



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 represent 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.

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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).

$$N \geq 1.96^2 \times \text{MAX}(CV_i^2) / A^2 \quad (1)$$

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

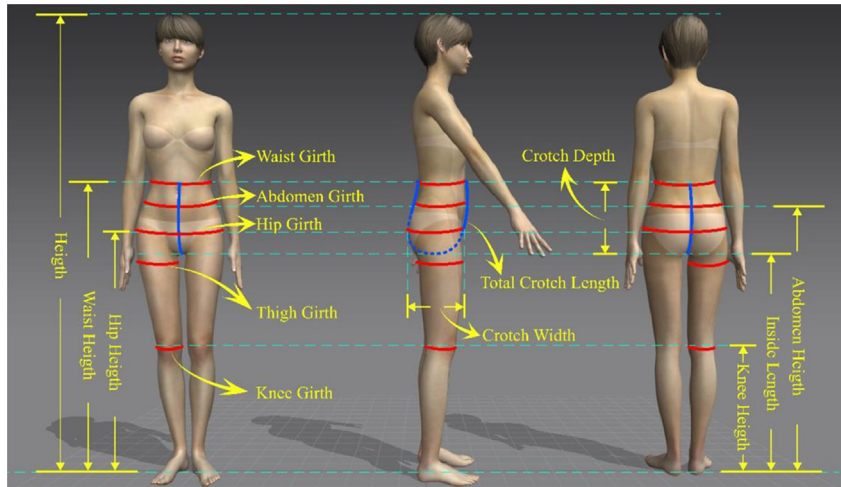


Fig. 1. Legend of measurement dimensions.

“N”, with a target value of at least 100. Considering some invalid samples and special body types, 116 young women were selected ultimately.

2.2. Data preprocessing

Actually, data is generally incomplete in the real world, so it is inappropriate to process data directly without preprocessing (Han et al., 2011). Test of outliers and descriptive analysis were applied for subsequent preprocessing the anthropometric data.

2.2.1. Test of outliers

Through the method of 3σ -rule (Han et al., 2011), we detected some outliers, and on validating with the raw data, we established that they were not measured by mistake but are special dimensions. Special body dimensions exist in data and can lead to an anamorphic analysis results; therefore, we excluded these outliers. These outliers only accounted for about 8% of the total samples leaving 106 samples for the subsequent analysis.

2.2.2. Descriptive analysis

Descriptive analysis is a practical approach that is simple, direct and effective to reflect some data features (Fraenkel et al., 1993). The mean, which is important to establish intermediate of body shape, can reflect a central tendency of data. In order to get more accurate dimensions of the median-body, we select the mean, median and average of the sum of three means (upper quartile, lower quartile and mean) as researchable indexes. Compared to the median body dimensions from the Chinese National Standard which were collected around 2005, the data in Table 1 indicate that waist girth, hip girth and height dimensions have increased 0.8 cm, 1.5 cm and 1.4 cm respectively. Together with the Mean, SD and CV of variables, the result shows that the distribution of H-W is relatively spread out.

2.3. Factor analysis

We explored factor analysis, which is widely applied for data reduction or structure detection, to process the data. The aims of the factor analysis were: (1) reducing the number of anthropometric items and (2) detecting structure in the relationships among anthropometric items.

2.3.1. Kaiser-Meyer-Olkin test and Bartlett's test of sphericity

Kaiser-Meyer-Olkin (KMO) (Cerny and Kaiser, 1977; Dziuban and Shirkey, 1974; Kaiser, 1970) and Bartlett test (Dziuban and Shirkey, 1974) were applied to test whether factor analysis was appropriate for data processing in this research. In Table 2, the KMO value is about 0.8, indicating that, factor analysis can be meritoriously conducted; the significance (sig) value is 0, indicating that the hypothesis of independence is rejected, thereby providing evidence that factor analysis may be suited to the data (Dziuban and Shirkey, 1974).

2.3.2. Principal factors extraction and explanation

According to the factor load coefficients of rotated component matrix in Table 3, we can extract 13 components at most due to the existence of 13 measure items and rank them according to their contribution rates. However, most of the low ranked components are not applicable in the real scenarios and their contribution rates are very small (see Table 4). Only the highest ranked components are of interest to us. The procedure of their selection is given as follows. We first select the highest ranked component, but its contribution rate is only 54.7% though it is the largest one of all the components (see Table 4). Therefore, we have to select the second highest ranked component and combine it with the first one. The accumulative contribution rate is 79.2% (see Table 4). If the accumulative contribution rate is still low, we continue to add new components one by one until the accumulative contribution is high enough for representing the body information. In our study, according to this principle, if the threshold for the accumulative contribution rate set to be 95%, we need to select the first five components because their accumulative contribution rate (94.8%) can almost reach this threshold (see Table 4). In general, the more components we select, the more accurate result we obtain. However, too many components will increase the complexity and difficulty in interpretation of results.

The first factor mainly includes height, inside length, waist height, hip height, abdomen height and knee height. These items reflect the height of the corresponding parts of the body. Therefore, we denote it as the “height factor”.

The second factor mainly includes crotch width, waist girth, abdomen girth, thigh girth, and knee girth. These items reflect the thickness and circumference of the corresponding parts of lower body. Actually, the width dimensions have a strong correlation with

Table 1
Descriptive statistics of anthropometric measurements (unit: cm and n = 106).

