

A TOOL BOX TO IDENTIFY HOLES IN 3D HUMAN BODY SCANS

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Even the best 3D whole body scanners can not guarantee 100 percent coverage of the body surface area due to occlusion effects. Hence, holes will appear in the obtained 3D body scans. It is important for the user to know the location and magnitude of the holes in the resulting scans. Therefore, a tool box was developed that reads the input model, corrects topological errors and identifies, classifies and visualizes holes in 3D.

INTRODUCTION

Although 3D body scanning has powerful applications in several research areas (Jones and Rioux, 1997), the problem of holes in the scans limits their use. Due to the appearance of holes in the scans, several measurements, like body surface area and body volume, can not be made and milling a hardcopy of the scan is impossible. Methods are available that fill holes automatically (e.g. Carr et al. 2001). However it is important to realize that the filled gaps do not represent the actual data. Therefore, a hole identifier tool box has been designed to be able to clean the input scan and detect, classify and show the holes in the 3D body scan.

METHODS

Topological Cleaning

The goal of the topological cleaning method of the tool box is to create a 2-manifold mesh out of the input mesh generated by the surface reconstruction software. A 2-manifold mesh has the desired properties to describe the surface and the volume of a real world object, in this case a human body. The mesh is defined by a set of points and a set of polygons, which connect these points. Each polygon is a subset of these points, with a minimum of size three, defining a face. A 2-manifold mesh does not contain:

- single, unconnected vertices,
- single, unconnected edges,
- self intersections,
- singular edges,
- singular vertices.

The appearance of self intersections in the mesh (Fig. 1a) is checked and solved by the surface reconstruction software.

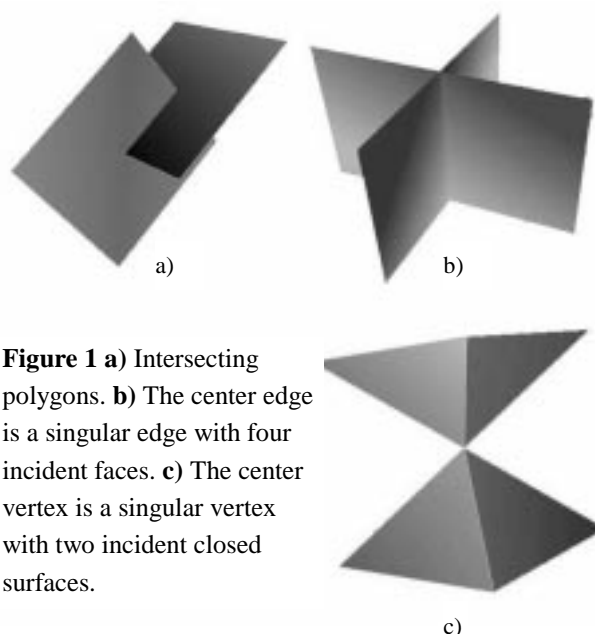


Figure 1 a) Intersecting polygons. b) The center edge is a singular edge with four incident faces. c) The center vertex is a singular vertex with two incident closed surfaces.

The unconnected vertices and edges are easily removed by the tool box. The singular edges and vertices are solved as well.

An edge is singular when it has more than two incident faces. An example is shown in Fig 1b. To solve the problem, the least important faces incident to this singular edge are removed, until the number of incident faces reaches the number of two. The decision on which faces are the most important is made by looking at the degree of the vertices within a face. The degree of a vertex is the number of incident faces of that vertex. The average of the degrees of the incident vertices of a face defines the importance of the face: the higher the average, the more important the face. The decision to just remove the least important face(s) in

stead of repairing the situation may seem to be rigorous, but the situations in which these topological errors occur are often caused by unreliable information given by the scanner in that region. That is why removal of these faces is probably the best solution.

Solving the problem of singular vertices in the model is another problem. A vertex is singular when it is surrounded by faces which shape a closed surface and incident to faces which are not part of this enclosing surface. An example of such a situation is shown in figure 1c. The faces which are not part of the enclosing surface have to be removed. When two enclosing surfaces come together in the vertex, the faces of one of these surfaces should be removed.

Again the removal of these faces may seem rigorous, but because of the same reason mentioned before, it is probably the best way to deal with the problem.

When the singular edges and vertices are removed, a 2-manifold mesh is created, which is ready for the next step of the hole identification.

Hole detection

To detect the holes in the 2-manifold model, the polyhedral data structure (Kettner, 1999) is applied which is implemented as part of CGAL (Computational Geometry Algorithms Library, <http://www.cgal.org>). For an exhaustive report we refer the reader to Van Stralen (2003).

Hole classification

The hole classification is done using two different methods. The first method is a rule based method using classification boxes, the other method is segmentation based.

