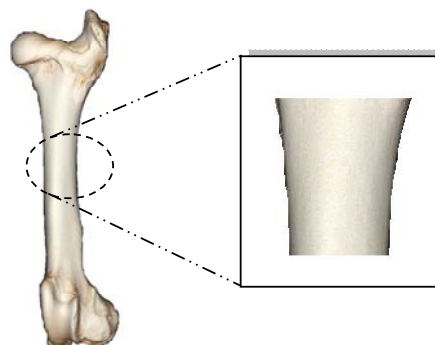


Figure 3 – Part of the femur to be studied.

4.1 Data Acquisition

The tomography examination of the femur was made in a helicoidal tomography scan machine from General Electric Medical Systems, model HiSpeed CT, as shown in figure 4.



Figure 4 – Bone in the tomographic scanner.

The software used for the image acquisition was the Image Works System, also from General Electric. The bone was lined up on the tomography scan machine with its “Z” axis coinciding with the machine scan directions. 288 tomography images were obtained, starting from the base of the femur and going up in the scan axis (z) a millimetre and a half for each tomographic image.

4.2 Data Analysis

The procedure for cleaning and pre-processing the tomography cuts is now discussed, by using the example of cut number 100. Each cut was treated in a similar manner, and cut number 100 was made at 151 mm from the base of the bone, in relation to the z axis. Firstly, the digital image was extracted from the DICOM archive, as shown in figure 5.

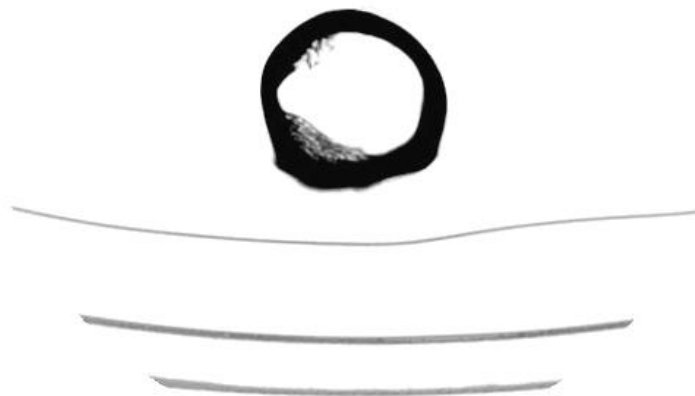


Figure 5 – Tomography cut number 100.

The following 5 steps were applied to obtain the points of clouds data. The results of each step are shown in figure 6.

Step 1: The image was cleaned to remove unwanted lines and imperfections due to the bone porosity. A filter can also be applied to improve the image intensity.

Step 2: The internal edge was then removed, whilst the external edge was maintained by keeping the original pixel values.

Step 3: Edge detection techniques (differentiation method) were applied.

Step 4: Prepared the image for the capture of the Cartesian coordinates. The edges of the image were split into two parts called left and right side. This division is necessary to avoid incoherency in the Cartesian coordinate's vectors obtained by the scan.

Step 5: Acquisition of the Cartesian coordinates. This capture was made in two stages: first the left side coordinates were captured and then the right side. After the capture, the coordinates were united to form a single vector.



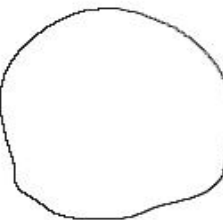

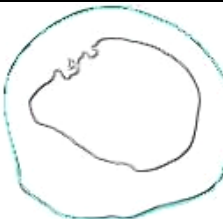
Image after Step 1.	
Image after Step 2.	
Image after Step 3.	
Image after Step 4.	
Image after Step 5.	

Figure 6 – Changes to Image during 5 steps of cleaning and pre-processing.

After these five steps of processing, the cloud of the points archive was obtained. It is important to note that the values were initially obtained in pixels and were later converted to mm. When the cloud of points archives had all been processed in this way, the data was imported into the CAD system and the repositioned planes were used in the loft command. Forty cuts (from the two hundred and eighty eight) were used for the reconstruction. See Figure 7.

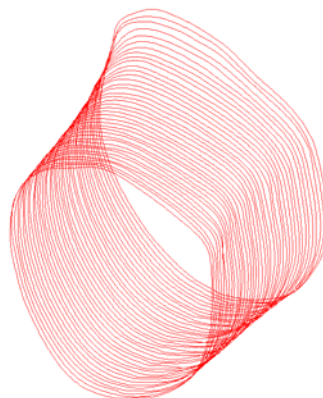


Figure 7 – Cuts positioned for the application of loft technique.

The loft command was then applied to the data to obtain the solid model. Figure 8 illustrates the union of the profiles.