Variable	Min	Max	Range	Mean	Median	SM	SD	CV (%)
Height	151.5	173.2	21.7	161.9	160.9	161.4	5.21	3.2
Inside length	64.8	80.7	15.9	71.7	71.2	71.5	3.29	4.6
Waist height	93.4	111.0	17.6	101.2	100.5	100.8	3.97	3.9
Abdomen height	86.2	103.3	17.1	94.5	94.1	94.2	3.80	4.0
Hip height	75.2	91.1	15.9	82.9	82.4	82.7	3.76	4.5
Total crotch length	64.5	93.9	29.4	73.2	72.8	73.1	4.10	5.6
Crotch depth	23.9	36.1	12.2	29.5	29.3	29.3	2.30	7.8
Knee height	39.0	48.1	9.1	43.5	43.3	43.3	2.04	4.7
Crotch width	17.2	22.2	5.0	19.7	19.8	19.7	1.04	5.3
Hip girth	78.0	101.8	23.8	92.2	92.5	92.4	4.75	5.1
Waist girth	58.3	81.3	23.0	69.1	68.8	69.0	4.94	7.1
Abdomen girth	65.0	91.2	26.2	79.2	79.2	79.2	5.35	6.8
Thigh girth	42.4	60.8	18.4	52.9	52.6	52.7	3.75	7.1
Knee girth	31.6	43.9	12.3	37.4	37.3	37.3	2.26	6.0
Difference of hip-waist (H-W)	16.1	29.8	13.7	23.1	23.4	23.3	3.08	13.3

Note: Min stands for minimum; Max stands for maximum; SM stands for average of the sum of three means (upper quartile, lower quartile and mean); SD stands for standard deviation; CV stands for coefficient variation.

Table 2
KMO and Bartlett test.

KMO	Kaiser-Meyer-Olkin measure of sampling adequacy	0.791
Bartlett's test of sphericity	Approx. Chi-Square df Sig	2290.396 78.000 0.000

Note: *df* stands for degrees of freedom; *Sig* stands for minimum significance.

Table 3
Rotated component matrix of anthropometric measurement.

No.	Items	Component				
		1	2	3	4	5
1	Height	0.956	0.156	0.116	0.172	0.064
2	Inside length	0.932	0.001	-0.087	-0.123	0.006
3	Waist height	0.944	0.16	0.162	0.178	0.068
4	Hip height	0.951	0.17	0.133	0.126	0.019
5	Abdomen height	0.94	0.166	0.136	0.184	0.07
6	Total crotch length	0.339	0.349	0.095	0.841	0.129
7	Knee height	0.898	0.204	0.044	0.191	0.139
8	Crotch width	0.091	0.941	0.083	-0.07	-0.063
9	Waist girth	0.105	0.892	-0.357	0.152	0.123
10	Abdomen girth	0.238	0.872	-0.086	0.255	0.13
11	Thigh girth	0.159	0.873	0.105	0.216	0.225
12	Knee girth	0.207	0.626	0.046	0.199	0.712
13	Difference of Hip-Waist (H-W)	0.212	0.084	0.964	0.074	0.029

Note: Extraction method is principal component analysis; Rotation method is varimax with Kaiser Normalization.

Table 4
Total variance explained.

Component	Factor	Initial eigenvalues		
		Total	% of Variance	Cumulative %
1	Height factor	7.12	54.73	54.73
2	Girth factor	3.18	24.45	79.18
3	Type factor	1.07	8.25	87.43
4	Crotch factor	0.61	4.67	92.10
5	Leg width factor	0.35	2.68	94.78

Note: Extraction method is principal component analysis.

their corresponding girth dimensions. These items mainly reflect the girth of the corresponding parts of the body. Therefore, we denote the second factor as the “girth factor”.

The third factor only includes H-W. This item reflects the magnitude of the difference of waist girth to hip girth. The shape

between waist and hip depends on H-W. Moreover, this part is important for bottoms design. Therefore, we denote it as the “type factor”.

The fourth factor only includes the total length of the crotch. This item reflects the shape of the seat. Therefore, we denote it as the “crotch factor”.

The fifth factor only includes the width of the leg. This item reflects the width of leg. Therefore, we denote it as the “leg width factor”.

Table 4 indicates that the cumulative contribution of height factor, girth factor and type factor accounts for 87.43%. The height factor, girth factor and type factor are three main factors, which could represent the major information of lower body shape.

Considering these findings, we deduce that height factor, girth factor and type factor as three main indexes to classify lower body shape.

2.4. Correlation analysis

The purpose of correlation analysis was to find a representative item from each principal factor, and then use these items for body classification.

All results of significance test are zero (Table 5), indicating the null hypothesis should be rejected. Hence, each principal factor has correlation with their anthropometric items.

The height factor score has a higher correlation to height than inside length, waist height, hip height, abdomen height and knee height (Table 5). Furthermore, of all anthropometric items in the height factor, height is the most convenient to measure; therefore, we select height as the first index for body classification.

The girth factor score has a higher correlation to waist girth, abdomen girth and thigh girth than knee girth and total crotch length (Table 5). Comparing with waist girth and thigh girth, abdomen girth is more difficult to measure. Moreover, waist girth and hip girth are inevitable elements of pattern making instead of thigh girth. We can easily get hip girth through waist girth plus H-

Table 5
The correlation between principal factors and variables.

