

## DIGITAL RECONSTRUCTION OF A HUMAN SKULL

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### 1. Introduction

This paper describes the process of reconstruction of the digital model of a human skull. 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 centered 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 has 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.

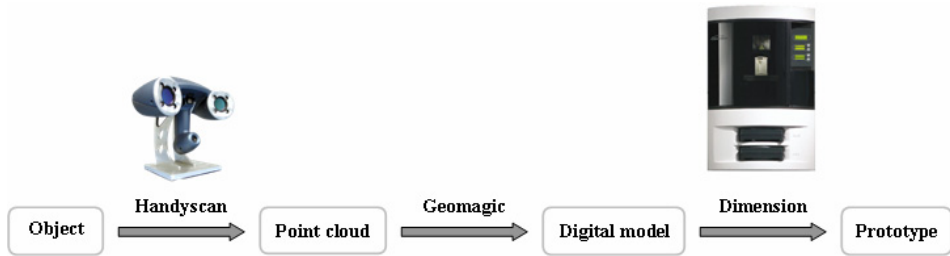
Once the skull is digitized, the next stage is to scan a human jaw and to digitally reproduce the real motion of both elements (skull and jaw). The final purpose is to be able to digitize any element and reproduce its movement in a semi-automatic and effective way. A thorough analysis of this movement will allow improving the design and placement of the prostheses.

### 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.

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 the beginning of each scanning session, the first time the scanner “sees” at least four targets, it fixes the system coordinate axis in the position the scanner is at that moment and calculates and saves the position of each target.



**Figure 1. Reverse Engineering in PDL**

These targets and the ones that the scanner “sees” along the scanning session bring up the positioning model. 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 [Hébert, 2001].

Once the scanner is located in the system coordinates, 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, and the image of this projection is captured by the cameras. As the relative position of both cameras and the laser emisor is calibrated, the software calculates the coordinates of the points that set the crosshair by triangulation [Prieto, 1999].



**Figure 2. Triangulation**

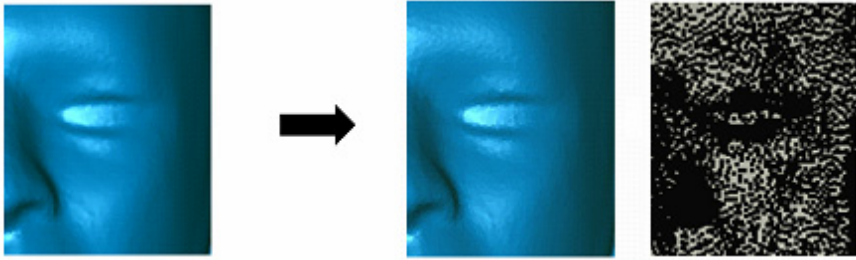
When the crosshair is well defined in the images captured by the cameras, the software is able to take high quality data, with minimum noise. Otherwise, noise may appear in the point cloud.

To obtain the best definition in the images, scanner’s parameters can be adjusted to each object that is going to be digitized. The parameters to adjust are the laser power and the shutter time; dark surfaces reflect less light than clear ones, so a higher laser power and a longer shutter time will be required. A too low power or a too short shutter time will make a too weak reflection, so that the crosshair will have a poor definition. On the other hand, when working with light surfaces, a too high power or a too long shutter time can blind the cameras.

Moving the crosshair throughout all the 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 [Deschênes, 2005].

Due to the scanning object’s geometry and the position of the scanner’s laser emisor 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. As seen in Figure 3, point density can be significantly reduced without losing surface quality (quantity of points have been reduced to 20%) [Hormann, 2001].



**Figure 3. Optimization of the density of the point cloud**

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 the Dimension SST Rapid Prototyping machine, so that the original object and the new one can be compared [Sierra, 2006].

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 the part is built.

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:



**Figure 4. The digitized skull**

### 3.1 Non uniform surface

The surface of the skull has not a uniform color. When setting the sensor parameters, it has not been possible to find a laser power and a shutter value that produce the best result all over the surface of the skull.

Generally, when scanning a non uniform surface, the object is 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
- some under-exposed points cause holes in the point cloud
- some 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:

- Some 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.

