From 3-D Scans to Design Tools

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Abstract

Many products are designed for human use and need to fit the human body shape. However, current CAD tools are focused on the object to be designed and have little capability of accessing human shape information. 3-D anthropometry – an emerging field – leverages the recent advances in 3-D imaging technology, providing new opportunities for designers to access accurate, complete, and detailed human shape information. However, the 3-D scan data are drastically different from the traditional anthropometric data, which are linear 1-D measurements. New geometry processing and statistical techniques have to be developed in order to make the 3-D data usable. In this paper, we describe these tools and techniques and their potential use in augmenting or integrating 3-D anthropometric data with existing CAD tools. In particular, we discuss three types of tools: 1. Data exploration tools – visualizing the space of human shape and helping understand shape variability; 2. Shape generation tools – bridging the traditional data and the 3-D data; and 3. Sizing tools – helping design sizing systems that optimally accommodate populations.

Keywords: 3D anthropometry, digital human modeling, design tools

1. Introduction

The main purpose of many 3-D anthropometric surveys is to collect human shape information for designing products that need to fit the human body. Over the past twenty years, 3-D imaging technology has matured to the extent that full-body digitization can be conducted with sufficient accuracy and efficiency. Many large-scale 3-D surveys have been completed, obtaining huge amount of data [1, 11].

The main advantage of the 3-D data is that they capture detailed shape information. Comparing to the 3-D data, the traditional anthropometric data provide limited shape information. Restricted by the tools (mostly tape measures and calipers), traditional anthropometry collect sparse, 1-D data of the human body. For example, a set of 1-D measurements do not uniquely define the 3-D body shape; multiple shapes may correspond to the same set of measurements.

Another advantage of the 3-D data is that they can be visualized easily. 3-D shapes can be displayed on graphics devices and manipulated interactively.

However, raw, unorganized 3-D data are seldom useful for design. Sophisticated processing is required before the full potential of the data can be realized. Shu et al. [13] reviewed the basic data processing techniques for 3-D anthropometric data. In this paper, we give an overview of the design tools that are built on the basic data processing techniques.

We will discuss three kinds of design tools: data exploration, shape generation, and sizing. Beyond simple visualization of individual 3-D models, we can process the 3-D database and create a statistical shape model. This model will allow us to navigate the space of the human shapes spanned by the 3-D data (section 2.1). The statistical shape model will also help establish the relationship between the 3-D shapes and partial shape information such as 1-D measurements and 2-D images. A regression model can be built and realistic human shapes can be generated from these partial shape data (section 2.2). Finally, we will show that optimal sizing systems can be developed by combining 1-D measurements and the 3-D data (section 2.3).

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2. Design Tools

2.1. Data exploration tool

Raw scan data consists of 3-D coordinates representing points on the surface of the human body. These points are typically connected to form triangle meshes, creating a piecewise linear representation of the continuous surface. A full-body scan contains 100,000 to 300,000 points. Due to sensor limitations, raw 3-D data are noisy and incomplete. For example, the area under the arms is occluded from the sensor's viewpoint in certain postures, leaving holes in the model.

Early applications of the 3-D data involve minimal processing, including opening individual models in graphical systems, visualizing the 3-D shape from different viewpoints, and taking dimensional measurements from the 3-D model. However, a large 3-D dataset consists of thousands of models. Simple visual examination of random models does not give rise to an understanding of the shape variation of the population.

In order to cope with the large amount of data, 3-D search tools have been developed [10]. The 3-D scans are pre-processed to create view-invariant shape descriptors. Body shapes can then be searched based on shape similarity. The search tools organize the dataset and provide an easy way to access the 3-D data.

To realize the full potential of 3-D anthropometry, the 3-D data have to be organized such that shape variability can be understood in a quantitative but intuitive way. This is achieved by creating statistical shape models [2,9,18]. Unlike the traditional 1-D data, which consist of sparse dimensional measurements, the 3-D data consist of dense coordinates. Furthermore, the scans have different number of points and different mesh structures. This represents a major difficulty for performing statistical analysis. The solution to this problem is to create correspondences across the models [15]. A complete, smooth mesh is deformed to fit geometrically each data model. Once the fitting is completed, every model has the same number of vertices and the same mesh structure. This technique is also called *consistent parameterization* [2, 18]. A side benefit of this process is that it automatically cleans up the scan data and fills the holes smoothly.