		Height	Inside length	Waist height	Hip height	Abdomen height	Knee height	
Height factor score	Pearson correlation	0.959**	0.921**	0.947**	0.950**	0.944**	0.904**	
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	
	N	106	106	106	106	106	106	
		Total crotch length	Waist girth	Abdomen girth	Thigh girth	Knee girth		
Girth factor score	Pearson correlation	0.582**	0.909**	0.914**	0.925**	0.811**		
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000		
	N	106	106	106	106	106		
							The difference of hip-waist (H-W)	
Type factor score	Pearson correlation						0.941**	
	Sig. (2-tailed)						0.000	
	N						106	

Note: **. Correlation is significant at the 0.01 level (2-tailed); Sig stands for the result of signification test; N stands for the observation number of variable.

W. Furthermore, the ease allowance at waist is only between 0 and 2 cm, but this value at hip is at least 4 cm for pants. In other words, waist girth needs to be more accurately controlled than hip girth; therefore, based on practical application, we selected waist girth as the second index for body classification.

There is only one item in the type factor (Table 5); ultimately, H-W is selected as the third index for body classification.

3. Results

In this section, firstly we used the CCM to classify lower body into three categories, and then used the FCM to represent lower body type. Finally, we discuss the advantage of FCM by comparing with CCM.

3.1. Crisp classification of lower body

In the field of pattern making, body dimensions are divided into two categories: control dimensions and reference dimensions. Control dimensions, should have significant correlation with fitness, but not be highly correlated with each other (Staples and DeLury, 1949); Reference dimensions, which can be calculated based on control dimensions, are not necessary for pattern making. According to Table 1, the dimensions of the median-body are adopted as follows: height is 161 cm, and waist girth is 69 cm, which are both control dimensions. In order to use control dimensions to calculate reference dimensions and grade garment pattern expediently, we grouped height and waist girth, and used the median of each interval to represent all the values. In other word, 161 stands for not a concrete value but an interval (Table 6). We divided height into five equal intervals and waist girth into nine equal intervals, and their grading are 5 cm and 3 cm respectively (Table 6).

Fig. 2 shows that the distribution of H-W can basically be divided into three different stages: in steep increasing portion from 15 cm to 21 cm, a linear region from 21 cm to 36 cm, and then a second steep increasing portion from 26 cm to 30 cm. From Table 7, we define H-W within [15, 21] is type “C”, within (21, 26] is type “B”,

and within (26, 30] is type “A”. This classification excludes people whose H-W is over 30 cm or below 15 cm which account for about 8 percent of the sample population. Types “C”, “B” and “A” account for 22.6, 64.2, and 13.2 percent of the population respectively, and type “B” makes up the vast majority (Table 7).

On the basis of the above analysis, we define the crisp representing method of lower body type as follows:

$$L + Mh/MW + TYPE \quad (2)$$

Where

L stands for lower body classification in order to distinguish upper body classification,
Mh is the median value of the interval which the height belongs to,
MW is the median value of interval which the waist belongs to,
TYPE is the type of lower body which the people belong to,

For example, if a woman's body dimensions are height = 162 cm, waist girth = 68 cm and H-W = 22 cm, her lower body shape is represented as:

L161/69 B

3.2. Fuzzy classification of lower body

After Zadeh proposed fuzzy set theory in 1965 (Zadeh, 1965) and Dubois proposed the concept of triangular fuzzy number in 1980 (Dubois, 1980), this theory has been applied in many fields, such as quality control (Cheng, 2005), risk analysis (Chen and Chen, 2003), performance evaluation (Ishibuchi et al., 1999), fuzzy decision (Wan et al., 2013). Although many scholars research somatotype by CCM for the development of size systems (Choi and Nam, 2010; Geršak, 2013; Zakaria, 2014), there are few studies on fuzzy body classification. Therefore, we propose a novel method of body classification

Table 6
Divisory intervals of height and waist girth (cm).

Height	Median	151	156	161	166	171				
	Interval	149–153	154–158	159–163	164–168	169–173				
Waist girth	Median	57	60	63	66	69	72	75	78	81
	Interval	56–58	59–61	62–64	65–67	68–70	71–73	74–76	77–79	80–82

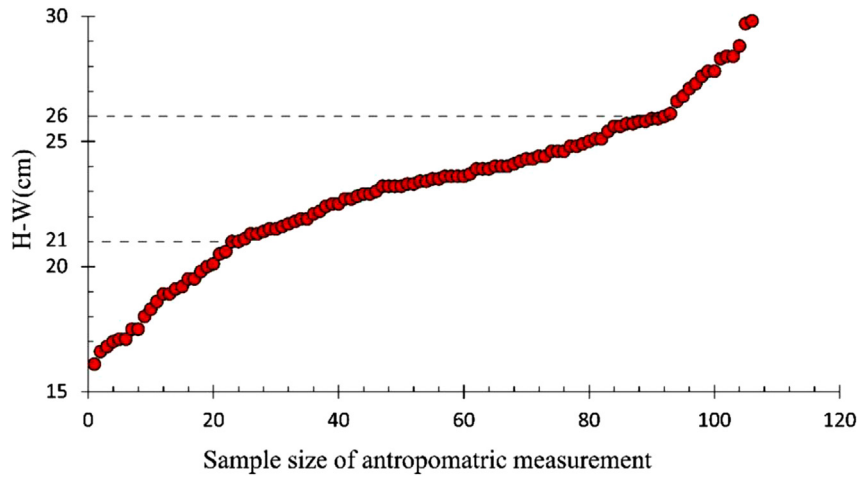


Fig. 2. Scatter diagram of H-W.

