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Example-based statistical framework for parametric modeling of human body shapes

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ABSTRACT

This paper proposes a new example-based statistical modeling framework to conduct the parametric modeling of 3D human body shapes from linear anthropometric parameters. The modeling framework consists of the following three phases: construction of a training database of human body shapes, statistical analysis of human body shapes and human body shape modeling. In the training database construction phase, a consistent parameterization was carried out on 3D whole-body scan data of 80 males and 80 females with a wide variety of body shapes as the examples for this study. The surface-fitting process, which was improved relative to existing methods, was used to guarantee the high-quality parameterization in this phase and to generate an articulated body shape model in the modeling phase. To characterize the range of body shape variation, the training database was analyzed statistically. Additionally, a correlation between the body shapes and the anthropometric parameters was learned in the statistical analysis phase to estimate body shapes from intuitive and semantic parameters. A new technique to generate an optimal body shape model that precisely satisfies user input body dimensions was developed in the model generation phase. This technique enables the estimation of body shape variation, not only within the body shape space that was learned statistically, but also outside of the body shape space, while maintaining body shapes that stay in the human shape space. Our approach produced reasonable results having a high modeling accuracy satisfying user-specified anthropometric parameters, and high visual quality in expressing realistic body shapes. The resultant models were then segmented into 16 key regions of the human body, and had information on 15 key joints, and thus they could be a useful tool in various industries. Compared with other statistical modeling approaches, the proposed method contributes to related areas by introducing an improved surface-fitting process and a non-linear optimization-based optimal body shape modeling technique.

1. Introduction

In this paper, an example-based statistical modeling framework was developed for parametric modeling of realistic human body shapes based on user-specified anthropometric parameters. Such realistic body shape models are powerful tools used in various fields including ergonomics [1,2], garment design [3,4], biomechanics [5,6], and computer graphics [7,8]. In ergonomics and garment design, realistic models that are accurate and reliable between users and products are utilized for human factors-considered interaction analysis. This ultimately enables better human-centered design in the ergonomics and garment design fields. In the biomechanics field, for example, these models are utilized in crash simulations essential for the occupant safety design of vehicles. The ability to generate detailed human body shapes enables the creation of virtual humans, including human bones or internal organs (e.g. liver, stomach, lungs, etc.), and consequently more accurate biomechanical responses can be predicted through crash simulations. With respect to computer graphics, these models are used to generate very realistic computer animations of human characters. Given these various and diverse reasons, much effort has been devoted to the generation of realistic body shape models. In this regard, existing researches introduced in literature [9–25] are discussed in detail in Section 2 of this paper.

2. Related works

This section of the paper describes the limitations and drawbacks of the existing methods for generating realistic and

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detailed body shape models, as well as detailing the methods proposed in this study.

DeCarlo et al. [9] presented the initial concept for example-based synthesis methods using many anthropometric facial measurements for modeling 3D human face shape variation. They deformed a template facial model, based on a free-form deformation technique, to generate a new face shape satisfying input measurements. Blanz and Vetter [10] carried out principal component analysis (PCA) on face shapes and texture data. They searched for the new face shape that gave the best description of their input image within the learned PCA space for statistical face shape modeling, starting with the construction of a parameterized database of textured 3D faces. Inspired by these studies, Allen et al. [11] presented a method to generate various body shape models by building a training database for modeling human body shape variation using 3D whole-body scans and learning linear mapping, called feature analysis, between body shapes and body sizes. Within the field, they established the basis for other example-based statistical modeling methods [13–15] by introducing a template-based non-rigid registration technique that improved upon the method proposed by Praun et al. [12] to construct a training database of human body shapes. However, the methods proposed by Azouz et al. [13], Xi et al. [14] and Hasler et al. [15] did not encompass this technique in synthesizing a new model corresponding to input body dimensions and, therefore, current methods are still not satisfactory for parametric modeling of human body shapes.