The rule based method uses classification boxes to describe the areas where certain body parts are located. It requires knowledge about the position of the scanned subject. The subjects are all scanned in a standard standing position defined in the CAESAR project (Robinette et al., 2002). The position and the dimensions of the classification boxes are derived from the subject's stature and interscye (distance between right and left axilla), which can be easily extracted from the scan. Formulas which describe these positions and dimensions of the boxes are derived from the Dutch NedScan (<http://www.nedscan.nl>) data. Formulas for the height of certain body parts are derived, as well as the

distance to the horizontal center of the body. Different formulas are used for left and right, and for men and women. For example the formula for the right axilla height for men is (in mm):

$$\text{RightAxillaHeight (men)} = 0.803 * \text{Stature} - 98.4$$

The dimensions of the right axilla box (in mm) are determined with the following formulas:

$$\text{Min. X-coordinate} = \text{Average}(X) - 60$$

$$\text{Max. X-coordinate} = \text{Average}(X) + 120$$

$$\text{Min. Y-coordinate} = \text{Average}(Y) + 1/4 * \text{Interscye}$$

$$\text{Max. Y-coordinate} = \text{Average}(Y) + 4/7 * \text{Interscye}$$

$$\text{Min. Z-coordinate} = \text{RightAxillaHeight} - 0.07 * \text{Stature}$$

$$\text{Max. Z-coordinate} = \text{RightAxillaHeight} + 0.02 * \text{Stature}$$

The average x- and y-coordinates denote the x- and y-coordinate of the centroid of the scan, which is defined as the mean of all points from the scan.

These boxes are defined to border the feet, armpits, shoulders and the top of the head. To locate the boxes for the hand the finger tips are found using the segmentation algorithm.

The segmentation based method uses a simple but robust 2D segmentation algorithm. This algorithm projects the mesh on the 2D YZ- and XZ-plane. The projection on the YZ-plane results in a silhouette of the subject like the one in Fig. 2. The algorithm uses this silhouette to identify arms, legs, torso, head and crotch. The silhouette lies on a grid. Each point in the mesh is projected on the plane and for each cell in this grid an 'X' is shown when there are one or more points projected in it and a '.' if no point is projected in the cell. To determine the body parts the number of segments in each line in the projection is counted. By looking at each line from top to bottom, all the segments are given a meaning using a scheme which defines the state in which the algorithm can be. A possible state can be 3_{ATA} for example, which means that in that line there are three segments: the first is part of the Arm, the second of the Torso and the last one of the other Arm. The position and the width of the segments, in relationship to the previous and next line, are used to determine when the neck is found and whether a right or left axilla etc. is found.

In some cases the crotch will be found too low in the (front) projection on the YZ-plane, because the inside of the thighs

are making contact. To improve the algorithm a projection on the XZ-plane is used as well.

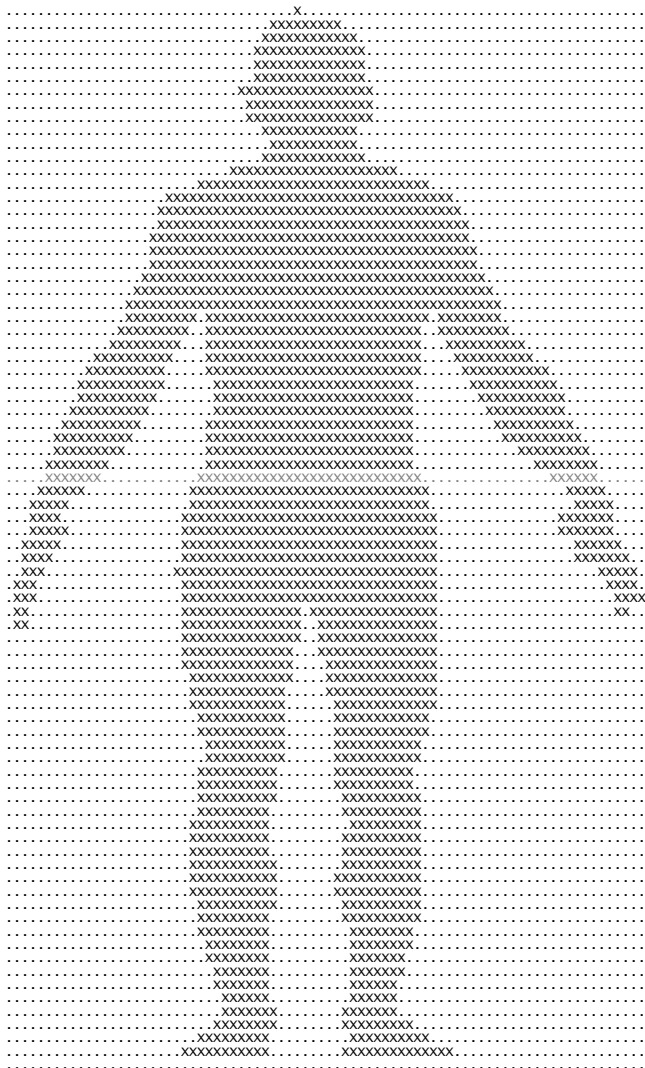


Figure 2 The projection of a scan on the YZ-plane. The gray line shows an intersection with three segments.