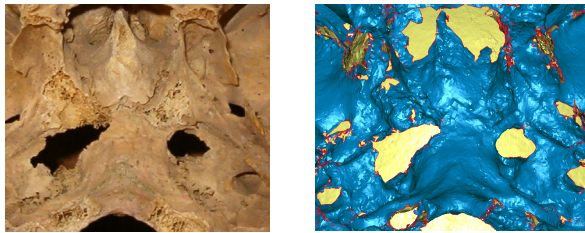


Figure 5. Noisy data around the holes

### 3.3 Complex geometry

Another difficulty presented by the skull is its complex geometry. Due to the ubication 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.

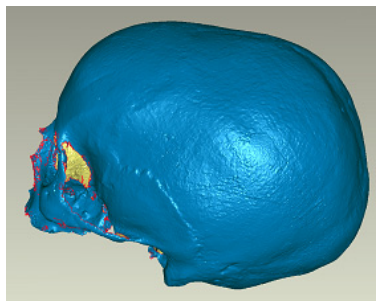


Figure 6. Blind zones generate hollows

### 3.4 Minimize targets in the skull

To avoid losing surface data, minimum targets have been fixed to the skull, and instead, targets have been placed around the object, in auxiliary elements. As 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 combine all the 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. These files have been imported in Geomagic Studio to generate and edit the digital model of the skull. To register the point clouds to bring up the whole skull, common points have been indicated in the several point clouds in order to generate an initial composition of the model. To refine this first approach, Geomagic processes all data to calculate the best relative position of the point clouds [Benkő, 2001]. Once registered, they can be 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.

The Handyscan REVscan scanner processes all the collected data to generate a high quality point cloud. If the scanner sweeps the same surface several times, the software will have more data to process, and the result will be more accurate. But in the limits of the point clouds there is few data that can be processed, so boundary data has been deleted as it may have plenty of noise.

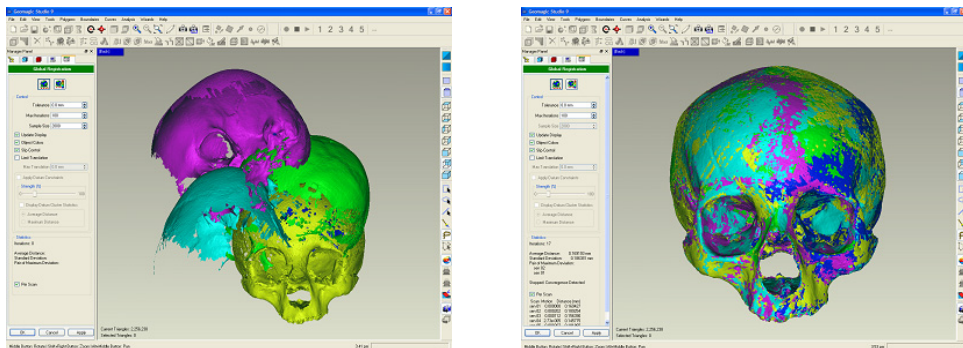


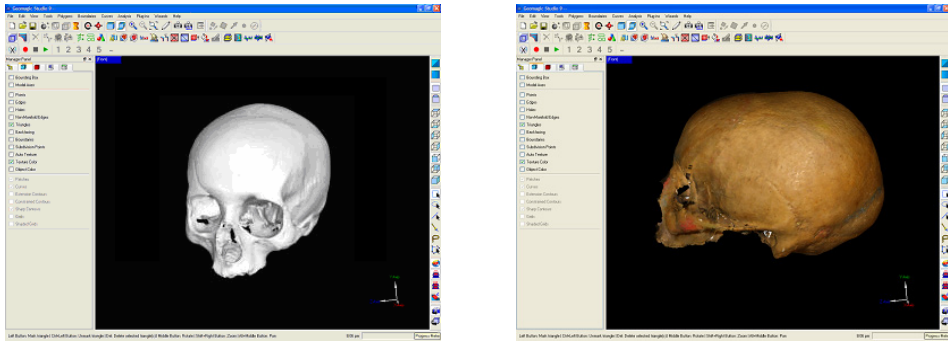
Figure 7. Registered point clouds

When merged, a single point cloud of the whole skull has been obtained. It 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. Geomagic has not specific tools to rebuilt these zones, but it has been done by means of filling holes tools.

