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Importance of Body Shape Categorization in Developing Size Charts for Female Pants

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Abstract: *Each country needs its own size chart to suit its population, because researchers have found that human body shapes, proportions and measurements change significantly with geographical and demographical differences. However, the ready-to-wear apparel industry still faces the problem of poor fit of apparels. Therefore, this research aims at developing size charts for female pants by primarily categorizing the diverse lower body shapes of Sri Lankan females and clustering their anthropometric dataset using global kernel k-means clustering approach. A sample of 1068 Sri Lankan females of ages 20-40 years were measured and thirteen lower body measurements were collected. This dataset was preliminary categorized into three categories using waist-to-hip ratio (WHR) in order to accurately represent the female lower bodies. The categorized dataset was clustered separately using the global kernel k-means clustering approach. This clustered data was used to develop size charts for female pants and the resultant size charts were validated by live model fitting of fabricated pants and through a standard feedback questionnaire. It showed that the developed size charts clearly represent the Sri Lankan females aged 20-40 years, which will lead to a reduction of fit problems in the ready-to-wear pant market.*
Keywords: *Kernel-based clustering, size chart development, Waist-to-Hip Ratio*

I. Introduction

Achieving proper apparel fit is a major concern in the global ready-to-wear apparel industry. Apparel fit is directly related to the anatomy of the human body and a well-fitted garment conforms to the human body with adequate ease of movement[1]. In the custom-made tailoring method of garment manufacturing, consumers achieve a good fit in their garments because the direct interaction between the consumer and the manufacturer facilitates having exact measurements of the consumer as well as his/ her fit preferences. When this system is changed into a mass production system, which is the manufacturing of garments in large quantities, fitting problems could arise in ready-to-wear garments. In the mass production system where the manufacturer and the consumer are not linked together, the manufacturer creates the product and it is up to the consumer to accept or reject it [2]. Although this mass production systems enable low cost garment manufacturing, it badly affects customer satisfaction due to poor fit. Hence, the concept, “mass customization” where consumers are incorporated into the product development process at the beginning and hence, products follow the specifications of the consumer, was introduced in order to achieve customer satisfaction [2]. When mass customization is targeted, availability of advanced technology such as computer-aided design and manufacturing (CAD/CAM), 3-D body scanning facilities and flexible manufacturing systems are vital. Therefore, this mass customization concept was not popularized among the majority of apparel manufacturers due to the huge investment in the above mentioned technologies, as well as due to other practical constraints such as receiving consumer’s exact requirements.

In the mass production system, standard size charts act as a communication tool among manufacturers, retailers and consumers. The purpose of these size charts is to divide varied body measurements of a population into homogeneous sub groups. The size charts used for apparel production directly affect the fit of apparels. However, each consumer cannot achieve a good level of fit in ready-to-wear garments due to the existence of vast differences in body shape and proportion among the population. Along with the large number of relevant body dimensions, the body proportions and shapes vary by a great extent [3]. Classifying a population into homogenous body sizes is therefore a highly complex problem. Further, body dimensions and shapes vary depending on different factors such as ethnicity, life style changes, racial mixes, and generational variability [4]. Therefore, establishing its own sizing system based on up-to-date anthropometric data of the population is a must for any country to eliminate fit problems [5].Further, it was understood that the selection of a proper method to segment the anthropometric dataset and identification of available different body shapes within the population is very important in developing an accurate size chart.

There are different female pelvic shapes which directly relate to different lower body shapes of females [6]. These lower body shapes have a significant impact on the fit of female pants. Therefore, it is important to have an understanding of these different pelvic shapes in developing size charts for female pants. The female pelvic shape can be subdivided as (i) the normal and its variants (ii) symmetrically contracted pelvis(iii) the Rachitic flat pelvis and (iv)the asymmetrical pelvis [6]. Therefore, in developing a size chart for the female lower body, there should be a technique to differentiate these lower body shapes.

1.1 Effect of waist-to-hip ratio in lower body shapes

When the female lower body is considered, the Waist-to-Hip Ratio (WHR) is a significant factor in classifying its shapes. Further, this WHR of females is an important factor in several aspects such as attractiveness, healthiness, fertility, and cognitive ability of her child [7].Due to testosterone and estrogen levels and their effect on fat distribution in the body, the WHR varies. Therefore it is clear that fat distribution patterns and different pelvic shapes affect the shapes of the lower body. Furthermore, this girth ratio approach can provide a more reasonable and convenient identification of figure types to facilitate apparel manufacturing [8]. It is stated that the preferable level of WHR is 0.67 to 0.8 for women[9]. Further, it was revealed that women with a waist to hip ratio of 0.7 are more attractive [10][11], and men in western countries prefer women whose WHR is in between 0.6-0.7 [12].