Figure 8 – Application of loft command (to the parallel profiles).

4.3 Data Validation

To prove the dimensional results of the virtual model, the tomography femur was dimensioned. The first step was to precisely define which part was reconstructed by the methodology. As previously, explained, the interval of the analysed cuts started at the CUT 100 and finished at the CUT 140. The cut 100 is at 151mm from the bone base, the cut 140 is at 211 mm. Approximately 60 mm of the femur had therefore been studied and modeled.

After the interval of interest was determined, three marks were made to prove the dimensioning, at the beginning, middle and end of the sample (cuts 100,120 and 140). The Figure 9 shows the position of these marks in the part.

The dimensioning was made through a tri dimensional coordinates measure machine (DEA - Sirroco) with a certainty of 3 microns.

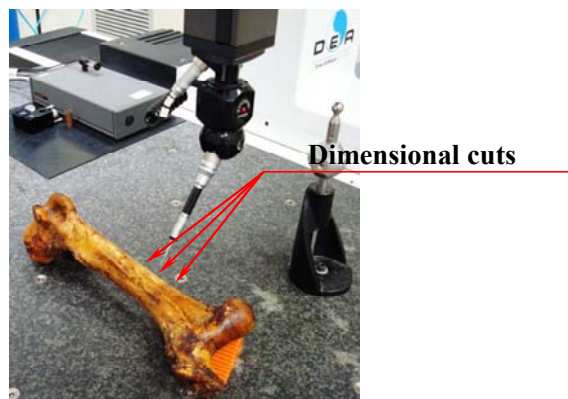


Figure 9 – Marks in the femur.

4.4 Comparative analysis of the Cartesian Points

Through the acquisition of the Cartesian points which were obtained with the help of the tri-dimensional machine the profiles at the positions of the three marks were reconstructed. The points were obtained through the contact, at each mark, of the pointer of the equipment with the bone part. An average of 18 points was captured for each curve. Figure 10 shows the reconstruction of the straight line segments from the points obtained.

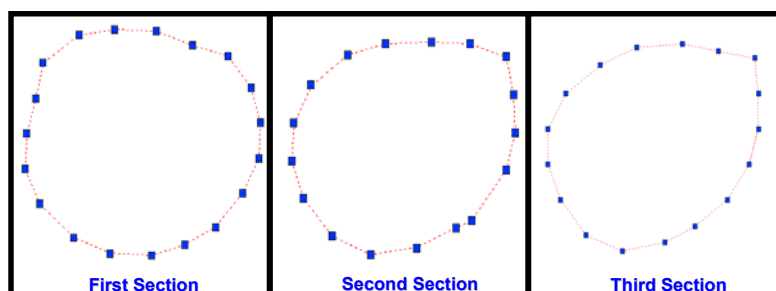


Figure 10 – Re-design of the profiles through tri-dimensional coordinate measurement machine software.

The virtual model obtained by the methodology and the virtual model obtained by the tri-dimensional were compared at eight referential points in order to verify their accurate comparison. These points were generated from the division of the profile in eight parts, from its centre, considering the origin of the Cartesian plan. Figure 11 illustrates the referential points for each marked location.

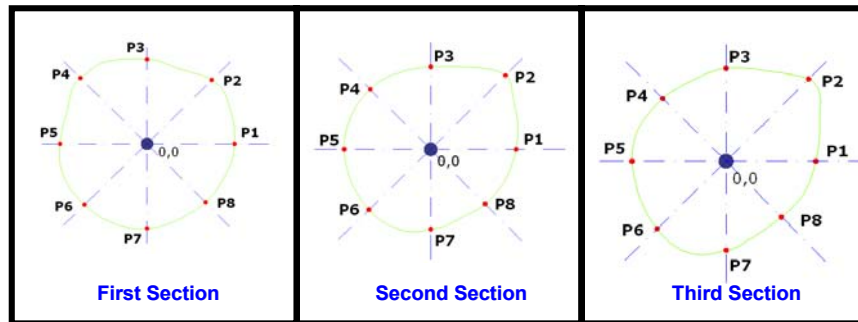


Figure 11 – Points references for each marks.

First Mark: As showed in table 1, in the first mark the point 6 (P6) in red had the greatest error, 0,201 mm in the xy axes. The biggest error in the x axis is in the point 5 (P5) in yellow, the value is 0.164mm; in the y axis the biggest error is in the point 7 (P7) in green, value of 0.232 mm.

Table 1 - Referential points for the first section.

