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Fuzzy classification of young women's lower body based on anthropometric measurement

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ABSTRACT

The traditional method of body classification is discrete, using crisp and rather dichotomous classification methods; there are many shortcomings for ergonomic design of clothing products by this method. This paper proposes a fuzzy method to classify lower body shapes based on triangular fuzzy numbers. By using factor analysis and correlation analysis, we found that the height, the waist girth, and the difference of hip-waist are crucial dimensions to represent lower body shape. We then classified the lower body shape into three categories according to the difference of hip-to-waist, and finally used the membership of triangular fuzzy numbers to represent the lower body shapes. Results show that the fuzzy method of body classification can more accurately represents body information than the traditional method without increasing the number of body types. Additionally, we established that the mean of the height, waist girth and hip girth of the young women of northeast China increased by about 0.8 cm, 1.5 cm and 1.4 cm respectively compared with ten years ago.

Relevance to industry: Anthropometric data is the basis of garment pattern design, and body classification is a necessary precondition for developing a garment size system. These research achievements will add value to the pattern design of young women's lower body clothing, the development of new sizing systems and related industries.

1. Introduction

Anthropometric measurement is a prerequisite for ergonomic design. In order to develop easy-to-use, safe and comfortable products, many anthropometric surveys have been carried out recently. For example, for the development of an urination device, a 3D scanner was used to measure females' perineum (Wang et al., 2015). Obi et al. (2015) and Syuaib (2015) measured farm workers to develop farm equipment. Castellucci et al. (2015) and Van Niekerk et al. (2013) optimized school furniture design, and Hsiao et al. (2015) optimized a fire-apparatus seat and seatbelt design from anthropometric aspects. Khadem and Islam (2014) collected anthropometric data of Bangladeshi male population for designing ergonomic products. Zhou et al. (2016) proposed an efficient and convenient method to structure a digital human model through anthropometric measurement for the evaluation of the product's ergonomic performance. Zhuang et al. (2013) researched the head-and-face shape variations for protective equipment design. Sadeghi et al. (2015) analyzed the difference in body shapes between Iranian and other regions through anthropometric measurement.

However, the above ergonomics studies rarely involved anthropometric measurement for the development of clothing products. Clothing is considered as the second skin of the human body. Garment design depends entirely on anthropometric data and body classification is the precondition for the size designation design. In this aspect, Wu et al. (2015) researched the shape of late pregnant women for the development of maternity dresses and other related products. Jee and Yun (2016) classified hand shape into four types based on hand measurement for products and interfaces design. Y.-C. Lee and Wang (2015) used a 3D foot scanner to collect foot dimension data and then classified foot shape into three

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types for footwear design. Park and Park (2013) classified large person body shape into four types by factor analysis and cluster analysis. However, the common disadvantage of these traditional classification methods is that they are discrete and cannot represent body shape accurately.

With the development of the apparel industry, and consumers' increasing requirements on individuality (Roach, 1994) and fitness (Alexander et al., 2005), clothing manufacturers need precise information of consumers' body shape to produce well-fitting clothing. Customers also want to know which body types they belong to for choosing well-fitting garments. More accurate body classification yields more size designations, but, too many size designations puzzle consumers easily (Chun-Yoon and Jasper, 1995) and bring many problems to clothing manufacturers. Finding an appropriate classification of body shape, which cannot only help consumers to identify their body types easily but also help garment manufacturers to produce well-fitting clothing, is a difficult and key question in the clothing industry.

In the early days of the ready-to-wear apparel industry, women's figure types were almost always classified according to bust circumference (Chun-Yoon and Jasper, 1994), but there is no scientific explanation for the choice of bust as the gist of body classification. However, it could stem from experience obtained from years of practice (Chun-Yoon and Jasper, 1994). In contrast to this body classification, another method to classify women's body shape is according to age (Kidwell and Christman, 1974), such as "Misses", and "Junior" among others. This method of body classification has no foundation in science. Age and body dimensions may be related, but not necessarily tied to each other. "Misses", "Junior" etc. no longer refer to age groups as before, but have evolved to indicate figure types. Then the figure types are further divided based on height and hip girth (Commerce, 1958), which is the rudiment of modern body classification methods. International Standardization Organization (ISO) updated size designation in 2012 (ISO, 2012a), recommending consumers to choose pants according to height, waist girth and hip girth. Nevertheless, the current ISO standards do not consider the difference of hip-waist (H-W). In the previous studies, many researchers regarded upper and lower body as a whole to classify body shape according to height, bust girth, waist girth, H-W, etc. (Chung et al., 2007; Hsu, 2009; Simmons, 2003). But rarely have researchers studied lower body classification specifically. Obviously, the method of whole body classification is not suitable for lower body classification. Moreover, the current body classification methods are crisp, and there is limited research on fuzzy body classification.