Table 7
Descriptive statistics of H-W of each lower body type (cm).

Type	MIN		Max		Interval		Mean		Proportion
A	CALV	ADOV	CALV	ADOV	CALV	ADOV	CALV	ADOV	13.2%
	16.1	15	21	21	[16.1,21]	[15,21]	18.7	19	
B	CALV	ADOV	CALV	ADOV	CALV	ADOV	CALV	ADOV	64.2%
	21	21	26.1	26	(21,26.1]	(21,26]	23.6	24	
C	CALV	ADOV	CALV	ADOV	CALV	ADOV	CALV	ADOV	22.6%
	26.1	26	29.8	30	(26.1,29.8]	(26,30]	27.9	28	
Total					CALV	ADOV	CALV	ADOV	100%
					[16.1,29.8]	[15,30]	23.1	23	

Note: CALV stands for calculated value; ADOV stands for adopted value.

based on the membership function of fuzzy triangular number. Let us introduce the following definition of fuzzy triangular number (Dubois, 1980; Van Laarhoven and Pedrycz, 1983):

Definition. We define a triangular fuzzy number M on R ($= (-\infty, +\infty)$) with its membership function $MS(x):R \rightarrow [0, 1]$ is equal to:

$$MS(x) = \begin{cases} \frac{x}{m-s} - \frac{s}{m-s}, & x \in [s, m] \\ \frac{x}{m-u} - \frac{u}{m-u}, & x \in [m, u] \\ 0, & otherwise \end{cases} \quad (3)$$

Where

$s \leq m \leq u$, m stands for the possible value of the fuzzy number. s and u stand for the lower and upper limit values of the fuzzy number respectively.

Next, we design the lower body shape's membership function $MS_C(x)$, $MS_B(x)$ and $MS_A(x)$ based on the theory of triangular fuzzy number and Table 7. Here, it is important to note that s and u in Formula (3) are not the minimum and maximum of the crisp classification interval. Instead, the median of the crisp classification interval is the lower or upper limit value of the fuzzy number. Moreover, for each body, its total memberships for type A, B and C must equal to 1. For this reason, we propose the following rules. If the value of H-W is between 15 and 19, the corresponding body type completely belongs to type C. If H-W is between 28 and 30, the body type completely belongs to type A (see Fig. 3). As shown in Fig 3, if the value of H-W is equal to 21, the body type is located on the

boundary between type C and B. If the value of H-W is 26, the body type is on the boundary between type B and A. For different body types, their membership degrees on the boundaries should be equal to 0.5. Therefore, we can adjust the line segments of the membership functions when H-W is equal to 21 (see Fig. 3). The membership function $MS_C(x)$, $MS_B(x)$ and $MS_A(x)$ are defined as follows:

$$MS_C(x) = \begin{cases} 1, & (15 \leq x \leq 19) \\ \frac{23}{4} - \frac{x}{4}, & (19 \leq x \leq 21) \\ \frac{24}{6} - \frac{x}{6}, & (21 \leq x \leq 24) \\ 0, & (24 \leq x \leq 30) \end{cases} \quad (4)$$

$$MS_B(x) = \begin{cases} \frac{x}{4} - \frac{19}{4}, & (19 \leq x \leq 21) \\ \frac{x}{6} - \frac{18}{6}, & (21 \leq x \leq 24) \\ \frac{28}{4} - \frac{x}{4}, & (24 \leq x \leq 28) \\ 0, & (15 \leq x \leq 19 \cup 28 \leq x \leq 30) \end{cases} \quad (5)$$

$$MS_A(x) = \begin{cases} 0, & (15 \leq x \leq 24) \\ \frac{x}{4} - \frac{24}{4}, & (24 \leq x \leq 28) \\ 1, & (28 \leq x \leq 30) \end{cases} \quad (6)$$

Where

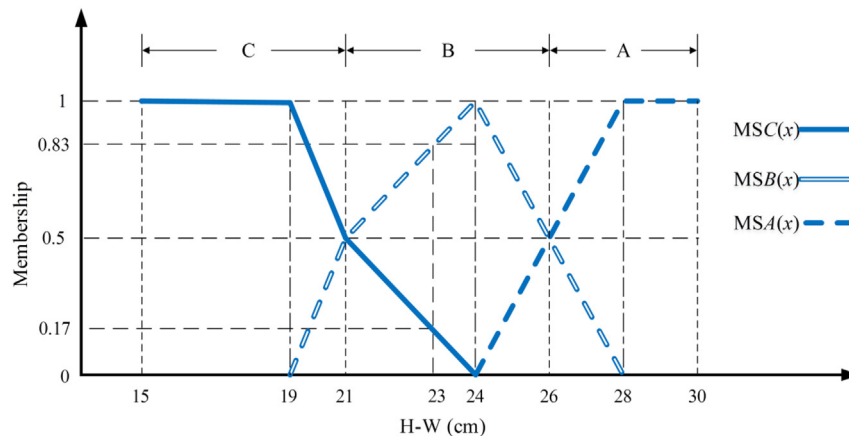


Fig. 3. Lower body classification base on triangular fuzzy number.

$MSC(x)$, $MSB(x)$, $MSA(x)$ stand for the membership of type “C”, “B” and “A” respectively (Fig. 3).

x stands for the value of H-W (Unit: cm).