1.2 Application of global kernel k-means clustering approach for anthropometric data clustering

In literature, it was found that the k-means clustering method was mainly used for segmenting anthropometric data in order to develop size charts [13] [14]. However, in k-means clustering the resulted clusters depends on the initial positions of the cluster centers which may trap in local optimal solutions and it can only find linearly separable clusters in input data space [15]. Further, when applying k-means clustering for a dataset with a high number of variables, it requires reduction of variables[15]. Since, anthropometric data are not linearly separable due to complex combinations among variables, the k-means approach might not work well. Further, variable reduction in anthropometric data is not effective because one variable cannot represent another.

Global kernel k- means clustering which was used for MRI segmentation was identified as a suitable approach in clustering anthropometric data [15] [16]. It was a combination of the global *k*-means clustering method[17] and kernel *k*-means clustering method [18] and it avoids the problems encounter with *k*-means clustering. Kernel *k*-means clustering method is capable of handling high dimensional data [18] and this is a very strong reason for using kernel *k*-means for clustering anthropometric data which *k*-means cannot handle efficiently. Further, through a kernel function, input data is mapped to high dimensional feature space where this data can be separated linearly which in turn separate input data nonlinearly identifying the non-linear structures in input space [19].

Since prior knowledge on number of clusters were not available the best number of clusters was recognized through cluster validation which was done using kernel-based Dunn's index .The Dunn's index [20] measures the ratio between the smallest inter-cluster distance and the largest intra-cluster distance and hence maximum value of Dunn index is the optimal cluster number. Dunn's Index was extended to kernel-based Dunn's Index as given in (1).

$$kDI(K) = \min_{1 \le i \le K} \left\{ \min_{1 \le j \le K} \left\{ \frac{\delta^K(C_i, C_j)}{\max_{1 \le k \le K}\{\Delta^K(C_k)\}} \right\} \right\} \qquad (1)$$

where $\Delta^{\kappa}(C_{\kappa})$ is the largest intra-cluster separation of cluster k in the feature space, $\delta^{\kappa}(C_i, C_j)$ is the minimum of kernel based distance between cluster i and cluster j in the feature space [21] .Hence, maximum value of this index is corresponding to the optimal number of clusters.

1.3 Problem Identification

A Kurt Salmon Associates' study (2000) reported that 50percent of women cannot find a good fit in apparel, and fit problems are the reason for 50percent of catalog returns [22]. Furthermore, it was stated that the most dissatisfied apparel consumers were women[23] [24]. Further, it was revealed that women were mostly dissatisfied with the fit of their pants at the waist, hip and thighs mainly[25] and50 percent of the female survey group reported having fit problems at the same lower body areas[26]. From a questionnaire survey done by this researcher regarding the fit of the ready-to-wear female garments in Sri Lanka, it was found that the majority had problems with pants. It was revealed that 66 percent of females return the pants due to fit problems and 74 percent of females had to fit-on three or more pants to achieve a satisfactory level of fitting. Hence, the rate of return of female pants as well as customer dissatisfaction is high in ready-to-wear garments in Sri Lanka. Since different body shapes directly affect the fit of ready- to-wear garments, separate size charts should be developed for available body shapes. Identifying these different body shapes is a very difficult task due to its complexity.

The main objective of this research is to explore different lower body shapes available among Sri Lankan females and develop size charts for female pants using Global kernel k-means clustering approach.

II. Methodology

A sample of 1068 Sri Lankan females of the age limit of 20-40 years was selected for the study based on a 95% confidence level and 3% margin of error. Thirteen dimensions of the lower body of females'(waist, hip, thigh, mid thigh, knee, mid-calf, ankle, outseam, inseam, knee height, ankle height, waist to hip height and crotch length) were measured following the procedures of [27]. The data set was initially categorized based on waist-to-hip ratio. Referring to literature, cut-off limits of the WHR were selected as 0.7 and 0.8 to segment the lower body shapes into three categories.

Global kernel *k*-means clustering algorithm with Gaussian(RBF) kernel function which is given in (2)was used in clustering the datasets.

$K(X, Y)=exp(-\|X-Y\|^2/2\sigma^2)$ ....(2)

where $\sigma \in \mathbb{R}$ is called Gaussian kernel parameter

The sigma value which gave the highest variance of the kernel matrix was selected as the optimum value[28].Since prior knowledge of the number of clusters were not available, the clustering process was repeated for several number of clusters and the best number of clusters was recognized through kernel based Dunn's index. For analysis, Matlab version 7.7 and SPSS version 16 were used.

In developing size charts from those clustered data, out of thirteen variables, waist, hip and inseam length were identified as key variables based on Pearson correlation coefficients. Further, the size interval for waist, hip and inseam were decided based on measurement range and international size standards [29] .

2.1 Validation of Size Charts

Resulted size charts were validated statistically using "aggregate loss of fit" factor [30] and using live fit assessment sessions which access the fit of the pants. For the fit session, waist, hip and inseam measurements were taken from twenty participants who were selected arbitrarily and their corresponding sizes among the developed size charts were selected. Medium weighted calico fabric was selected for samples and the required ease allowances for producing patterns were decided based on [31]. Accordingly, samples were stitched and fitted-on by the participants. Then, photographs of front, back and side views of the lower body of the participants were taken. A pre-tested questionnaire[32] was used to get the feedback regarding the fit of the pants. The survey result was statistically analyzed to identify the causable reasons amidst the possible coincident due to randomness.

