Analysis and classification of three-dimensional trunk shape of women by using the human body shape model

Kensuke Nakamura*

Department of Advanced Fibro-Science,
Graduate School of Science and Technology,
Kyoto Institute of Technology,
Matsugasaki Hashigami-cho, Sakyo-ku,
Kyoto, 606-8585, Japan
E-mail: kensuke@ma2.seikyou.ne.jp
*Corresponding author

Takao Kurokawa

Department of Systems Innovation,
Graduate School of Engineering Science,
Osaka University,
Machikaneyama-cho 1-3, Toyonaka,
Osaka, 560-8531, Japan
E-mail: kurokawa@sys.es.osaka-u.ac.jp

Abstract: This paper proposes a new method for extracting shape components of the trunk of women from three-dimensional measurements and tries a classification of the trunk shapes. Subjects in this study are 560 Japanese women, ranging in age from 19 to 63 years. First, the authors describe three-dimensional (3D) trunk shape using the control points given by fitting the human body shape model to 3D measurements of the subjects and reduce the number of the control points to be suited for statistical analysis based on correlation strength. The principal component analysis is applied to the shape data or the reduced set of the control points. Then, the authors interpret trunk shape components by combining factor loading map and averaged shape figures. Finally, the authors try to classify the trunk shape of Japanese women by means of the cluster analysis of component scores of the above results.

Keywords: body shape model; Japanese women; three-dimensional shape analysis; trunk.

Reference to this paper should be made as follows: Nakamura, K. and Kurokawa, T. (2009) 'Analysis and classification of three-dimensional trunk shape of women by using the human body shape model', *Int. J. Computer Applications in Technology*, Vol. 34, No. 4, pp.278–284.

Biographical notes: Kensuke Nakamura received his Bachelor (2002) and Master (2004) from Kyoto Institute of Technology (KIT), Japan. He is now a Graduate student of KIT. His specialty is a study on treating three-dimensional measurements of human body for designing products suitable with customers. He has studied a model of 3D measurements, simulation of brassier-wearing figure and human body size estimation. He has also participated in collaborative projects of KIT and Wacoal Corporation.

Takao Kurokawa received his Bachelor (1966), Master (1968) and Doctor (1971) in Control Engineering from Osaka University, Japan. He was a Research Associate of Osaka University (1971–1987), an Associate Professor (1987–1990) and a Professor (1990–2006) of KIT. He was also a Guest Research Director in Advanced Software Technology and Mechatronics Research Institute of Kyoto (2000–2004). He received the title of Professor Emeritus from KIT in 2006. He is currently Professor of the Graduate School of Engineering Science, Osaka University. His research interests include human interface, cognitive engineering and ergonomics.

1 Introduction

Identifying shape components of human body is essential for designing close-fitting products. Especially in the field of apparel, analysing the shape of the women's trunk is the most important issue because many woman customers still have strong demands for size-fit, wear-comfort and sensuousness of underwear, garments or other products.

Many researchers had studied the body shape of human by use of body measurements, photographic imagery or silhouette. However, these methods are not sufficient to describe the three-dimensional (3D) shape of the body. Therefore, the approaches using the 3D measurements are recently investigated with the spread of the laser metrology (Azouz et al., 2006). The authors have also proposed the method of dealing with 3D shape of the human body by combining the 3D human body shape model developed by T. Kurokawa and his colleagues (Kurokawa, 1997, 2006) with analysing or searching methods. For example, the principal components for women's breast and abdomen shape have been found through the principal component analysis of the control point coordinates of the model (Choi et al., 2006; Jung et al., 2006).

In this paper, the authors propose a method of statistically analysing the overall shape of the trunk and classifying those of Japanese women into smaller number of classes. The main problem in this research is that the number of the coordinates of the control points in the shape data is more than 1,000 so that the principal component analysis or other many statistically analysing methods are inapplicable to them. To address this problem, the authors use correlation coefficients between coordinates of each pair of the control points to reduce the number of the data without loss of the overall information on trunk shape and then apply the principal component analysis to the reduced shape data. In this paper, the authors apply the proposed method to 560 Japanese women and classify their trunk shapes into five classes.

We can expect that the method will be applied to various sorts of customer groups and the results will be reflected in cloth design instead of seat-of-the-pants approach of designers. As a result, it will be helpful in producing not only size and shape fitting clothes, but also functional clothes in shape adjustment, posture adjustment and wear-comfort.