With the help of Fig. 3, we can easily understand the distribution of the membership of type “C”, “B” and “A”. Finally, we define the fuzzy representing method of lower body shape as follows:

$$L + Mh/MW + TYPE_{max} + (MS_C, MS_B, MS_A) \quad (7)$$

Where

L stands for lower body classification in order to distinguish upper body classification.

Mh is the modal value of the interval which height belongs to.

MW is the modal value of interval which waist belongs to.

$TYPE_{max}$ stands for the body type which has the biggest membership of all body types.

MSC , MSB , and MSA stand for the membership of type “C”, “B” and “A” respectively.

For example, if a woman's body dimensions are height = 163 cm, waist girth = 73 cm and H-W = 23 cm, according to Formulas (4–6) and definition (7), her lower body shape is represented as:

$$L 161/72 B (0.17, 0.83, 0)$$

Where, the values in the bracket indicate that the membership degree of the woman's body type is 0.17 for Type C, 0.83 for Type B and 0 for Type A.

4. Discussion

4.1. The relationship between lower body and lower clothing

Body shape information has been widely applied in ergonomics design. Some researchers focused on analysis of specific anthropometric measurement, such as pregnant women (Dumas et al., 2009; Wu et al., 2014); handicapped (Nowak, 1996), the elderly (Haitao et al., 2007), male (Khadem and Islam, 2014), female (Tehard et al., 2002), workers (Barroso, Arezes, da Costa and Sérgio Miguel, 2005; Del Prado-Lu, 2007), and babies (Yajnik et al., 2003). However, most of these research studies didn't combine real-world cases of different industries to analyze the anthropometric data.

Many also lack the link of these analytic results with ergonomics design for related fields. For this research, body classification is aimed at improving the fitness of clothing and providing more accurate information on body shape for the fashion industry; therefore, it is important to analyze the relationship between lower body shape and clothing for the lower body.

As shown in Fig. 4, designers divide lower body into three zones: fit-zone, action-zone, and design-zone (Zhong, 2000). The fit-zone is where clothing should fit the body well is a crucial part for fitting. In the action-zone, clothing should provide for appropriate human body comfort. Also, the ease allowance of the action-zone is closely related to movement comfort. Stylists design various below-the-waist apparel according to ideas in the design-zone. From this information, we know that the fit and comfort of lower clothing depend on rational fashion and pattern design in the fit-zone and action-zone. Pattern makers design darts between waist and hip (fit-zone) for well-fitting clothing, as shown in Fig. 5. The values of front and back dart depend on the H-W; hence, H-W is a crucial factor to fit.

Given the above, it is quite reasonable to select H-W as the type factor for lower body classification in this research.

4.2. Comparing with CCM and FCM

The traditional method of body classification is crisp, and an either-or way; but it is too absolute. For example, two women with H-W of 25 cm and 27 cm are actually of the same body shape. However, in the CCM, they are classified differently. Hence, fitting issues are common with this method, final patterns might fit a few people. This is the exactly reason why many customers complain that they are always unable to select form-fitting clothing.

FCM is a better approach to these shortcomings. For example, if H-W of two women are 25 cm and 27 cm, according to FCM of lower body (Formula (4–7)), their body shape are represented as (0, 0.75, 0.25) and (0, 0.25, 0.75) respectively; however, according to CCM, their body shape belong to B and A respectively. We propose the Fitting Ease Allowances (FEA) of lower clothing of the type A and B are a cm and b cm respectively (Fig. 6 (1) and (2)). Using CCM, the woman with H-W of 25 cm is more close to type B than type A; therefore, this woman's fitting ease allowance is b cm according to the traditional design method (Fig. 6 (3)). However, the woman with H-W of 27 cm is more close to type A than type B; therefore, this woman's fitting ease allowance is a cm according to the traditional design method (Fig. 6 (4)). Actually, neither a cm nor b cm suits the two women (too loose or too tight). Using our fuzzy

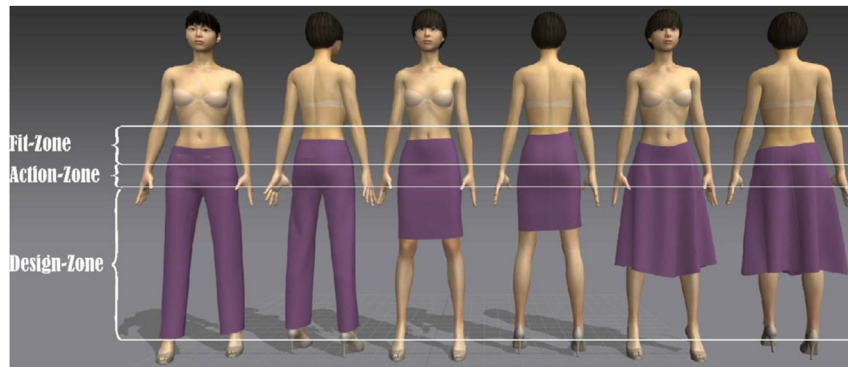


Fig. 4. Functional zones of fashion design.