Standard statistical shape analysis can be applied to the parameterized models. Principal Component Analysis (PCA) is the most often used statistical technique for this purpose. It reduces the complex human body shape to a small number of dimensions.

A major advantage of a statistical shape model is that it has intuitive visualization. In the case of PCA, the component coefficients represent the variability along the corresponding PCA dimensions. New shapes can be synthesized by varying the coefficients, and thus the users can explore the space of the human shape interactively.

A more useful tool for the designers is to explore the shape variation and simultaneously visualize the object under design. Meunier et al. [8] superimpose 3-D scans with the helmet under consideration to evaluate fit to individual scans. With a statistical shape model, we can go one step further to evaluate a design with respect to a whole population. Figure 1 show helmets displayed as if they were worn by people with different head size and shape.

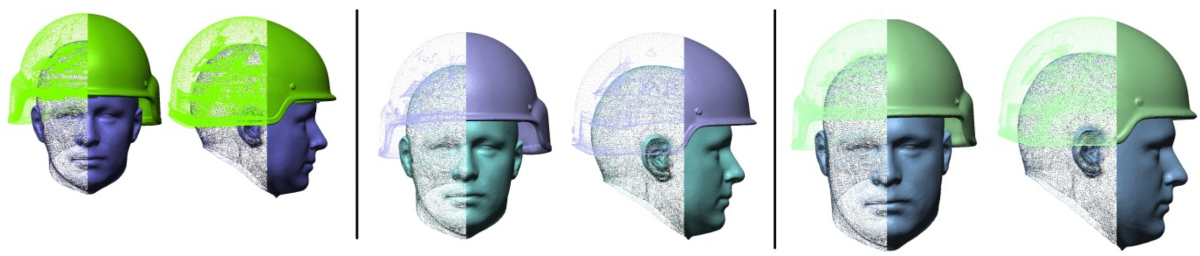

Fig. 1.Head shapes co-displayed with a helmet that is being designed.

2.2. Shape generation tool

A statistical shape model provides a compact description of the human shape space. With this model, it is possible to study the relationship between the shape space and other measurements such as the traditional 1-D anthropometric data. Once this relationship is established, we can leverage the knowledge of the human shape space to generate 3-D shapes from sparse measurements.

We want to learn a mapping between the space of human body shapes and a set of linear measurements. Starting with a set of consistently parameterized 3-D models, we first compute the 1-D measurements from the models. Then the PCA weights of the 3-D models are computed. A linear map between the measurements and the PCA weights can be solved by the least square method. This approach is called *feature analysis* in Allen et al. [2]. The shape thus obtained is drawn from the space of human shapes spanned by the 3-D data. This guarantees that it is a realistic human shape. However, if the measurements were taken from a person that is outside the shape space spanned by the 3-D dataset, the shape obtained from the linear map will not fit the measurement data well. To solve this problem, Wuhrer et al. [16] extend the linear method by adding an extrapolation step, which deforms the shape to fit the measurement data using nonlinear optimization.

Figure 2 shows a few models generated by using 34 body measurements. Figure 3 compares the generated models with the ground truth [16].