2 A method of trunk shape analysis

2.1 The human body shape model

The 3D human body shape model developed by Kurokawa and others (Kurokawa, 1997, 2006) can describe 3D human body shape with high precision among existing methods. This model also plays an important role for analysing 3D body shape and simulating wearing figures. The model is a periodical cylinder-like surface of the bi-cubic B-spline:

$$\boldsymbol{p}(u,v)=\sum_{i=1}^{m+3}\sum_{j=1}^{n}N_{i,3}(u)N_{j,3}(v)V_{i,j}, \tag{1}$$

where $\boldsymbol{p}(u, v)$ is a point on the B-spline surface normalised by the anatomical feature points, u and v are surface coordinates, $N_{p,q}$ is a B-spline basal function and $V_{i,j}$ are control points. i and j are the indices of the segments forming the B-spline surface. The control points $V_{i,j}$ are determined through least-square fitting of the surface (1) to a set of 3D measurements of a female subject and the authors make m = 30 and n = 25 for high precision modelling of the female trunk with error less than 1.54 mm in depth. Thus, obtained 750 control points can reconstruct the trunk shape of the subject.

Moreover, the B-spline surface has the locality, that is, surface transformation induced by displacement of control points within a small region remains local. Based upon this property, we can expect that the shape of any local area on the trunk surface can be expressed with a small subset of control points. In addition, each control point labelled as i and j has the same meaning among different modelled women.

The authors have already demonstrated that we can easily calculate and display average body shape using two or more models (Kurokawa, 1997). The authors have also described that the model is useful to estimate body size (Nakamura and Kurokawa, 2006), to simulate brassiere-wearing figures (Choi et al., 2005a, 2005b) and to analyse 3D shape of the breast (Choi et al., 2006) and the abdomen (Jung et al., 2006).

2.2 3D body measurement

3D measurements of 560 Japanese women between the age of 19 and 63 were taken on laser metrology in 2000 at Wacoal Corp. Subjects were scanned in a natural standing posture wearing only panties. The obtained data for each subject consist of approximately 160,000 body surface points. After measurement, the body shape model was fitted to the measurements of each subject. Then, 560 sets of shape data were extracted from the models.

2.3 Reduction of shape data

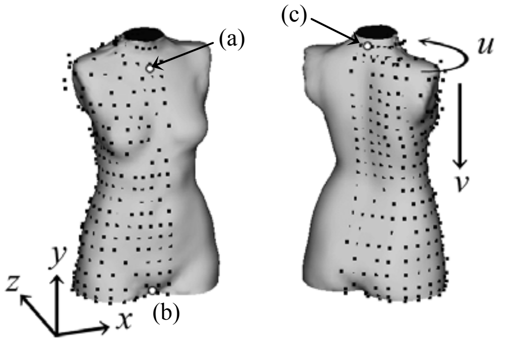
The shape data of the trunk consist of 750 (control points) × 3 (x, y, z) = 2,250 coordinates or variables. As this number of 2,250 is, as mentioned in Section 1, much larger than the number of subjects, the authors cannot use them in the analysis. The authors therefore reduce the shape data in two steps: reduction of analysing region and elimination of the control points.

The authors have no reason to believe that there is a statistical difference in shape between the right and left trunk. This enables the authors to treat the half side of the trunk instead of the whole trunk without lacking shape information. The authors choose the right side of the trunk for shape analysis.

The 18 × 23 control points shown in Figure 1 are necessary to describe the shape of the right side of the trunk except the neck. These points are aligned along the circumferential (u) and the height (v) coordinates on the cylindrical coordinate system. Hence, the authors have the shape data composed of (18 × 23 × 3) = 1,242 coordinate variables. For the purpose of focusing on shape analysis, the authors redefine the origin of coordinates for each subject. The redefined origin corresponds to the x and y coordinates of the pubic foot point shown in Figure 1(b) and z coordinate of the fossa jugularis point shown in Figure 1(a).

Here, the pubic foot point is not an anatomical point, but a point marked on a photographic image. And all of the coordinates are normalised to the height difference between the cervicale [Figure 1(c)] and the pubic foot point in order to eliminate the size factor.