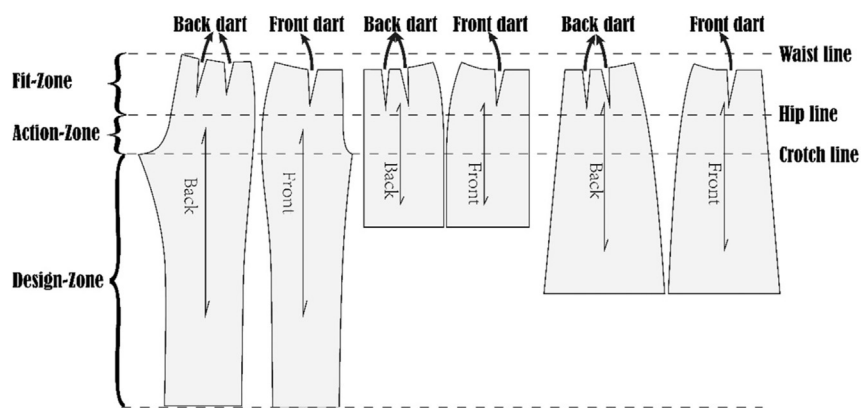


Fig. 5. Functional zones and darts of pattern design.

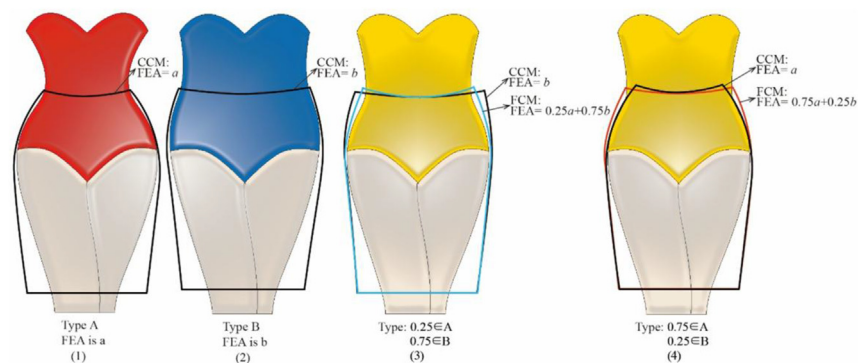


Fig. 6. Comparing with CCM and FCM on Clothing fitting.

method, the two woman's fitting ease allowances are: $0.75a+0.25b$ cm and $0.25a+0.75b$ cm respectively (Fig. 6 (3) and (4)). The result indicates that the FCM is more accurate than the CCM.

In addition, fashion designers design garments according to empirical knowledge rather than rigorous calculation. This empirical knowledge is too tacit and abstract to be summarized, thus fuzzy theory could be better and more widely applied in the fashion industry.

5. Conclusions and prospects

According to analyses of anthropometric measurement data of young women's lower body, we derive three main conclusions: Firstly, the lower body shape can be well represented by height, waist girth and H-W; Secondly, FCM of lower body can more accurately represents body information than CCM without increasing the number of body types; Finally, the mean of height, waist girth and hip girth of young woman of northeast China

increased by about 0.8 cm, 1.5 cm and 1.4 cm respectively compared with ten years ago.

This research proposes a FCM of lower body; certainly, this is only a small scope of the research in the fashion industry. There is still much work to be done in the direction of this research. Moreover, our research was limited to young women's lower body in the northeast of China; it would certainly be of significance to further analyze the possibility of applying the result of this study for the whole body or with children or adult males as the target population.

