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# Modeling of female human body shapes for apparel design based on cross mean sets ☆

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ABSTRACT

This paper is concerned with a method to build prototypes of human bodies that can be used for apparel design. One of the most important issues in the apparel development process is to define a sizing system to provide a good fitting for the majority of the population. Since anthropometric measures do not present the same linear growth with size in each dimension, it is very important to find a prototype that represents as accurately as possible each class in the sizing system. In this paper we propose a method based on the concept of random compact mean set to define prototypes in apparel design. From a cloud of 3D points obtained with a 3D scanner a solid that represents the human body is obtained. 2D cross sections of this solid are extracted at certain heights corresponding to key points of the body. These different cross-sections can be seen as a realization of a random compact set in the plane. A very popular definition on mean set is applied to each sample of 2D cross sections, and finally the prototype is obtained as the 3D reconstruction of these 2D mean sections. As a real example, the proposed methodology is applied to the 3D database obtained from a anthropometric survey of the Spanish female population conducted in this country in 2006.



## 1. Introduction

Anthropometry data is a fundamental information used in the design process of products and environments to assure ergonomics and provide a better comfort (Pheasant, 1996). In the particular case of the clothing industry, designers and pattern makers use mannequins for representing the main anthropometry of a basic size, which is then scaled proportionally to cover most of the population.

The primary anthropometric information used by clothing designers consists of size tables that list the mean values for each size of the main anthropometric measures. These tables exist for upper and lower garment. Additionally, physical mannequins based on these anthropometric dimensions are used to test the garment fitting during the pattern development process. Most of this information has been developed by the designers' own experience or it is based on a beauty canon far from the real shape of the greatest percentage of population (Fan, Yu, & Hunter, 2004).

For the last years, new technology for body scanning has emerged, as reported in Daanen and Haar (2013), and user's fitting problems with mass production of clothing has promoted new sizing surveys to update anthropometric data of the population in different countries (USA, UK, France, Australia, Spain and Germany) Rissiek and Trieb (2010). Most of these studies have mainly addressed apparel applications (Alemany et al., 2010; Carrier & Faust, 2009; Unspecified author, 2004). So far, most of the research studies that have been done are focused on the analysis of these data for their application in apparel design (Gillies, Ballin, & Cs'aji, 2004; Simmons, Istook, & Devarajan, 2004; Sul & Kang, 2010; Wang, 2005).

Although a lot of anthropometric information exists, most of it is just available as static aggregated data published on books and scientific articles (Peebles et al., 1998; Unspecified author, 2011). This provides useful information for studying population changes but was never either reliable or sufficient for designers and ergonomics engineers to apply appropriately. The extended use of computer aided design promotes the development of many tools that use information from anthropometry measures to create virtual

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3D models of humans. These models can be added to any virtual environment or workspace, to assess ergonomics, comfort and performance (Duffy, 2009). There are two types of 3D human body models: digital human models (DHM) and avatars.

DHM are parametric body models, which simulate body proportions, postures, reach ranges and motions of a user population to analyze classic ergonomics concerning postures, envelopes and reaches applied to their interaction with virtual environments, mainly in automotive and work place design (Blanchonett, 2010; van der Meulen & Seidl, 2007). DHM use 1D anthropometric scaling by applying regression equations to create a family of mannequins. Percentiles of anthropometric measures could be introduced in the parametric model to create mannequins representing the mean body, the 5% percentile or the 95% percentile of a specific population. Interesting examples of this approach using clustering techniques are found in Ibáñez et al. (2012) where the authors apply trimmed k-medoids and OWA (ordered-weighted average) operators and in Vinué, León, Alemany, and Ayala (2014) in which the clustering technique is hierarchical PAM (partitions around medoids). The univariate characteristic of these approaches is a severe limitation that requires a careful use; the combination of anthropometric dimensions, even in the same range of percentiles, will lead to an unknown percentage of the given population that cannot be accommodated (Zehener, Meindl, & Hudson, 1993), And they will easily produce an unreal body type totally unsuitable for ergonomic design. Additionally, shape information of the body is not considered. The main difference with our approach is obviously the data reduction: as it will be explained later, we work with all the body shape considered as a solid without using the numerical parameters that could be extracted from it.