Figure 1 The human body shape model, its 18 × 23 control points that describe the right side of the trunk and mark points used for definition of the origin and normalisation of shape data, (a) the fossa jugularis point (b) the pubic foot point (c) the cervicale



The second step of shape data reduction is based upon the correlation analysis between coordinates of the neighbouring control points in (u, v) arrangement. The number of coordinates describing the right side of the trunk is 1,242 and is yet larger than that of the subjects. The authors' idea is to eliminate one of the pair of neighbouring control points if the two is highly correlated in one coordinate among all the subjects. Though correlation strength may differ among the three coordinates, this correlation judgment and elimination are carried out in each coordinate. The procedure of the elimination of control point coordinates is shown in Figure 2.

Figure 2(a) illustrates an example of the correlation coefficients between the coordinates of control points on control point map. The map denotes the 18 × 23 control points of the shape data. Each cell of the map corresponds to one control point of the right side of the trunk. For instance, the cell $(u, v) = (2, 1)$ is the closest control point to the cervicale and cell (17, 23) means the pubic foot point shown in Figure 1.

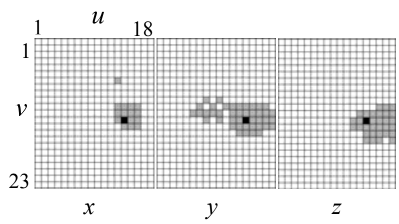
1 For each cell (target cell) on the map, we firstly look for coordinates that have a correlation coefficient of above 0.80 with the target cell as pictured in Figure 2(a). And if the coordinates are located within plus or minus two cells to u and v direction from the target, we consider these coordinates as representable by the target cell.

2 Then, we choose the control point that has the largest sum of the representable coordinates of x, y and z as a representative control point.

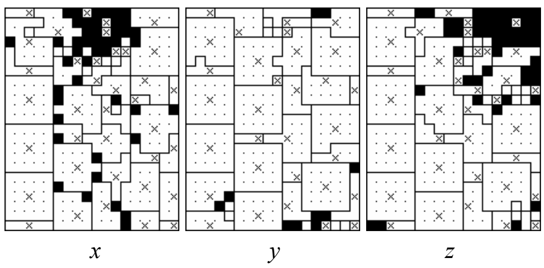
3 The coordinates of the representative control point and their representable coordinates are removed from the map.

Steps 1–3 are repeated until the remaining coordinates have no representable coordinates.

Figure 2 Maps of control points, (a) an example of the relations between the coordinates of the control points* (b) the 111 representative coordinates (x mark) and their representative coordinates**



(a)



(b)

Notes: *The black-cell and each grey-cell have correlation coefficients above 0.80 among 560 subjects and **the region surrounded by the solid lines.

