Facial Shape Analysis and Sizing System

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Abstract. The understanding of shape and size of the human head and faces is vital for design of facial wear products, such as respirators, helmets, eyeglasses and for ergonomic studies. 3D scanning is used to create 3D databases of thousands of humans from different demographics backgrounds. 3D scans have been used for design and analysis of facial wear products, but have not been very effectively utilized for sizing system. The 3D scans of human bodies contain over hundreds of thousand grid points. To be used effectively for analysis and design, these human heads require a compact shape representation. We have developed compact shape representations of head and facial shapes. We propose a sizing system based on cluster analysis along with compact shape representations to come up with different sizes for different facial wear products, such as respirators, helmets, eyeglasses, etc.

Keywords: Anthropometry, shape descriptor, cluster analysis, PCA

1. Introduction

The understanding of shape and size of the human head and faces is vital for design of facial wear products, such as respirators, helmets, eyeglasses and for ergonomic studies. With the emergence of 3D laser scanners, there have been large scale surveys of humans around the world, such as the CAESAR anthropometric database. The 3D scans of human bodies contain over hundreds of thousand grid points. To be used effectively for analysis and design, these human bodies require a compact shape representation. We have developed two such compact representations based on human head shape by applying Principal Component Analysis on the facial surface and in the second method the whole head is transformed to a spherical coordinate system expanded in a basis of Spherical Harmonics. Then we use cluster analysis on these shape descriptors along with the number of cluster that come up with the sizing system for different product; such as, facial respirators, eyeglasses, helmets, and so on. Cluster analysis is a technique for extracting implicit relationship or patterns by grouping related shape descriptors. A cluster is a collection of objects that are similar to one another and are dissimilar to the objects in other clusters. There are a number of clustering techniques, but we have only tried k-mean and k-median techniques.

Paquet et. Al [11] have used cluster analysis for adjusting the sizes of virtual mannequin using anthropometry data.
Facial respirators are used by millions of people around the world to reduce their risk to diseases, harmful and hazardous airborne agents. At the heart of the effectiveness is the seal of the respirator which mainly depends on the fit, which prevents harmful gases and particulates from enter into the wearer's respiratory system.

The Los Alamos National Laboratory (LANL) fit test panel developed in the 1970's is based on an anthropometric survey conducted in 1967 of Air Force personnel and still the standard for today's respirator fit tests. The National Institute for Occupational Safety and Health (NIOSH) conducted a new survey in 2001 entitled the NIOSH Head-and-Face Anthropometric Survey of U.S. Respirator Users to produce a more accurate picture of the civilian workforce. Following analysis of the survey revealed that the LANL panels were in fact not representative of most respirator users in the U.S. Out of the 3997 respirator users in the survey, 15.3% of them were outside of the LANL fit test panel.

Although the fit test panel is in the process of being updated, the core of these fit tests is still traditional anthropometric measures, which simplify the complexity of the shape of the human face.

Today most manufactures supply half and full facial mask respirators based on the facial grouping that are based on the above surveys. However, many researchers have shown that there are little or no correlations between facial dimensions and the fit of half mask respirator (Yang et.all 2008). Hence the best respirator shape for the best seal fits can only be archived by using the full 3D facial data.

In this paper, we describe the CAESAR database. Then the different compact shape descriptors to represent the facial and head shape. Then finally, we discuss cluster analysis along with the shape descriptors for sizing system for facial wear products.

2 CAESAR database

The CAESAR (Civilian American and European Surface Anthropometry Resource) project has collected 3D Scans, seventy-three Anthropometry Landmarks, and Traditional Measurements data for each of the 5000 subjects. The objective of this study was to represent, in three-dimensions, the anthropometric variability of the civilian populations of Europe and North America and it was the first successful anthropometric survey to use 3-D scanning technology. The CAESAR project employs both 3-D scanning and traditional tools for body measurements for people ages 18-65. A typical CAESAR body is shown in Figure 1.

Fig. 1. A CAESAR body with three postures

The seventy-three anthropometric landmarks points were extracted from the scans as shown in Figure 2. These landmark points are pre-marked by pasting small stickers on the body and are automatically extracted using landmark software. There are around 250,000 points in each surface grid on a body and points are distributed uniformly.