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References

- Alexander, M., Jo Connell, L., Beth Presley, A., 2005. Clothing fit preferences of young female adult consumers. *Int. J. Cloth. Sci. Technol.* 17 (1), 52–64. <http://dx.doi.org/10.1108/09556220510577961>.
- Barroso, M.P., Arezes, P.M., da Costa, L.G., Sérgio Miguel, A., 2005. Anthropometric study of Portuguese workers. *Int. J. Ind. Ergon.* 35 (5), 401–410. <http://dx.doi.org/10.1016/j.ergon.2004.10.005>.
- Castellucci, H.I., Arezes, P.M., Molenbroek, J.F.M., 2015. Analysis of the most relevant anthropometric dimensions for school furniture selection based on a study with students from one Chilean region. *Appl. Ergon.* 46, 201–211. <http://dx.doi.org/10.1016/j.apergo.2014.08.005>. Part A.
- Cerny, B.A., Kaiser, H.F., 1977. A study of a measure of sampling adequacy for factor-analytic correlation matrices. *Multivar. Behav. Res.* 12 (1), 43–47. http://dx.doi.org/10.1207/s15327906mbr1201_3.
- Chen, S.-J., Chen, S.-M., 2003. Fuzzy risk analysis based on similarity measures of generalized fuzzy numbers. *Fuzzy Syst. IEEE Trans.* 11 (1), 45–56. <http://dx.doi.org/10.1109/TFUZZ.2002.806316>.
- Cheng, C.-B., 2005. Fuzzy process control: construction of control charts with fuzzy numbers. *Fuzzy sets Syst.* 154 (2), 287–303. <http://dx.doi.org/10.1016/j.fss.2005.03.002>.
- Choi, Y.L., Nam, Y.J., 2010. Classification of upper lateral body shapes for the apparel industry. *Hum. Factors Ergon. Manuf. Serv. Ind.* 20 (5), 378–390. <http://dx.doi.org/10.1002/hfm.20188>.
- Chun-Yoon, J., Jasper, C.R., 1994. Development of size labelling systems for women's garments. *J. Consumer Stud. Home Econ.* 18 (1), 71–83. <http://dx.doi.org/10.1111/j.1470-6431.1994.tb00692.x>.
- Chun-Yoon, J., Jasper, C.R., 1995. Consumer preferences for size description systems of men's and women's apparel. *J. Consumer Aff.* 29 (2), 429–441. <http://dx.doi.org/10.1111/j.1745-6606.1995.tb00055.x>.
- Chung, M.-J., Lin, H.-F., Wang, M.-J.J., 2007. The development of sizing systems for Taiwanese elementary- and high-school students. *Int. J. Ind. Ergon.* 37 (8), 707–716. <http://dx.doi.org/10.1016/j.ergon.2007.05.004>.
- Commerce, U. D.o, 1958. National Bureau of standards Commercial standard CS 215-58. Body Measurements for the Sizing of Women's Patterns and Apparel. U.S. Government Printing Office, Washington, DC.
- Daanen, H.A.M., Ter Haar, F.B., 2013. 3D whole body scanners revisited. *Displays* 34 (4), 270–275. <http://dx.doi.org/10.1016/j.displa.2013.08.011>.
- Daanen, H.A.M., Van de Water, G.J., 1998. Whole body scanners. *Displays* 19 (3), 111–120. [http://dx.doi.org/10.1016/s0141-9382\(98\)00034-1](http://dx.doi.org/10.1016/s0141-9382(98)00034-1).
- Del Prado-Lu, J.L., 2007. Anthropometric measurement of Filipino manufacturing workers. *Int. J. Ind. Ergon.* 37 (6), 497–503. <http://dx.doi.org/10.1016/j.ergon.2007.02.004>.
- Dubois, D.J., 1980. *Fuzzy Sets and Systems: Theory and Applications*, vol. 144. Academic press, New York.
- Dumas, G.A., Upjohn, T.R., Delisle, A., Charpentier, K., Leger, A., Plamondon, A., McGrath, M.J., 2009. Posture and muscle activity of pregnant women during computer work and effect of an ergonomic desk board attachment. *Int. J. Ind. Ergon.* 39 (2), 313–325. <http://dx.doi.org/10.1016/j.ergon.2008.03.003>.
- Dziuban, C.D., Shirkey, E.C., 1974. When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychol. Bull.* 81 (6), 358. <http://dx.doi.org/10.1037/h0036316>.
- Fraenkel, J.R., Wallen, N.E., Hyun, H.H., 1993. *How to Design and Evaluate Research in Education*, vol. 7. McGraw-Hill, New York.
- Geršak, J., 2013. Clothing sizing systems. In: Geršak, J. (Ed.), *Design of Clothing Manufacturing Processes*. Woodhead Publishing, Cambridge, pp. 21–52.
- Haitao, H., Zhizhong, L., Jingbin, Y., Xiaofang, W., Hui, X., Jiyang, D., Li, Z., 2007. Anthropometric measurement of the Chinese elderly living in the Beijing. *Int. J. Ind. Ergon.* 37 (4), 303–311. <http://dx.doi.org/10.1016/j.ergon.2006.11.006>.
- Han, J., Kamber, M., Pei, J., 2011. *Data Mining: Concepts and Techniques: Concepts and Techniques*. Elsevier, Waltham, MA.
- Hsiao, H., Whitestone, J., Wilbur, M., Lackore, J.R., Routley, J.G., 2015. Seat and seatbelt accommodation in fire apparatus: anthropometric aspects. *Appl. Ergon.* 51, 137–151. <http://dx.doi.org/10.1016/j.apergo.2015.04.004>.
- Hsu, C.-H., 2009. Data mining to improve industrial standards and enhance production and marketing: an empirical study in apparel industry. *Expert Syst. Appl.* 36 (3), 4185–4191. <http://dx.doi.org/10.1016/j.eswa.2008.04.009>. Part 1.
- Ishibuchi, H., Nakashima, T., Murata, T., 1999. Performance evaluation of fuzzy classifier systems for multidimensional pattern classification problems. *Syst. Man, Cybern. Part B Cybern. IEEE Trans.* 29 (5), 601–618. <http://dx.doi.org/10.1109/3477.790443>.
- ISO., 2012a. *Size Designation of Clothes - Women's and Girls' Outerwear Garments*. ISO 3637:1977. Geneva.
- ISO., 2012b. *General Requirements for Establishing Anthropometric Databases*. ISO 15535:2012, p. 22. Geneva.