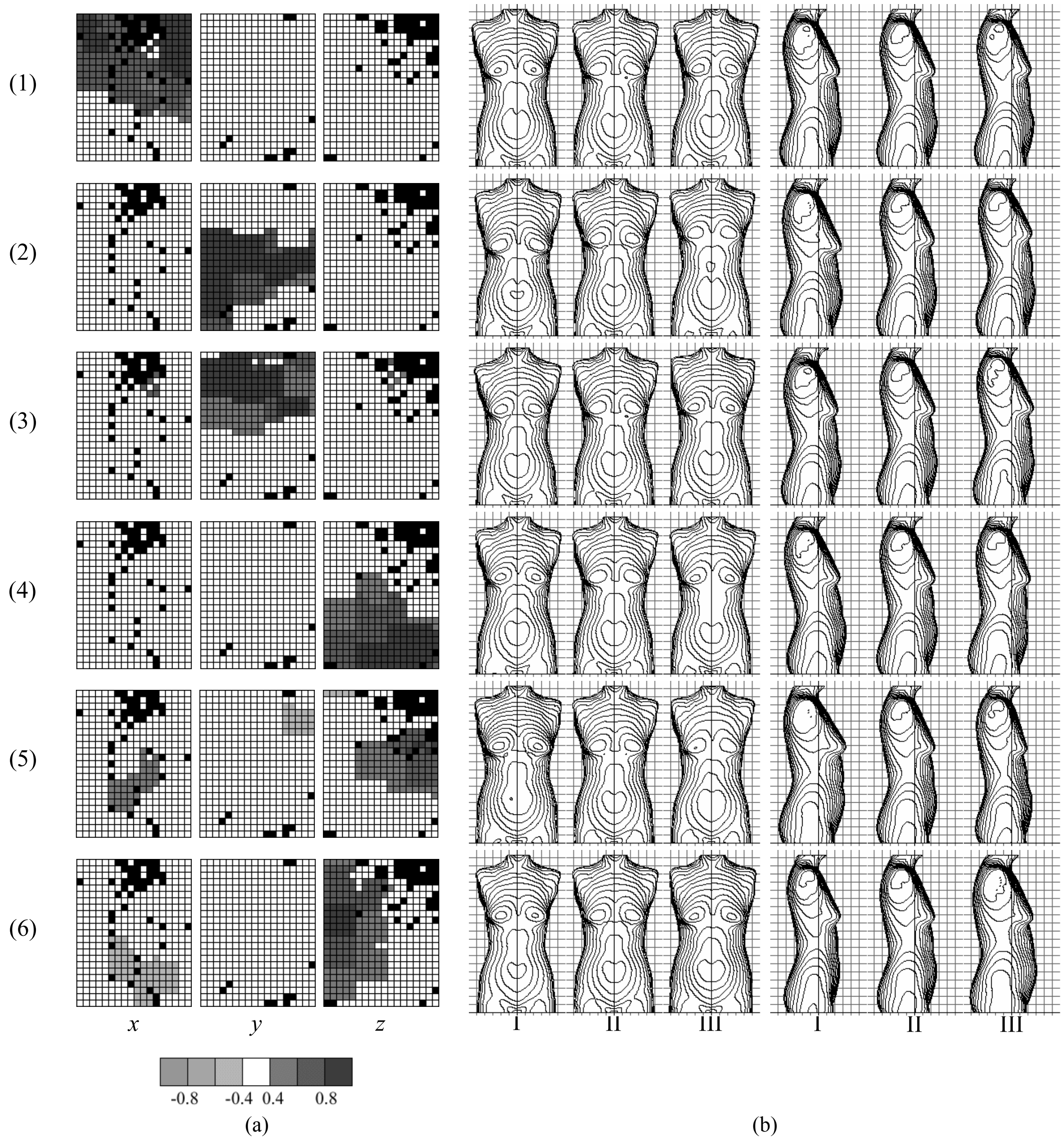
As a result, 111 representative coordinates that can cover approximately 92% of the original coordinates were chosen as the dataset for shape analysis. The representatives are indicated by x in Figure 2(b). The remaining 8% of the coordinates expressed by black cells are highly independent from those of adjacent control points and have no representable coordinates. These independent coordinates are removed from the shape data because this study is aiming to characterise the overall shape of the trunk. The compressibility rate of this method is approximately 91%.

3 Principal component analysis of trunk shape

3.1 Principal component analysis

Principal component analysis with varimax rotation is applied to variance-covariance matrix of the 111 representative coordinates of the 560 subjects in order to extract the shape factors of the female trunk.

Figure 3 Factor loading maps and average figures of the three subject groups, (a) the factor loadings of x, y and z coordinates are grey scaled (b) three groups (I, II and III) are arranged in increasing order of component scores for each of the first six principal components (1)–(6)



3.2 Results of the principal component analysis

The first six of principal components can be clearly interpreted as shape factors of the trunk. The seventh or later components contain the shape factors of the neck, the shoulder, the upper and the lower abdomen, etc. And they are not enough to characterise the whole shape of the trunk since these components relate to only small part of the body and their contribution rates are relatively low.

Table 1 shows the contribution ratio of the six higher principal components. Figure 3(a) illustrates factor loading maps in each principal component and each of the three coordinates x, y and z of the control points using the grey scale shown below the maps where the coordinates of the control points are arranged as in Figure 2. These maps depict which part of the truck each principal component mainly relates to. For example, in Figure 3(a)(4), z coordinate in the lower truck is strongly loaded with positive loadings. This means that the subjects with negatively large component score on the fourth principal component have a strongly outstanding lower trunk. Drawing subjects' body figures having variety of component scores assists interpretation of these maps. For this purpose, the authors calculate the average figures of subjects in the three groups split by the standard deviation σ of the component scores for each principal component. Let $P_{i,j}$ denote the ith component score of subject j and σ_i be the standard deviation of the ith scores $P_{i,j}$ (j = 1,..., 560), then the 560 subjects are classified into three groups: Group I ($P_{i,j} \leq -\sigma_i$), Group II ($-\sigma_i < P_{i,j} \leq \sigma_i$) and Group III ($\sigma_i \leq P_{i,j}$).