In China, women's body forms are classified in four categories according to the difference of bust-waist (B-W); there are "Y", "A", "B" and "C". For B-W values, 19–24 cm belong to type "Y", 14–18 cm belong to type "A", 9–13 cm belong to type "B", while 4–8 cm belong to type "C". This system only uses height, waist girth and the body type (Y, A, B, and C) to represent lower body shape. For example, "160/68 A" means that the person's height is 160 cm, waist girth is 68 cm and B-W is between 14 cm and 18 cm. However, the current Chinese body classification method is also crisp. One important point in our approach is that we combine the continuous and discrete data representations using fuzzy logic. A continuous body measurement, is sometimes too sensitive to small changes in body size (noise), and these small changes can be easily absorbed and transformed into a fuzzy variable, can be easily transformed into a fuzzy variable, which can be easily interpreted according to the real scenario. In this way, the criteria of accuracy, robustness and interpretability can be taken into account together in the proposed method. This method is particularly significant for processing data far from the standard references. For example, 18 and 19 are two different classes according to the sizing standards. However, as both of them are quite far from their standards (center of their classes), if we compute with a classical method based on the distance between two class centers, their body shapes will be quite different. In contrast, if we compute using the proposed fuzzy method, we will obtain similar body shapes, which is closer to the reality. Furthermore, the latest Chinese official body classification was issued about eight years ago, including an additional lag of 10 years for data collection and processing time. Research indicates that the average of body dimensions change significantly every ten years (Y. S. Lee, 2014). China has the largest population in the world, of more than 1.4 billion people. Thus, it would expend significant time, funds and manpower to launch a national anthropometric measurement. Young women usually spend more on clothing and easily accept new fashion styles. In this context, we studied lower body classification of young woman in the Northeast of China based on continuous anthropometric measurements. As fuzzy logic can effectively represent both continuous and discrete data according to the user's needs, we proposed a fuzzy classification method (FCM) using triangular membership functions.

We propose the FCM on the basis of predecessors' work of crisp classification methods (CCM). The first objective of this study is to offer anthropometric data of young women's lower body based on samples drawn from northeast China. The second objective of this study is to look for a more accurate representative method of lower body shape. To do this, we structure the rest of this paper as follows: In section 2, we briefly introduce the anthropometric measurements; and then use factor analysis and correlation analysis to process anthropometric data; In section 3 and section 4, we use FCM and CCM to classify lower body shape, and also discuss the results; Finally, we present some conclusions and possible further works in section 5.

2. Method

2.1. Anthropometric measurement

116 young women aged 20–30 years old were randomly selected from the northeast area of China. Their height ranged between 145 cm and 180 cm. A 3D body scanner (Vitus Smart), which has many obvious advantages (Daanen and Ter Haar, 2013; Daanen and Van de Water, 1998), was used to measure and extract body dimensions. This 3D body scanner automatically extracted dozens of body dimensions from each subject. We choose only 14 body dimensions (See Fig. 1), which are closely related to lower body shape.

The sample size was calculated according to the formula (1) at 95% confidence interval, for the 5th and 95th percentiles (ISO, 2012b).

$$N \geq 1.96^2 \times MAX\left(CV_i^2\right) \Big/ A^2 \quad (1)$$

Where

N is the minimum quantity of sample size,
CV_i is the coefficient of variation of each measuring item,
A is the relatively permissible error.

Considering this study as a common scientific research project, we set the value of "A" at 1.6%. Finally, we calculated the sample size