

Digital modelling of a human skull

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Analysis and modelling

ABSTRACT

Purpose: This paper describes the first step of a project that aims to improve the design and placement of dental prostheses through an in-depth analysis of jaw movement. This analysis requires prior obtaining quality digital models of all elements involved in the movement. The paper describes the process to obtain the digital models through Reverse Engineering techniques, and evaluates their quality.

Design/methodology/approach: The process of digitalization of a human skull by means of a hand-held 3D laser scanner has been evaluated to see the suitability of this technique. A skull has been chosen as test element as it has several characteristics that make its digitisation by optical techniques difficult, such as a non-uniform surface and a complex geometry. The surfaces obtained by the scanner have been edited by point cloud edition software.

Findings: Reverse Engineering optical hardware has several limitations to correctly digitize complex geometries, but these deficiencies can be solved using the Reverse Engineering software properly.

Research limitations/implications: The same analysis should be performed by point clouds obtained through other Reverse Engineering technologies, such as structured light scanners. These technologies can achieve best values of accuracy and resolution, so that both results should be compared.

Practical implications: This paper gives the chance to apply Reverse Engineering techniques to achieve high quality digital models of free form complex geometries. The constraints presented by optical digitization technologies can be solved through powerful point cloud edition software.

Originality/value: This paper describes the process of digitalization of complex free form geometries and the subsequent point cloud edition.

Keywords: Engineering design; Reverse engineering; Surface reconstruction; Rapid prototyping

1. Introduction

This project comes up from the need to obtain quality digital models of the elements of the human skeleton, allowing a later digital reproduction and analysis of its movement. This can be achieved by means of Reverse Engineering tools.

This development was made in the Product Design Laboratory (PDL), in the Faculty of Engineering of Bilbao (The University of the Basque Country).

This Laboratory has centred its investigation efforts in Reverse engineering and Rapid Prototyping knowledge areas and is looking for new fields of application for these new design methods and promoting the technological transference with the surrounding companies.

The digitalization of the skull is the first stage of a project that PDL is developing together with a research group at the University of Cordoba.

In this first step, the digitization process and the quality of the digital model achieved by the reverse engineering techniques available in PDL have been evaluated. A skull has been chosen for this purpose because of its complex geometry. It has several holes and cavities that make the digitization process difficult. If it is possible to correctly digitize the skull, it will be possible to digitize any other element of the skeleton too.

Once the skull is digitized, the next stage is to scan a human jaw and to digitally reproduce the real motion of both elements (skull and jaw). The final purpose is to be able to digitize any element and reproduce its movement in a semi-automatic and

effective way. A thorough analysis of this movement will allow improving the design and placement of the prostheses [1].

2. Technical resources

The Reverse Engineering process in PDL uses the Handyscan REVscan 3D scanner and its software (VXscan), Reverse Engineering and Computer-Aided Inspection Software (Geomagic Studio and Qualify) and a Rapid Prototyping machine (Dimension SST). Figure 1 shows how PDL implements this process.

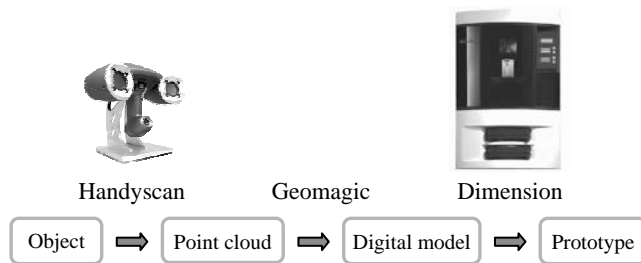


Fig. 1. Reverse Engineering in PDL

The Handyscan REVscan scanner from Creaform (Québec) is a versatile hand-held laser scanner. It can quickly create the point cloud of a surface with an accuracy of 0.05 mm and a resolution of 0.1 mm. Another advantage of this scanner is its software: VXscan uses powerful algorithms to create a high quality polygonal surface.

One of the main characteristics of this scanner is its method to position itself in space with the aid of reflective targets. At any moment, if the scanner can "see" at least four targets of the positioning model the software will be able to calculate its position in the system coordinates [2, 3], and it can start taking the needed data to build the point cloud of the object to be digitized.

To take that data, the scanner projects a crosshair over the surface (Figure 2), and the image of this projection is captured by the cameras. As the relative position of both cameras and the laser source is calibrated, the software calculates by triangulation the coordinates of the points that set the crosshair [4-6].