Figure 3(b) shows the average body figures of all the three groups of the subjects for the six principal components. In Figure 3, the figures are presented in contour to emphasise differences of shape among the component score groups.

Table 1 Contribution rate of the main components

Component	*Contribution (%)*	*Cumulative contribution (%)*
1st	13.32	13.32
2nd	11.36	24.67
3rd	10.77	35.44
4th	8.46	43.90
5th	7.02	50.92
6th	6.75	57.67
7th	6.61	64.28
8th	5.49	69.77

3.3 Interpretation of principal components

In this section, the first six principal components are interpreted according to the factor loadings and the average figures of the three groups illustrated in Figure 3. The shape of the left side of the body is not included in the shape analysis, but is referred to if needed.

The first principal component [Figure 3(1)] represents a factor of horizontal of the trunk while the average figure of Group I leans to the left, the figure of Group III leans to the right. Moreover, Group II slightly leans to the right.

The second principal component is interpreted as a factor of breast height. The intermediate trunk is positively loaded with larger absolute values. This means that an increase in the component score results in a longitudinally elongated abdomen. The averaged figures shown in Figure 3(b)(2) also confirm this. In addition, width and thickness of the waist of Group III looks smaller than those of Group I.

The third principal component corresponds to shoulder shape. When the component score increases, shoulder slope decreases. This also lifts up the chest and the breasts.

The fourth principal component can be considered to be a factor of longitudinal inclination of the trunk. In Figure 3(4), z coordinates of lower half of the trunk show high factor loadings: therefore, z coordinates in the lower region of Group III figure have larger values compared to the upper region. This means that the higher the component score is, the more posterior the waist and hips are relatively located against the fossa jugularis point or the z origin.

The fifth principal component may be a factor of breast size. As the component score increases, the breast and the upper abdomen lose their volume, the waist slenderises and shape of the upper chest flattens.

The sixth principal component is considered as a factor of fatness of the trunk. z coordinates of the back of the trunk are thoroughly loaded with positive values and as a result, thickness of the trunk is fairly increases. This is clearly confirmed in Figure 3(b)(6), too. It is particularly worth noting that only the sixth one among the six principal components has a significant correlation with the subjects' age ($R = 0.39$, $p = 0.00 < 0.01$).

4 Classification of trunk shape

4.1 Cluster analysis

In this section, in order to classify trunk shape of Japanese women, the authors carry out the cluster analysis of the component scores of the six principal components given in Section 3. We can easily derive classes by dividing a multidimensional principal component space (Choi et al., 2006) where the 560 subjects are distributed according their component scores as the authors tried in Figure 3(b). However, this method yields needlessly many classes. Clustering is a reasonable way in the sense that we can get the preferred number of classes in many cases. The preferred number of classes is determined on the basis of the dendrogram reflecting the relationship among classes.

The authors adopt Ward's method and utilise the square Euclidean distance as the metric. The component scores are not normalised since the variance of each component has special importance as a shape factor of the trunk.

4.2 Result of classification

The obtained dendrogram is illustrated in Figure 4. As the authors want to have a relatively small number of classes, based on the dendrogram, they judge that 'five' is an appropriate number of classes. Therefore, the authors obtain five classes: C1, C2, C3, C4 and C5. The number of subjects included in each class is indicated in Table 2. The authors also utilise the human body model to calculate the average figure in each class in order to understand classification property. The resultant average figures are shown in Figure 5.

Figure 4 Dendrogram of cluster analysis and the level of the five classes (the horizontal dotted line)