REFERENCES POINTS						
Points	CAD Model		Tridimensional Model		Erros "X"	Erros "Y"
	x	y	x	y		
P1	22.934	0	22.907	0	0.027	0
P2	16.93	16.93	17.04	17.04	0.11	0.11
P3	0	22.412	0	22.436	0	0.024
P4	-17.484	17.484	-17.514	17.514	0.03	0.03
P5	-22.842	0	-22.678	0	0.164	0
P6	-16.442	-16.442	-16.241	-16.241	0.201	0.201
P7	0	-22.519	0	-22.287	0	0.232
P8	15.349	-15.349	15.269	-15.269	0.08	0.08

Figure 12, compares the two curves obtained at the position of the first mark. As the curves are very similar and overlap, they have been shown in contrasting colours, i.e. blue for the curve obtained by the methodology and red for the curve obtained by capturing the points using the tri-dimensional coordinate measuring machine.

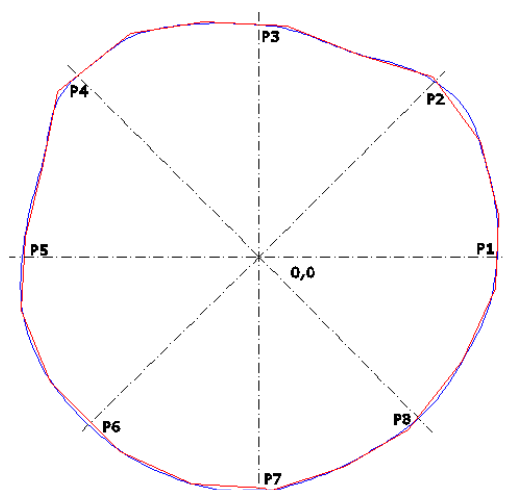


Figure 12 - Overlap curves for the first section.

Second Mark: As table 2 illustrates, for the second mark the point 2 (P2) in red presents the biggest error, in both axes the error was 0.232. The biggest error in the x axis is in the point 1 (P1) in yellow, value 0.405mm; in the y axis, the biggest error is in the point 7 (P7) in green, value of 0.236 mm.

Table 2 – Referential points for the second section.

REFERENCES POINTS						
Points,	CAD Model		Tridimensional Model		Erros "X"	Erros "Y"
	x	y	x	y		
P1	20.269	0	19.814	0	0.405	0
P2	17.751	17.751	17.519	17.519	0.232	0.232
P3	0	19.778	0	19.645	0	0.133
P4	-14.391	14.391	-14.184	14.184	0.207	0.207
P5	-20.599	0	-20.446	0	0.153	0
P6	-14.69	-14.69	-14.626	-14.626	0.064	0.064
P7	0	-19.171	0	-18.935	0	0.236
P8	13.027	-13.027	12.898	-12.898	0.129	0.129

Figure 13, compares the two curves obtained at the position of the second mark. As the curves are very similar and overlap, they have been shown in contrasting colours, i.e. blue for the curve obtained by the methodology and red for the curve obtained by capturing the points using the tri-dimensional coordinate measuring machine.

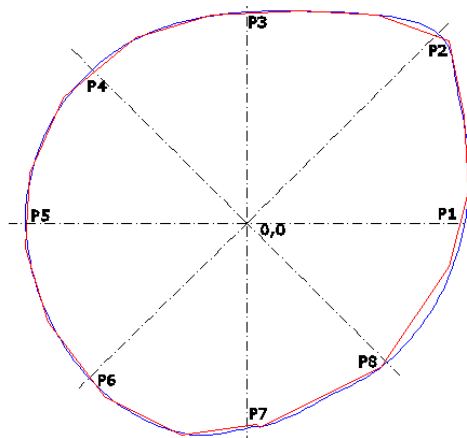


Figure 13 – Overlap curves for the second section.

Third Mark: As table 3 illustrates, for the third mark the point 4 (P4) in red presented the greater error, in both axes the error was 0.246mm. In the x axis there was no bigger error than point 4; in the y axis the biggest error is in the point 3 (P3) in green, value 0.259 mm.

Table 3 - Referential points for the third section.

REFERENCES POINTS						
Points,	CAD Model		Tridimensional Model		Erros "X"	Erros "Y"
	x	y	x	y		
P1	19.561	0	19.462	0	0.099	0
P2	18.026	18.026	18.072	18.072	0.046	0.046
P3	0	20.372	0	20.111	0	0.259
P4	-13.777	13.777	-13.531	13.531	0.246	0.246
P5	-20.511	0	-20.385	0	0.126	0
P6	-15.033	-15.033	-14.813	-14.812	0.221	0.221
P7	0	-19.526	0	-19.303	0	0.223
P8	12.047	-12.047	12.205	-12.205	0.158	0.158

In the Figure 22 is the overlapping of the two curves of the third Mark, in blue is the curve obtained by the methodology and in red the curve obtained by the capture of the points by the tri dimensional.