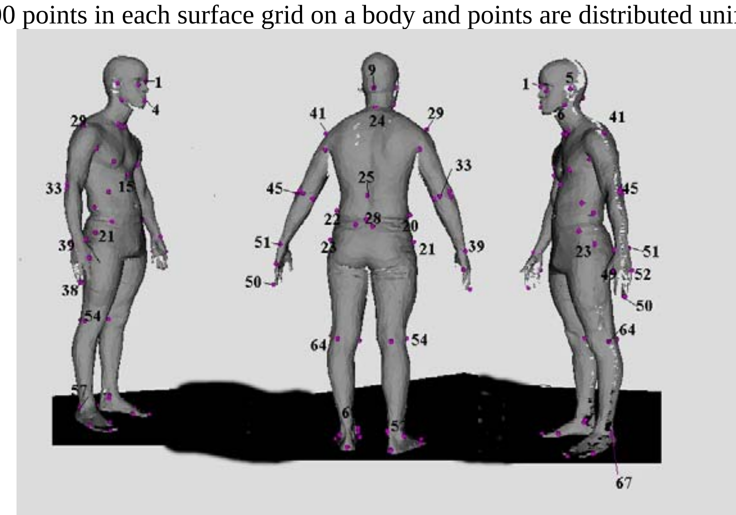

Fig. 2. A Caesar body with landmark numbers and positions

3 Head Shape Descriptor

We now describe two methods for creating descriptors based on human head shape.

3.1 PCA Based

The first shape descriptor is based on applying principal component analysis (PCA) on the 3D facial grid and the most significant eigenvectors is the shape descriptor. PCA is a statistical technique to reduce the dimensionality of the data set and it has also have been applied to face recognition.

First we use four anthropometric landmark points on the face from the database to properly position and align the face surface and then interpolate the surface information on a regular rectangular grid whose size is proportional to the distance between the landmark points. The grid size is 128 in both directions. Next we perform principal component analysis (PCA) on the set of regular 3D surface grid to create the PCA based shape descriptor.

The facial grid is cut from the whole CAESAR body grid using the landmark points 5 and 10 as shown in Figure 3 and listed in Table 1. Table 1 list all the numbers and names of landmark points used in our 3D face shape descriptor. The new generated facial grid for some of the subjects with two different views is shown in Figure 3. The facial grid is very coarse for some of the subjects in the seated pose.

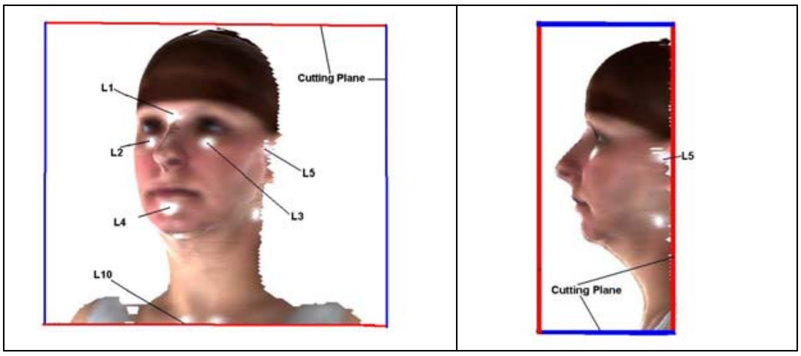

Fig. 3. Landmark points 1, 2, 3, 4, 5 and 10. Vertical and horizontal lines are the cutting plane

Table 1. Numbers and names of landmark points used in our 3D face

1 Sellion	2 Rt Infraobitale
3 Lt Infraobitale	4 Supramenton
5 Rt.Tragion	6 Rt. Gonion
7 Lt. Tragion	8 Lt. Gonion
10 Rt. Clavicale	12 Lt.Clavicale

Next, we use four anthropometric landmark points (L1, L2, L3, L4) as shown in Figure 5, located on the facial surface, to properly position and align the face surface using an iterative method. There is some error in alignment and position because of error in measurements of the position of these landmark points. Then we interpolate the facial surface information on a regular rectangular grid whose size is proportional to the distance between the landmark points L2 and L3 (d=| L3 - L2 |) and whose grid size is 128 in both directions. We use a cubic interpolation and handle missing values with the nearest neighbor method when there are voids in the original facial grid. For some of the subjects there are large voids in the facial surface grids. Figure 4, shows the facial surface and the new rectangular grid.