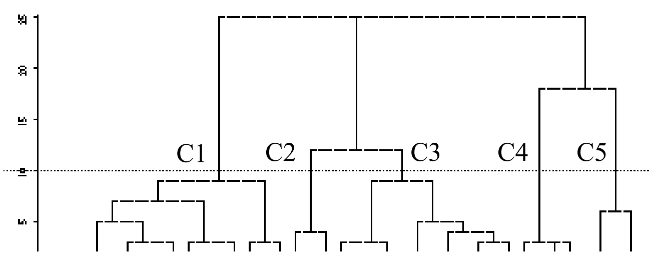
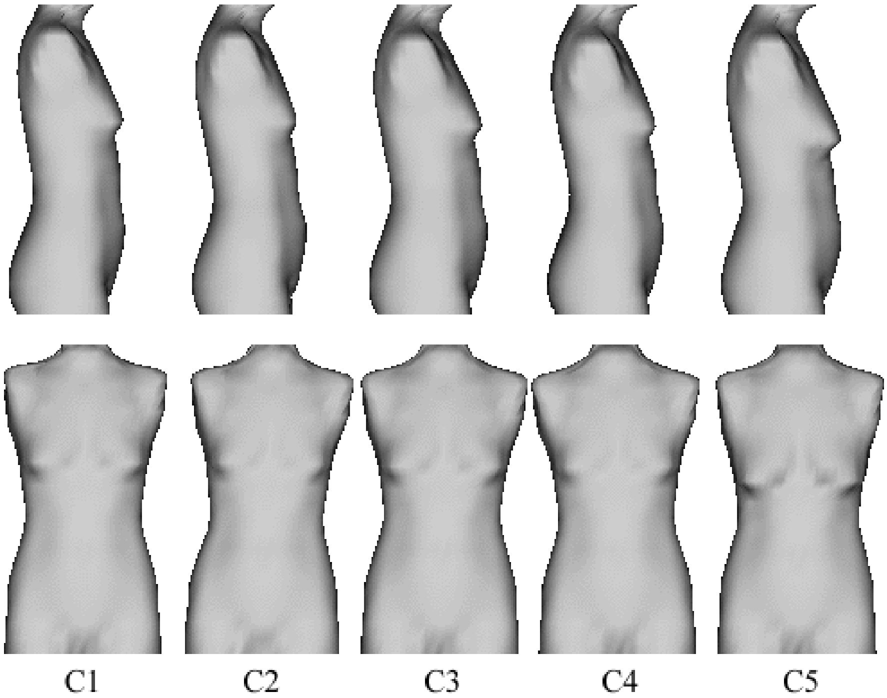


Table 2 Number of subjects in the classes C1 to C5

Class	*C1*	*C2*	*C3*	*C4*	*C5*
No. of subjects	180	45	195	63	77

Figure 5 Average figures in the classes C1 to C5



4.3 Interpretation of classes

Observation of average figures of the five classes is summarised below.

C1 is a slim figure bending forward and the angle of shoulder slope is closer to horizontal. C2 is leaned to the left and has the breast that is relatively small and located at the highest level. C3 is a posture of leaning backward and has about one-third of the subjects, the largest number in the classes. C4 is leaned to the right and the low shoulder and has the small breast. C5 looks a somewhat corpulent body and the position of the breast is lower than those of other classes.

5 Discussions

5.1 Discussion on analysis of trunk shape

In the reduction of the number of the shape data, the representative coordinates tend to be distributed onto the neck, the shoulder or especially onto the chest. The representatives are considered reasonable to describe the overall shape of the trunk of women. Furthermore, the authors have repeated the shape analysis, changing the condition of the parameters of the shape data reduction (the threshold of correlation coefficient and the range of representation) and confirmed that there were no significant differences among the results.

The extracted six components can describe approximately 57.67% of the all variation in the right side of the women's trunk. The remaining 42.33% is expected to be the information of respective small parts of the body (as mentioned in Section 3) or artifacts that are due to misalignment of the models.

The interpretations of the first six principal components seem to have some agreements with the results of studies on one- or two-dimensional data. The main advantage of the authors' method is that it allows them to quantify all of these shape factors of the trunk automatically and accurately from the 3D models. In contrast, the methods that are based on body measurements, photographic imagery or silhouette can treat only a part of the body shape or need time-consuming manual procedures.

The component scores that quantify the trunk shape can be calculated for any woman by combining the factor loadings derived in this research and the representative coordinates of the human body shape model of her own and helps us to understand the body shape objectively. However, it is necessary to choose the suitable components for the intended application. For instance, it would appear that the first or the fourth principal component is suitable for posture evaluation. The other four principal components may have a significant role in design of garments that must fit snugly.

5.2 Discussion on classification of trunk shape

The authors classified the subjects' shapes of the right side of the trunk into the five classes according to the component scores. These five classes are expected to represent the typical shapes of the trunk of the Japanese women. It is possible to classify the trunk shapes into more classes. However, in actual design of products, the authors have to consider the variation in shape and size of customer's body. Too many classes of the shape will raise cost of the products.