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 more than in other ones [Taubin, 2002]. Geomagic software can significantly reduce the size of the file by adapting the point density to the geometry of the skull. But in this case, as the skull has not a smooth surface, the original point distribution has been maintained to avoid losing surface details.



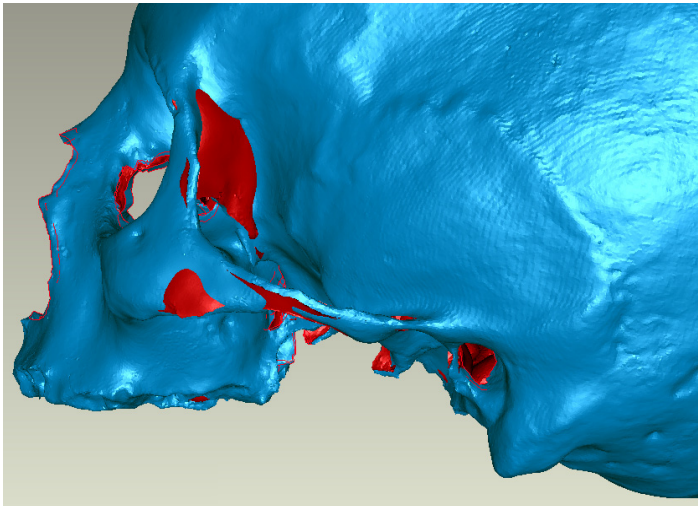
**Figure 8. Improved visualization**

To improve the visualization of the skull, several textures can be generated and even a similar finish to the original model can be achieved.

## 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.

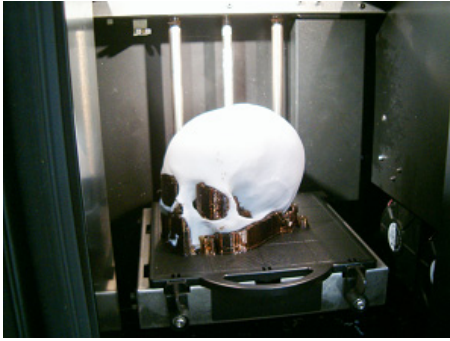
As the scanner only captures the surface of the skull, it has been necessary to create a closed surface to build up the model. This closed surface has been achieved by doing an offset of the surface, generating a 2mm thick shell.



**Figure 9. Self intersecting surfaces**

This operation has created self intersecting surfaces as shown in Figure 10, which 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.





**Figure 10. The original skull and the prototype**

## 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. In this way we 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, some 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.

Finally, in order to extend the study to the whole skeleton, a system to semiautomatically digitize each element of the skeleton and reproduce the motion of the whole group will be sought. A deep analysis of this movement will be the departure point to improve the design of the surgical prostheses, and the placement of these ones.

## References

- Benkő, P., Martin, R., Varady, T. "Algorithms for reverse engineering boundary representations models", *Computer Aided Design*, Vol. 33, No. 11, 2001, pp. 839-851.
- Hébert, P., "A self referenced hand held range sensor", *Proceedings of the IEEE International Conference on Recent Advantages in 3-D Digital Imaging and Modeling*, 2001, pp 5-12.

Hormann, K., Labsik, U., Greiner, G., "Remeshing triangulated surfaces with optimal parameterizations", *Computer-Aided Design*, Vol. 33, 2001, pp. 779-788.

Sierra, E., Solaberrieta, E., Minguez, R., Barrenetxea, L., Belaustegigoitia, B., Larrakoetxea, I., "A University-company project: design of a new surfboards digital modelling process", *2<sup>th</sup> international conference on geometry and graphics, Salvador (Brazil), 2006*.

Deschênes, D., Hébert, P., Lambert, P., Quellet, J.-N., Tubic, D., "Multiresolution interactive modeling with efficient visualization", *5<sup>th</sup> Int'l Conf. on 3D Digital Imaging and Modeling, 2005*, pp. 39-46.

Taubin, G., "Detecting and reconstructing subdivision connectivity", *The Visual Computer*, No. 18, 2002, pp 357-367.

Prieto, F., Redarce, T., Lepage, R., Boulanger, P., "Visual systems for fast and automated inspection of 3D parts", *Revue Internationale de CFAO et d'informatique graphique, 1999*, pp 1-17

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