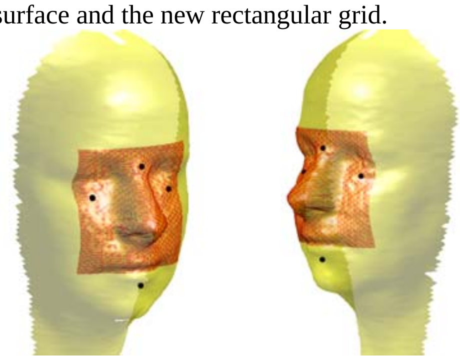

Fig. 4. Shows the new facial rectangular grid for two subjects

We properly positioned and aligned the facial surface and then interpolated the surface information on a regular rectangular grid whose size is proportional to the distance between the landmark points. Next we perform Principal Component Analysis (PCA) on the 3D surface and similarity based descriptors are created. In this method the head descriptor is only based on the facial region. The PCA recognition method is a nearest neighbor classifier operating in the PCA subspace.
To test how well the PCA based descriptor performs, we studied the identification between 200 standing and sitting subjects. The CMC at rank 1 for the study is 85%. More details about this descriptor are described in the paper by [Godil 2004, 2006]

3.2 Spherical Harmonics Based

In the second method the 3D triangular grid of the head is transformed to a spherical coordinate system by a least square approach and expanded in a spherical harmonic basis as shown in Figure 5. The main advantage of the Spherical Harmonics Based head descriptor is that it is orientation and position independent. The spherical harmonics based descriptor is then used with the L1 and L2 norm to create similarity measure. To test how well the Spherical Harmonics Based head descriptor performs, we studied the identification of the human head between 220 standing and sitting subjects. The CMC at rank 1 for the study is 94%.

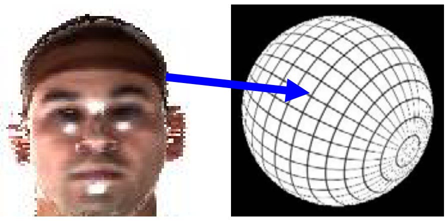

Fig. 5. 3D head grid is mapped into a sphere

4 Cluster Analysis

We have used the compact face descriptors for clustering. Clustering is the process of organizing a set of faces/heads into groups in such a way that the faces/heads within the group are more similar to each other than they are to other bodies belonging to different clusters. We use k-mean cluster analysis along with the shape descriptors and the number of clusters to come with sizes for products design such as respirator.

The k-means algorithm is an algorithm to cluster n objects based on attributes into k partitions, k < n. It is similar to the expectation-maximization algorithm for mixtures of Gaussians in that they both attempt to find the centers of natural clusters in the data, where there are k clusters.

$$V = \sum_{i=1}^{k} \sum_{x_j \in S_i} (x_j - \mu_i)^2 \qquad (1)$$

5 Results

For this initial study, we have used the facial surface of the first 200 standing subjects from the CAESAR database. The PCA based shape descriptor is calculated for these faces and then K-means clustering is applied and the number of cluster selected is four. Figure 6, shows the 40 faces out of the 200 faces that were used for clustering. The four different colors show the different clusters. When we are doing cluster analysis with the facial shape descriptor we can vary the emphasis on the shape verses the size. We should emphasis that these results based on cluster analysis are preliminary.

Figure 6. Shows the 40 faces out of the 200 faces that were used for clustering. The four different colors show the different clusters.

6 Conclusion

We have developed compact shape representations of head and facial shape. We have proposed a sizing system based on cluster analysis along with compact shape representations to come up with different sizes for different facial wear products; such as, respirators, helmets, eyeglasses, etc. We also present our preliminary results based on clustering analysis.

7 Disclaimer

The identification of any commercial product or trade name does not imply endorsement or recommendation by the National Institute of Standards and Technology (NIST). Also the findings and conclusions in this report are those of the authors and do not necessarily represent the views of the NIST.

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