Figure 14, compares the two curves obtained at the position of the third mark. As the curves are very similar and overlap, they have been shown in contrasting colours, i.e. blue for the curve obtained by the methodology and red for the curve obtained by capturing the points using the tri-dimensional coordinate measuring machine.

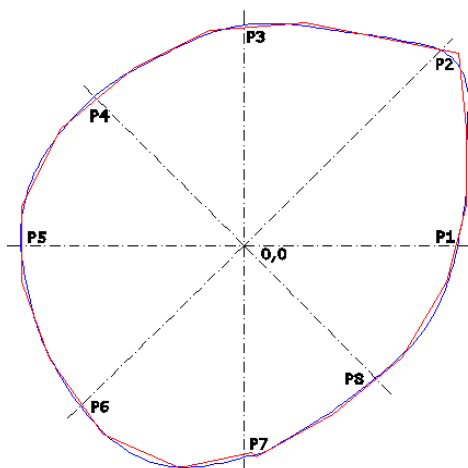


Figure 14 - Overlap curves for the third section.

5. CONCLUSIONS AND FURTHER WORK

This paper has discussed the feasibility of individually designing human prosthesis for surgical use and proposes a methodology for such design through mathematical extrapolation of data from digital images obtained via tomography of individual patient's bones. Fast and accurate design and manufacture of personalized prosthesis for surgical use in bone replacement or reconstruction is potentially feasible through the application and integration of several different existing technologies, which are each at different stages of maturity. Initial the case studied has been undertaken to validate the research concepts by making dimensional comparisons between a bone and a virtual model produced using the proposed methodology that was explored in section 3. Whilst the case study discussed in section 4 effectively demonstrates the feasibility of the concepts of this research, there is substantial extra research needed before these concepts could become a practical reality. The authors therefore propose to continue this work in several areas including:

- Understanding and investigating the information needs of both surgeons and patients in reconstructive surgery for bones;
- Evaluating the feasibility of the existing model for extrapolation of mathematical data from digital tomography of patients' bones to create virtual individually tailored human prosthesis;
- Further investigation of data cleaning and pre-processing techniques required to achieve the accuracy of alignment and sharpness of image from processed tomography sections for them to be used as the basis for initial design stage;
- Further investigation of image processing techniques for conversion to 3D models using CAD/CAM standards.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

- BAZAN, O. Usinagem de Próteses para cranioplastia a partir de imagens tomográficas. Curitiba. Dissertação (Mestrado). Universidade Federal do Paraná, 2004.
- BROGDON, B.G. Definitions in forensic and radiology. *Critical Reviews in Diagnostic Imaging*, v. 41, n. 1, p. 1-12, fev, 2000.
- COCQUEREZ, J.P., PHILIPP, S. *Image Analysis: Filtering and Segmentation*. 2 ed. Paris: Masson, 1995.
- CORDEIRO, F. M. Reconhecimento e Classificação de Padrões de Imagens de Núcleos Linfócitos do Sangue Periférico Humano com a Utilização de Redes Neurais Artificiais. Universidade Federal de Santa Catarina, 2002.
- D'URSO, P.S.; Stereolithographic (SL) biomodelling in caniofacial surgery. *British Journal of Plastic Surgery*, Edinburgh, V.51, n.7, p.522-530, 1998.
- DICOM, Digital Imaging and Communications in Medicine; <<http://medical.nema.org/>>, 2004.
- FRANCESCONI, T., "PROPOSTA METODOLÓGICA PARA MODELAGEM GEOMÉTRICA A PARTIR DE IMAGENS MÉDICAS". Curitiba, PPGEPS (Programa de Pós-Graduação em Engenharia de Produção e Sistemas), PUCPR, 2008.

- GRANDO, N. Segmentação de imagens tomográficas visando a construção de modelos médicos. Dissertação (mestrado), Centro Federal de Educação Tecnológica do Paraná, 2005.
- OHNISHI, O. Y. Método Baseado em Processamento Digital de Imagem para Diagnóstico Precoce de micro-Estruturas Dentárias. São Carlos. Dissertação (Mestrado). Universidade Federal de São Carlos, 2005.
- STATELLA, T., SILVA, E. A. Morfologia matemática aplicada a detecção de sombras e nuvens em imagens de alta definição. Bol. Ciênc. Geod., Sec. Artigos. Curitiba, v 14, n 2, p. 256-271, 2008.
- Website of the UK National Joint Registry (NJR), accessed January, 2009, www.njrcentre.org.uk.

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