Fig. 2. Laser crosshair

When the crosshair is well defined in the images captured by the cameras, the software is able to take high quality data, with minimum noise. Otherwise, noise may appear in the point cloud.

To obtain the best definition in the images, scanner's parameters (laser power and shutter time) must be adjusted to each object that is going to be digitized.

Moving the crosshair throughout the entire surface, the scanner takes the needed data to build the point cloud of the surface. The software processes all the available data to optimize the result, so sweeping several times the same surface does not mean increasing noise in the point cloud, but improving the quality of the point cloud [7].

Due to the scanning object's geometry and the position of the scanner's laser source and the cameras, there may be blind zones where the scanner cannot take any data.

Once the model is digitized, depending on the detail level required in the point cloud, its density can be adjusted to optimize memory requirements. Point density can be significantly reduced without losing surface quality (quantity of points have been reduced to 20%) [8,9].

Once the scanning session is finished, the built point cloud can be exported as a STL file and can be edited by Geomagic Studio. This software gives a wide range of tools to reduce the point cloud's noise, fill holes, rebuild missing areas and modify the original point cloud to obtain the needed digital model.

This digital model can be printed in Dimension SST the Rapid Prototyping machine, so that the original object and the new one can be compared [10-12].

This Rapid Prototyping machine uses the FDM (Fused Deposition Modelling) process to build functional 3D models from bottom up, layer by layer. These models are made of a tough, durable acrylnitrile butadiene styrene (ABS) plastic. This plastic is heated to a semi-liquid state and deposited in thin layers by an extrusion head.

In addition to this ABS, in some layers the extrusion head deposits a different material called support material to create support structures. In some parts these structures are necessary to hold the upper layers. As the support material is soluble, these structures can be easily removed once built the part.

The Catalyst software automatically slices the model and calculates the necessary support structures that must be created to build the part.

This fabrication method makes building any complex geometry possible in a very simple way.

3. Digitizing the skull

Some characteristics of the skull make the digitizing process difficult:

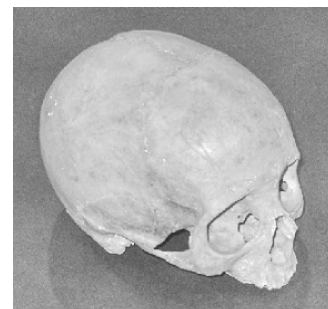


Fig. 3. The digitized skull

3.1. Non uniform surface

As seen in Figure 3, the surface of the skull has not a uniform colour. When setting the sensor parameters, it has not been possible to find a laser power and a shutter value that make the best result all over the surface of the skull.

Generally, when scanning a non uniform surface, the object uses to be powdered or painted to achieve a uniform and mate finish, the ideal for this sensor. But in our case this solution has been ruled out in order to avoid damaging the skull.

Therefore, values that give an acceptable outcome have been searched. This implies that there have been three different situations:

- Most reliable points make a quality point cloud
- Under-exposed points cause holes in the point cloud
- Saturated points stimulate noise creation

3.2. Surface discontinuity

On the other hand, the skull has many holes that make obtaining a good quality point cloud difficult (see Figure 4):

- Holes are so tiny that the software hasn't almost detected them and has created a continuous surface.
- For medium-sized holes, the software has detected the surface's discontinuity, but has not enough data to correctly define the hole, and noise has been generated around it.
- In bigger holes, the edge has been correctly scanned, so the software has been able to reproduce the hole.

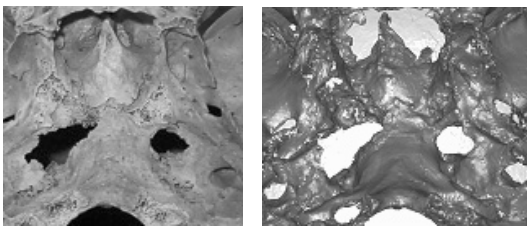


Fig. 4. Noisy data around the holes

3.3. Complex geometry

Another difficulty presented by the skull is its complex geometry. Due to the location of the scanner's cameras and the laser crosshair, it has been difficult or even impossible to take data of some areas. These hardly accessible areas have been carefully scanned with an adequate angle of attack to capture as much data as possible, but even doing so, some hollows have appeared in the point cloud [13].

3.4. Minimize targets in the skull

To avoid losing surface data, minimum targets have been fixed to the skull, and instead of it, targets have been placed around the object, in auxiliary elements. So that the coordinate system is fixed to these targets, it has not been possible to move the object during the scanning session.