- Jee, S.-c., Yun, M.H., 2016. An anthropometric survey of Korean hand and hand shape types. *Int. J. Ind. Ergon.* 53, 10–18. <http://dx.doi.org/10.1016/j.ergon.2015.10.004>.
- Kaiser, H.F., 1970. A second generation little jiffy. *Psychometrika* 35 (4), 401–415. <http://dx.doi.org/10.1007/BF02291817>.
- Khadem, M.M., Islam, M.A., 2014. Development of anthropometric data for Bangladeshi male population. *Int. J. Ind. Ergon.* 44 (3), 407–412. <http://dx.doi.org/10.1016/j.ergon.2014.01.007>.
- Kidwell, C.B., Christman, M.C., 1974. *Suiting Everyone: the Democratization of Clothing in America*. Smithsonian Institution Press, Washington, DC.
- Lee, Y.-C., Wang, M.-J., 2015. Taiwanese adult foot shape classification using 3D scanning data. *Ergonomics* 58 (3), 513–523. <http://dx.doi.org/10.1080/00140139.2014.974683>.
- Lee, Y.S., 2014. *Developing apparel sizing systems for particular groups*. In: Gupta, D., Zakaria, N. (Eds.), *Anthropometry, Apparel Sizing and Design*. Woodhead Publishing, Cambridge, pp. 197–254.
- Nowak, E., 1996. The role of anthropometry in design of work and life environments of the disabled population. *Int. J. Ind. Ergon.* 17 (2), 113–121. [http://dx.doi.org/10.1016/0169-8141\(95\)00043-7](http://dx.doi.org/10.1016/0169-8141(95)00043-7).
- Obi, O.F., Ugwuishiwi, B.O., Adeboye, B.S., 2015. A survey of anthropometry of rural agricultural workers in Enugu State, south-eastern Nigeria. *Ergonomics* 58 (6), 1032–1044. <http://dx.doi.org/10.1080/00140139.2014.1001446>.
- Park, W., Park, S., 2013. Body shape analyses of large persons in South Korea. *Ergonomics* 56 (4), 692–706. <http://dx.doi.org/10.1080/00140139.2012.752529>.
- Roach, A., 1994. Meeting consumer needs for textiles and clothing. *J. Text. Inst.* 85 (4), 484–495. <http://dx.doi.org/10.1080/00405009408631295>.
- Sadeghi, F., Mazloumi, A., Kazemi, Z., 2015. An anthropometric data bank for the Iranian working population with ethnic diversity. *Appl. Ergon.* 48, 95–103. <http://dx.doi.org/10.1016/j.apergo.2014.10.009>.
- Simmons, K.P., 2003. *Body Shape Analysis Using Three-dimensional Body Scanning Technology*. North Carolina State University (Doctor of Philosophy).
- Staples, M., DeLuury, D., 1949. A system for the sizing of Women's garments. *Text. Res. J.* 19 (6), 346–354. <http://dx.doi.org/10.1177/004051754901900605>.
- Syuaib, M.F., 2015. Anthropometric study of farm workers on Java Island, Indonesia, and its implications for the design of farm tools and equipment. *Appl. Ergon.* 51, 222–235. <http://dx.doi.org/10.1016/j.apergo.2015.05.007>.
- Tehard, B., Liere, M.J.V., Nougé, C.C., Clavel-Chapelon, F., 2002. Anthropometric measurements and body silhouette of women: validity and perception. *J. Am. Dietetic Assoc.* 102 (12), 1779–1784. [http://dx.doi.org/10.1016/S0002-8223\(02\)90381-0](http://dx.doi.org/10.1016/S0002-8223(02)90381-0).
- Van Laarhoven, P., Pedrycz, W., 1983. A fuzzy extension of Saaty's priority theory. *Fuzzy sets Syst.* 11 (1), 199–227. [http://dx.doi.org/10.1016/S0165-0114\(83\)80082-7](http://dx.doi.org/10.1016/S0165-0114(83)80082-7).
- Van Niekerk, S.-M., Louw, Q.A., Grimmer-Somers, K., Harvey, J., Hendry, K.J., 2013. The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school. *Appl. Ergon.* 44 (3), 366–371. <http://dx.doi.org/10.1016/j.apergo.2012.09.008>.
- Wan, S.-P., Wang, Q.-Y., Dong, J.-Y., 2013. The extended VIKOR method for multi-attribute group decision making with triangular intuitionistic fuzzy numbers. *Knowledge-Based Syst.* 52, 65–77. <http://dx.doi.org/10.1016/j.knosys.2013.06.019>.
- Wang, L., He, X., Wang, C., Wang, Z., Zhou, X., 2015. Anthropometric measurements of the female perineum for design of the opening shape of urination device. *Int. J. Ind. Ergon.* 46, 29–35. <http://dx.doi.org/10.1016/j.ergon.2015.01.004>.
- Wu, G., Liu, S., Wu, X., Ding, X., 2014. Research on lower body shape of late pregnant women in Shanghai area of China. *Int. J. Ind. Ergon.* 0 <http://dx.doi.org/10.1016/j.ergon.2014.12.007>.
- Yajnik, C., Fall, C., Coyaji, K., Hirve, S., Rao, S., Barker, D., Kellingray, S., 2003. Neonatal anthropometry: the thin-fat Indian baby. *The Pune maternal nutrition study*. *Int. J. Obes.* 27 (2), 173–180. <http://dx.doi.org/10.1038/sj.ijo.802219>.
- Zadeh, L.A., 1965. Fuzzy sets. *Inf. control* 8 (3), 338–353.
- Zakaria, N., 2014. Body shape analysis and identification of key dimensions for apparel sizing systems. In: Gupta, D., Zakaria, N. (Eds.), *Anthropometry, Apparel Sizing and Design*. Woodhead Publishing, Cambridge, pp. 95–119.
- Zhong, Z., 2000. *Body and Clothing: Body Structure, Esthetical Element and Pattern*. China Textile Press, Beijing (in chinese) (G. Yuan, Trans.).
- Zhou, X., Chen, J., Chen, G., Zhao, Z., Zhao, Y., 2016. Anthropometric body modeling based on orthogonal-view images. *Int. J. Ind. Ergon.* 53, 27–36. <http://dx.doi.org/10.1016/j.ergon.2015.10.007>.
- Zhuang, Z., Shu, C., Xi, P., Bergman, M., Joseph, M., 2013. Head-and-face shape variations of U.S. civilian workers. *Appl. Ergon.* 44 (5), 775–784. <http://dx.doi.org/10.1016/j.apergo.2013.01.008>.