Some problems still remain with the classification. Firstly, the result of the classification is greatly influenced by the first component as no normalisation applies to the component scores. Secondly, this type of mechanical classification is at risk of putting a person having exceptional shape of the trunk into one of those classes. As to these two issues, the authors have already tried some classification methods in the study of the breast shape (Choi et al., 2006). Thirdly, on the other hand, some results indicate normality of subject distribution in space of the six component scores. The normality will lead to misclassification. Now, the authors are in process of analysing these issues.

6 Conclusions

In this paper, the authors have proposed two methods of analysing 3D human body shape. The first is the method for getting the shape data to be analysed. The authors' human body shape model has many parameters or control points, to form a curved surface approximating the human body surface. This study has proved that these parameters serve as shape data. However, the number of them easily exceeds that of subjects when the model is of high accuracy and covers a wider region of the body surface. This is a major problem for statistical analysis.

The second is the method for solving the above problem by means of a sort of data compression. Adjacent control points of the shape model have a tendency to similarly behave when subjects are changed. Therefore, if a pair of adjacent control points is highly correlated over all subjects, one of the pair can represent them and another of the pair can be removed from the shape data without losing shape information. This idea has performed over the arrangement of all the control points of the trunk model and the data compressibility ratio of 91% has been attained.

The results of the principal component analysis of the compressed shape data were satisfactory. The results have been visualised by two ways: factor loading maps and body figures averaged using the shape model. Interpretation of principal components can be performed at any level of detail based on these visualisations, although it has remained at perfunctory level in this paper.

One of the remaining problems is the separation of body shape and posture. Posture may vary with time and may be standardised before analysing body shape. Selecting the classification criterion for body shape is also the important problem. This is dependent on application of the classification results. For designing ready-made clothes, the criteria should be simple in order to reflect it to pattern making, grading and so on. In this case, division of the principal component space may serve for practical use after carefully reducing the dimension number (Choi et al., 2006).

Acknowledgements

The authors appreciate the members of the Human Science Laboratory, Wacoal Corporation, Kyoto, Japan for their cooperation in measuring many subjects and offering data for this research. The authors also thank Dr. D-E. Choi of the University of Leeds, UK, for her fruitful discussion and cooperation in this study.

References

Azouz, Z.B., Rioux, M., Shu, C. and Lepage, R. (2006) 'Characterizing human shape variation using 3D anthropometric data', *Visual Comput*, Vol. 22, pp.302–314, DOI 10.1007/s00371-006-0006-6.

Choi, D-E., Nakamura, K. and Kurokawa, T. (2005a) 'Simulation of brassiere-wearing figures by combining a three-dimensional human body shape model and the genetic algorithm', *Proc. International Design Congress IASDR 2005*, JPLiP00561.pdf.

Choi, D-E., Nakamura, K. and Kurokawa, T. (2005b) 'Simulation of brassiere-wearing figures using multi-regression model and its evaluation', *Journal of the Textile Machinery Society of Japan*, Vol. 58, No. 6, pp.T68–T75.

Choi, D-E., Nakamura, K. and Kurokawa, T. (2006) 'Analysis and classification of 3-D breast shape using human body model', *Journal of the Textile Machinery Society of Japan*, Vol. 52, No. 6, pp.243–251.

Jung, H., Wakabayashi, T., Nakamura, K., Choi, D-E. and Kurokawa, T. (2006) 'Analysis and classification of three-dimensional shape of women's abdomen', *Human Interface Society, 10th Nonverbal Interface Society, 7th Human Media Society, Joint Symposium*, pp.63–66.

Kurokawa, T. (1997) 'Measurement and description of human body shape and their applications', *Keisoku to Seigyo*, Vol. 36, pp.77–83.

Kurokawa, T. (2006) 'Description of two- and three-dimensional human body shape', *Proc. 3rd International Symposium for Materials & Kansei in Textiles Fashion*, pp.33–40.

Nakamura, K. and Kurokawa, T. (2006) 'Estimation of body sizes by combining the body shape model and genetic algorithm', *Human Interface Society, 10th Nonverbal Interface Society, 7th Human Media Society, Joint Symposium*, pp.18–25.