Therefore, the skull has been digitized in five different positions to obtain five different point clouds that take on the entire skull's surface. Each position has been digitized independently, with no common targets, so each point cloud has been referred to its own coordinate system.

4. Point cloud edition

As result of the scanning of the skull, five separate point clouds have been exported from VXscan (Figure 5). These files have been imported and registered in Geomagic Studio to generate and edit the digital model of the skull [14]. Once registered, they have been merged to generate the point cloud of the whole skull.

Boundary data of each point cloud has been deleted before merging in order to reduce overlaps of surfaces and therefore, reduce noise in the point cloud.

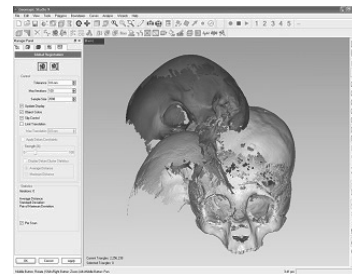


Fig. 5. The model is generated from five registered shells

The merged point cloud still has plenty of noise that must be removed, especially around the holes. Geomagic has several tools to automatically detect and even repair this wrong data. But these tools must be used with utmost care, as the user has little control over the operations.

As pointed out previously, due to the complex geometry of the skull, there are blind areas where the scanner has been unable to capture data, so they have been rebuilt by Geomagic repairing tools (Figure 6).

Once the digital model is edited, the last step is the optimization of the point cloud. There are several tools that can be used to optimize the model.

VXscan generates a uniformly distributed point cloud. But due to the shape of the surface, a higher point density will be required in some areas than in other ones [15]. Geomagic software can significantly reduce the size of the file by adapting the point density to the geometry of the skull.

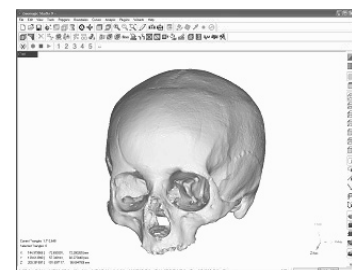


Fig. 6. The digital skull

5. Rapid prototyping

The digital model of the skull has been prototyped in Dimension SST. The new model is made of ABS plastic, by 0.254 mm high layers.

As the scanner only captures the surface of the skull, it has been necessary to create a closed surface by doing an offset of 2mm. This operation has created self intersecting surfaces that have been repaired to avoid changes in the shape of the model. This modification must be carefully done to maintain a minimum thickness of the shell. If the shell is too thin, holes may appear in the prototype [16]. Figure 7 shows the prototyped skull with the support structures.

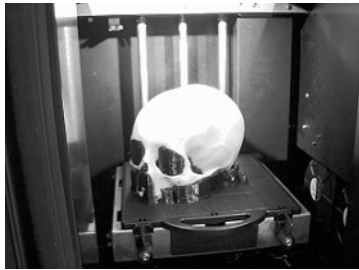


Fig. 7. The prototyped skull

6. Conclusions

As seen in this work, the Reverse Engineering system installed on PDL is a valid system to obtain a high quality digital model of the Skull and any other bone of the skeleton. Despite its heterogeneous surface, it has not been necessary to apply spray to the skull to get a good digital model. Moreover, even if the scanner was unable to pick up points in certain areas of the skull, these areas have been rebuilt with Geomagic, the point cloud editing software.

Throughout the digitalization process, a point cloud of as highest quality as possible has been looked for and any step that could deteriorate the skull has been avoided.

This process can be simplified and still get a high quality point cloud. The holes at the bottom of the skull can be covered without losing the shape of the skull. This would achieve a continuous surface, and thus a continuous point cloud, reducing the amount of holes and noise.

Moreover, targets can be fixed to the object instead of using auxiliary elements. Details of the surface would be lost in some areas, but the whole shape of the object would be captured in a unique point cloud. This would allow moving the object during the scanning session.

Furthermore, spray can be applied to get a uniform surface. This would get an optimal scanner configuration and consequently reduce the appearance of noise in the point cloud.

7. Future work

The whole process will be repeated with a structured white light scanner. The resolution, accuracy and the noise of the point clouds acquired by both, the laser scanner and the structured light scanner will be compared, as well as the quality of the digital models obtained after edition. This will enable to choose the best system in order to get the digital model of the skeleton.

Once the skull is digitized, the next stage is to scan a human jaw. The movement of both elements, skull and jaw, is going to

be analyzed and, as result of this study, the design and placement of surgical prosthesis will be improved.

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