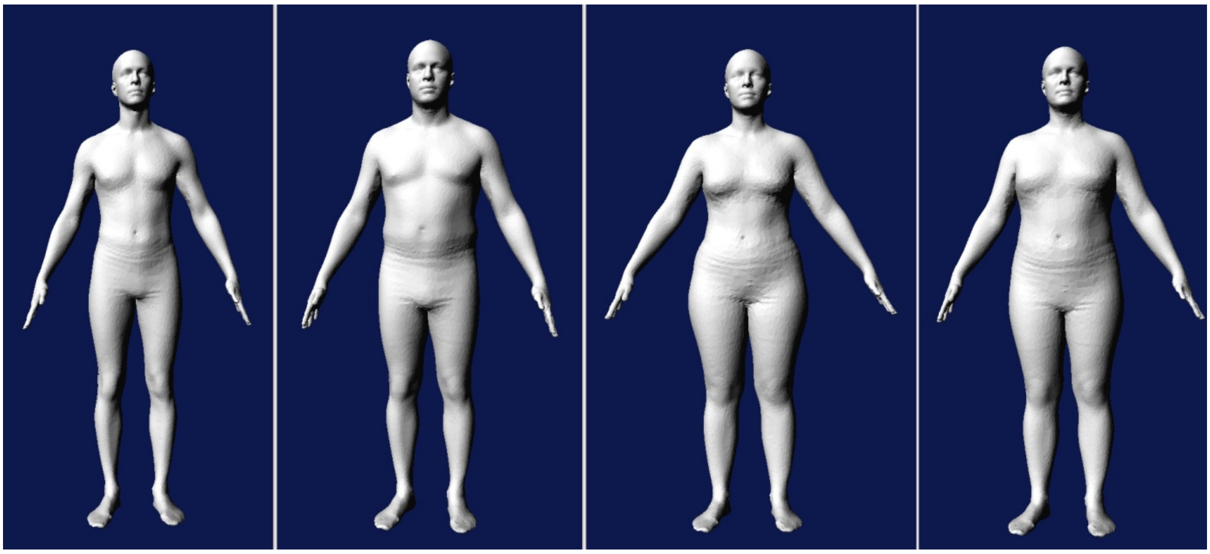

Fig. 2. Examples of 3-D shapes reconstructed from body measurements.

The same principle can be applied to image-based reconstruction where 3-D shapes are generated from one or more 2-D images. Here the partial shape information is the silhouette of the human shape extracted from the image [3,4,5]. Often a PCA is performed on the silhouette data and the regression analysis is done on the two sets of PCA weights.

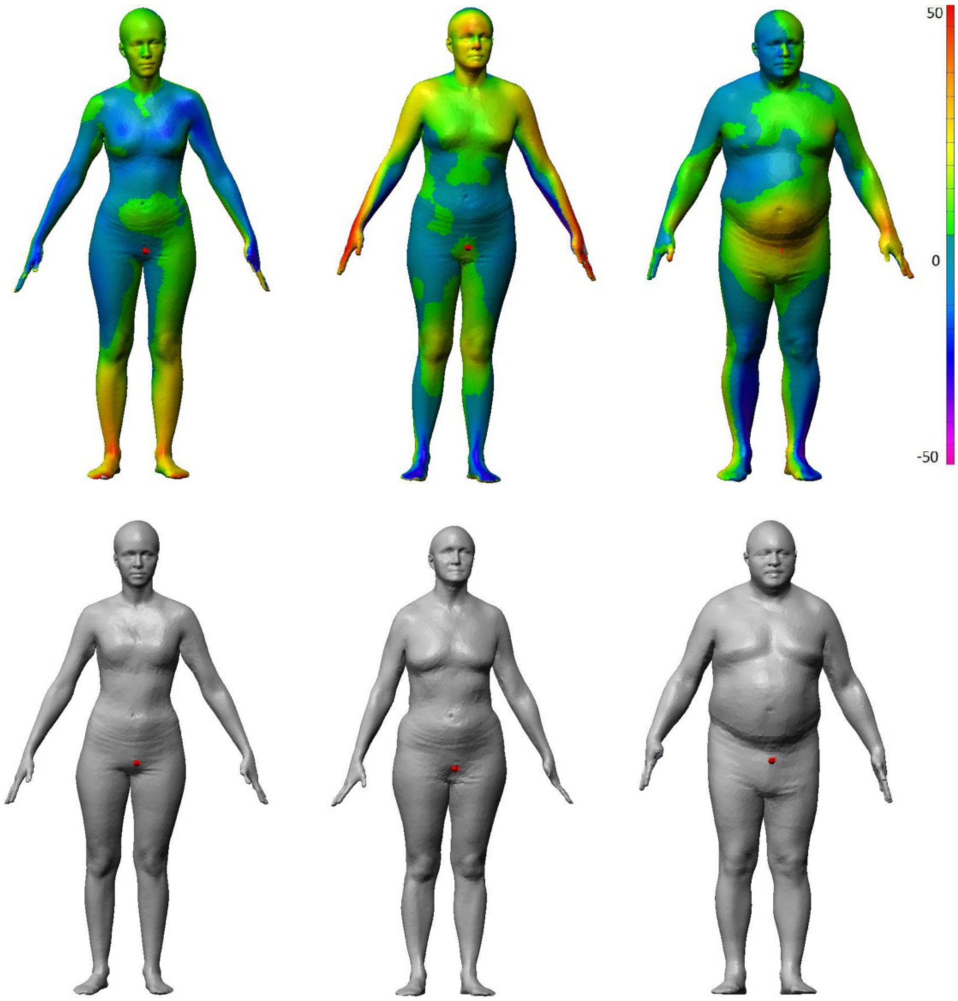

Fig. 3. Comparison between the generated models with ground truth.