To determine what label a hole deserves, the amount of vertices of that hole that are in a certain classification box is counted. This results in one or more labels that are attached

to the hole with a percentage equivalent to the percentage of vertices of the boundary of the hole that are in the classification box. The final result is printed in a table in which the holes with the largest circumference are ranked first. The tool box generates a 3D view of the (boundaries of the) holes. The holes have a color that is representative for the classification or segmentation type.

RESULTS

Fig. 3 shows the visual output of the program and Table 1 shows part of the table output.

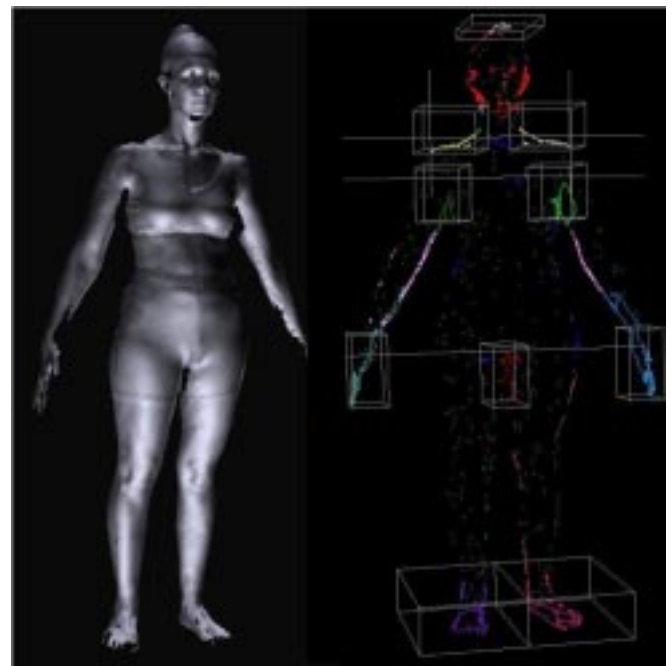


Figure 3 The visual output of the Hole Identifier Tool Box

The tool box has been tested on 54 scans that were made of 18 subjects, each scanned three times in the standard standing position using the Vitronic VITUS Pro scanner (<http://www.vitronic.de>). First the scans were processed using PolyWorks (<http://www.innovmetric.com>) to get an initial 3D mesh. They were aligned in 15 iterations, and

Table 1 The output of the Hole Identifier Tool Box. The properties of each hole are shown.

HoleID	#Vertices	Outline	“Half hole” outline	Av. dist to centroid	Label	Percentage	Centroid X	Centroid Y	Centroid Z
1	324	2059.0	1816.2	117.14	Arm Left	100%	-335.7	258.5	857.7
1	324	2059.0	1816.2	117.14	Hand Left	66%	-335.7	258.5	857.7
2	251	1590.1	1430.6	88.52	Arm Right	100%	-361.7	1006.8	853.7
2	251	1590.1	1430.6	88.52	Hand Right	73%	-361.7	1006.8	853.7

merged with a sub sampling distance of 4 mm and a maximum distance of 10mm. This resulted in Wavefront OBJ files with a size between 13 and 20 MB containing around 100k vertices.

These meshes were used as input for the tool box and made 2-manifold. The holes were detected and classified using a PC with a 950 MHz AMD Athlon processor with 256 MB RAM. The topological cleaning took approximately 7 minutes per scan and ran without any problems. The hole identification was much faster, approximately 90 seconds, and performed very well. Only in the case of one scan, the hole identification could not be done due to a CGAL error. The main classifications that were made by the tool box have been checked by hand and this showed that more than 98% of the holes were classified well.

An estimation of the total hole surface area (HSA) could be made by subtracting the total area of the faces in the mesh from the body surface area (BSA) estimated by the DuBois and DuBois (1916) method that was recently confirmed to be accurate (Tan et al., 2001).

The HSA of three consecutive scans shows similar results. The largest difference between the minimum and maximum HSA is only 11.4% and in most cases a lot less. However, these constant results did show the scanners difficulties in viewing between the legs and between the torso and the arms.

The HSA was significantly related to BMI (correlation 0.597), meaning that relatively corpulent people have larger holes in their scan.

CONCLUSIONS AND RECOMMENDATIONS

We have developed and implemented an easy to use tool box that removes topological errors from scans, classifies holes and interactively visualizes holes in 3D. The tool box may be used to compare different scanners or mesh reconstruction algorithms, or as a starting point for developing new methods to fill the holes in the scans.

The program can be downloaded from <http://Give-lab.cs.uu.nl/Student-projects/HoleIdentifier/>.

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