Seo et al. [16] correlated body shapes with sizing parameters using a radial basis function network, after constructing a training database of human body shapes from many scanned examples, as utilized in the method of Allen et al. Subsequently, they identified a relationship between body shapes and body sizes through a random search-based learning procedure. They then generated a new model, according to user input body sizes, by synthesizing parameterized example models within the training database from the defined relationship.

To construct a parameterized human body shape database from their example models, Wang [17] introduced a feature-based parameterization technique, different from the methods mentioned above. Using the technique, they proposed a new framework to generate feature-based mannequin models. For the parametric design of mannequins, they used example models from within the database having body dimensions similar to the input sizing dimensions, composed of feature patches, and then estimated new mannequin shapes with a linear combination of the models. In the model generation process, they adopted a numerical optimization method to minimize differences between the body shapes and the specified body dimensions. Chu et al. [18] introduced a statistical modeling method for parametric design of human body shapes by applying the feature analysis method introduced by Allen et al. to the training database of human body shapes built from the feature-based parameterization technique proposed by Wang.

Recently, Baek and Lee [19] presented a technique using hierarchical clustering to generate statistical models of human body shapes from their training database. They captured a correlation between body shape and body size by clustering the training database and performing multi-cluster analysis. To predict a new model satisfying the input body sizes from the correlation, they found the average shape that best described the sizes within the body shape space learned from the training database using their body shape parameter optimization.

Several other studies [20–25] have introduced into the literature approaches that are similar and use a set of images as the input to generate 3D human body shapes. These studies used correlations between the training sets and derived 2D images of body shapes to estimate new shapes. Because these approaches require an image set acquired from the prescribed angles of view as the input to estimate 3D human body shapes, innate limitations of the approaches exist, due to the background noise of the image, and development of an intuitive modeling interface for the parametric modeling of human body shapes is difficult.

In conclusion, such approaches described above have used knowledge of human body shape variation from the training database constructed by carrying out a consistent parameterization which guarantees the same topologies and mesh connectivities for across all example models. They generated new human body shapes based on input values by learning a linear or near-linear mapping between specific input information and a training set to synthesize new body shapes, based on the statistical training data of human body shapes. This research, however, has the following limitations: First, the existing methods limit the generation of new body shapes to the body shape space encompassed in the training set. Consequently, these methods cannot perform modeling of body shape variation outside of the shape space. Second, as a result of the existing methods, models do not contain information on body segments and skeleton joints required for posture adjustment. Consequently, very cumbersome and time-consuming additional manual work is required from users in order to appropriately utilize these models. Third, since most studies did not consider approximation error, derived from linear mapping between body shapes and body sizes, the modeling accuracy of the models is somewhat weak.

The contributions of this study for solving the above-mentioned limitations are summarized below, and these will be discussed with rest of the article.

The first contribution is a surface-fitting process extended from the previous methods to construct a training database of human body shapes. In the fitting process, new steps were developed to guarantee high quality parameterization for our examples and encompass the body segmentations and skeleton joints required to adjust the postures of the resultant models generated from the learning of the training database. Through such a process, high-quality body shape models with 16 body segments and 15 key skeleton joints were generated.

The second contribution is a novel modeling technique to generate optimal body shape models satisfying user-input body dimensions. Unlike the existing methods, we developed the modeling technique based on nonlinear optimization, so that this study generated optimal models satisfying the required body dimensions not only from within, but also from outside, the body shape space learned by the training database. Through such a technique, moreover, we solved approximation error caused by linear mapping between body shapes and body sizes.

3. Framework overview

This study proposes a new statistical modeling framework for conducting parametric modeling of human body shapes, based on linear anthropometric parameters, using the aforementioned concepts of example-based synthesis methods. Fig. 1 shows an overview of the proposed methods, and each step is summarized as follows:

a. Our surface-fitting process was carried out to create a consistent parameterization for the entire 3D scans used as examples in this study. Through such a fitting process, a training database of human body shapes was constructed from all the examples having a consistent mesh structure.
b. To characterize the tendency of human body shape variation, the training database was statistically analyzed through PCA. For intuitive modeling interface development of human body shapes, the correlation between the body shape modeling parameters drawn through PCA and the anthropometric