2.3. Sizing tool

In order to accommodate the shape variability of a population, it is often necessary to create multiple sizes of a product. When designing a product, designers usually have a few key dimensions of the human body in mind. Traditionally, anthropometric measurement data of these dimensions are collected and tabulated. Then a grading of the dimensions is formed to create the sizes [7]. A good sizing system should have minimal number of sizes to cover maximal number of people.

In many applications, designers need full 3-D models as representative shapes for the sizes [1,6,12]. These models are called *mannequins* in case that the full body is considered, as in clothing design. When designing wearable products for the head and face, such as helmet, mask, and glasses, these models are called *head forms* or *face forms*. For consistency, we call all of them *design models*.

Before 3-D anthropometric data were available, design models were created by artists who sculpted out the 3-D forms, interpolating the measurement dimensions using their knowledge of human shapes. This method is labor-intensive and does not produce accurate human shapes

3-D anthropometric data provide a new opportunity to improve the quality of the design models. Veitch and Robinette [14] select body shapes from real human scans based on body measurement criteria. The selected models are physically manufactured to create bio-fidelic mannequins.

Wuhrer et al. [17] propose a fully automatic solution. The method takes a set of *d* measurements as sizing parameters. Each measurement is given a range in which it can vary, forming a *d*-dimensional box. From each 3-D model, we can compute its *d* measurements, thus turning it into a point in a *d*-dimensional space. The sizing problem can be formulated as a covering problem in *d*-dimensional space. Well known techniques in computational geometry were used to solve the covering problem. Once the optimal positions of the boxes are found, the representative shapes (design models) can be computed by averaging the shapes inside the corresponding boxes. Figure 4 shows results of the sizing computation using three head measurements (head width, head depth, and face height).

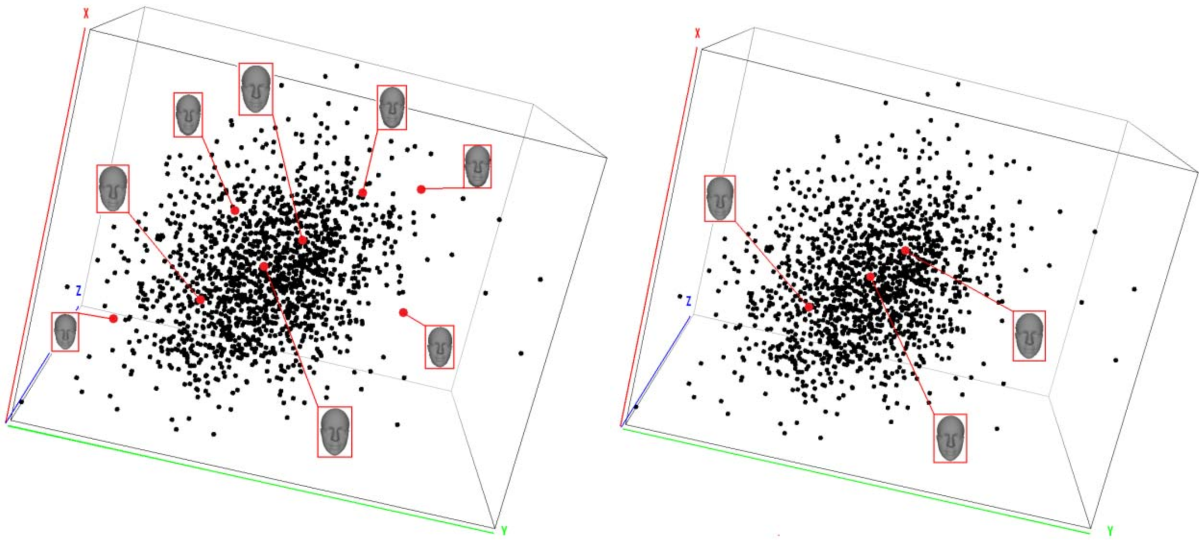

Fig. 4. Covering a population with 3-dimensional boxes (head width, head depth, face height).

3. Conclusions

Much effort in 3-D anthropometry has been focused on collecting data. As the data accumulate, we increasingly realize that we need tools to process them and make them usable for design applications. As we have seen, the key is to build effective statistical shape models to describe the shape variability of the population. These models allow us to work with the dataset as a whole, rather than at the individual scan level. We have demonstrated that three kinds of tools – data exploration, shape generation, and sizing – can be built upon a statistical shape model. If these tools are integrated with CAD tools, designers will be able to access accurate and comprehensive human shape information early on in the design stage.

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