An alternative is the use of multivariate methods. Robinette and McConville (1981) proposed the use of the principal component analysis, which reduces the number of anthropometric variables grouping and ranking it by the percentage of variability explained by each one. Using the plot of the first and second component, a circle can be imposed including the desired percentage of population, typically 95%. The center of this circle is used as a mean body representation for the principal anthropometric variability. Some points distributed over the boundary of this circle, are selected as representative cases to describe anthropometric variability. More recent examples of the use of PCA or related characteristics are Luximon, Zhang, Luximon, and Xiao (2012) that applies their methodology only to feet, and (Wuhrer, Shu, & Xi, 2012) that applies to a whole body, even in different poses. However, the use of actual cases instead of models to represent the anthropometric mean of a population and their boundary variability, presents an important problem: singularities in the body shape related to personal characteristics, with lower weight in the principal component representation, will influence product design and assessment. Again, the difference with this proposal is that PCA changes the representation space before model construction whereas we operate all the time with the original shapes.

Other alternative also based on anthropometric measures consists of using archetypes. Archetypal analysis assumes that there are several "pure" individuals who are on the "edges" of the data, and all others individuals are considered to be mixtures of these pure types. Archetypal analysis estimates the convex hull of a data set, and therefore favors features that constitute representative "corners" of the data, which are precisely the archetypes. This comments, and some advantages in a comparative analysis with Principal Component Analysis (PCA) is detailed in Epifanio, Vinué, and Alemany (2013).

In the case of avatars, the main specification is to provide a realistic visual representation. Commercial applications are focused on virtual try-on for apparel (commercial products from firms like Vidya, Browzwear or Optitex). They give priority to an aesthetic appearance, leading to unreal 3D body shapes. The parametric avatars, which enable to introduce specific anthropometric measures, use deformation methods that are not based on statistical distributions.

In this context, recent emerging research relying on 3D body shape analysis aims to generate 3D statistical body models from large 3D body databases. Different authors, analyzed human shape variability using a volumetric representation of 3D human bodies and applied a principal component analysis to the volumetric data to extract dominant components of shape variability for a target population (Azouz, Rioux, Shu, & Lepage, 2006; Seo & Magnenat-Thalmann, 2003; Xi, Guo, & Shu, 2011). As a result, through visualization, they showed the main modes of human shape variation. It is important to note, that the development of shape descriptors that can efficiently represent the human body shape and size at different levels of detail is still under research (van der Meulen & Seidl, 2007).

Also included in this line we must mention the approaches that start from the data provided by 3D scanners and build with them the prototypical human model. Almost all of them take the values of the body surface points, or a mesh of polygons that have the points as vertexes, as representation primitives; some of them build a Point Distribution Model (PDM) like Ruto, Lee, and Buxton (2006) and others make use of polygons/normal vectors, as in Allen, Curless, and Popović (2003) and Anguelov et al. (2005) or Hasler, Stoll, Sunkel, Rosenhahn, and Seidel (2009). In both cases correspondences are established between the different cases, which allows the generation of a mean model that, if done with the subjects of a given group, can be taken as the mean shape of that group. More recently other work have elaborated and improved these ideas, like Hsiao and Chen (2013) and Huang, Mok, Kwok, and Au (2012) or Baek and Lee (2012). Some of them even take into account deformability of the surface patches used to model the body surface so that characteristics of the cloth material can be incorporated to visualize a realistic representation of the fit of a given cloth to a given body. These approaches differ from ours in the obvious fact of using surfaces instead of volume as their main primitives. This brings some advantages, like the availability of a well established framework (differential geometry) to model and deform the surfaces but also what it is, from our point of view, an inconvenient: the lack of well studied statistical methods to work with the parameters that define the surfaces whose statistical distributions are totally unknown. Nevertheless, notice that our method does not exclude the use of surface-based methods at a later state: having the shape as a volume, the surface can be extracted, modeled with B-splines or other of the methods proposed by the aforementioned works and used to make realistic garment fitting.

Finally, it is worth to mention too some works that build the 3D model (using surfaces, even this is not intrinsic to their approach) using only relevant points extracted from the projections of the body scanner on lateral and frontal planes. These are Lin and Wang (2011, 2012); we have applied similar ideas (see Section 3.2 and in particular, Figs. 1 and 2). These methods can be very useful if a scanner is not available (even a simpler arrangement should be built to take the image of projections) but suffer the risk of loosing valuable.

In this work we present also an approach to generate a 3D body shape using a statistical methodology to define prototypes based on 3D clouds of points obtained with a 3D scan. The proposed method is applied to the 3D anthropometric survey of the Spanish female population. The difference with the aforementioned approaches that work with the surface points is that we work with volumes (a grid of voxels) from which slices are extracted only as a mean the make the method computationally feasible. In some of the surface based methods the shapes to be averaged are aligned