III. Results and Discussion

The data set was initially categorized based on WHR and the resulted lower body shape categories with the number of subjects in each category is shown in Table 1.

Table1: Distribution of the dataset according to WHR

Waist-to-Hip-Ratio	Lower body shape category	No. of subjects
WHR≤ 0.70	Small WHR(curvy lower body)	124
0.71 ≤ WHR ≤0.79	Medium WHR(medium lower body)	629
WHR≥ 0.80	Large WHR(straight lower body)	315

Here, the small WHR category came from females who have small waists and large hips resulting in a curvy lower body. The females whose difference between waist and hip is less, resulting in a straight lower body, formed the large WHR category while the medium WHR category resulted from females who have average waist and hip measurements. After initially dividing the dataset into the above three categories, further analysis was carried out separately on these three datasets.

The Analysis of medium WHR dataset, as an example, was described here. This dataset was clustered using Global kernel *k*-means clustering algorithm with Gaussian(RBF) kernel function. Here, the optimal sigma value of the Gaussian(RBF) kernel function which was calculated by the highest variance of the kernel matrix was thirteen. According to kernel based Dunn's index calculation, optimal number of clusters for medium WHR category was three. Therefore, the dataset was divided into three clusters and further analysis was done in order to develop size charts for female pants.

In developing size charts from these clustered datasets, a 4 cm interval was maintained for waist and hip while a 6 cm interval was maintained for inseam height which resulted in three inseam groups; short (68 cm/26.5"), regular (74 cm/29") and long (80 cm/31.5") for all clusters. After grouping the key variables as explained above, the mean values of the secondary measurements in each group were calculated and tabulated accordingly(Table2).

Table 2: Size chart for short height of medium WHR category

Inseam	Short 68cm									
Waist	58.0		62.0		66.0		70.0		74.0	78.0
Hip	78.0	82.0	82.0	86.0	86.0	90.0	90.0	94.0	94.0	102.0
Thigh	44.5	46.7	47.5	49.1	49.4	51.7	52.7	56.0	55.5	61.0
Midthigh	36.4	38.3	38.9	40.1	40.5	41.2	44.8	45.2	46.3	49.1
Knee	30.2	30.7	30.6	31.6	31.7	32.6	33.5	34.3	34.8	36.3
Mid calf	26.0	26.5	26.8	27.6	27.5	28.7	29.6	30.7	30.1	32.0
Ankle	19.7	20.6	20.5	21.2	20.8	21.7	21.5	21.8	22.1	22.7
Outseam	94.7	95.1	94.7	95.3	94.9	95.1	95.3	97.1	95.8	95.9
Crotchlength	60.4	62.5	62.3	64.2	63.5	65.8	65.7	67.4	68.7	71.5
Hipheight	16.5	16.5	16.7	16.6	16.5	16.8	17.0	17.3	16.6	17.4
Knee height	40.9	40.8	40.3	41.5	40.9	40.6	40.5	41.4	40.5	40.7
Ankle height	6.1	6.0	6.1	6.6	6.5	6.6	6.3	6.4	6.7	7.0
% from medium WHR category	2.54	3.18	4.29	5.56	5.72	3.66	2.86	3.34	1.91	0.95

3.1 Validation of size charts

Statistical validation of size charts through aggregate loss of fit factor (ALF),where the theoretically acceptable value is 4.4 cm, showed that the resultant size charts achieved less ALF value than above. For example, the ALF value for short height of medium WHR category size chart is 2.95. Therefore, it is proved that the resultant size charts are accurately representing the target population.

Further, size charts were validated through a live fit assessment session followed by a questionnaire survey. Fig. 1 (i) ,(ii), and (iii) show the front views of the fitted-on samples which belong to three body shape categories; small WHR, medium WHR and large WHR. Accordingly, the appearances of the front figures are satisfactory and it follows the body curves accurately.

(i) Small WHR category (ii) Medium WHR category (iii) Large WHR category

Fig. 1 Front views of the fitted-on samples in three categories

Pant fit may be difficult due to the shape and depth of the pelvic structure and the size and shape of the waist, stomach, buttock, and upper thigh. This poor appearance could be seen in the back upper thigh area of some pants developed for fit sessions as shown in Fig.2 (i) and (ii). Although, these two participants were in the same small WHR category, their shapes and depth of back muscle were different. Therefore, the first participant in Fig.2 (i) showed satisfactory appearance for the back view and the second participant's (Fig.2 (ii)) back view showed a wrinkled appearance. In this regard, it has been identified that the back rise curve of the pant needs to be scooped for the second participant in order to provide room for her back muscle to sit in. Therefore, by identifying sub-categories of body shapes available within the main categories, required changes of the pant patterns could be done as a provision to customize the product.

(i) First participant (ii) Second participant

Fig.2 Back view of participants in small WHR category

Further, for same circumferential proportions, different width/ depth proportions and different angles may prevail [20]. These facts were clearly shown in Fig3(i) and (ii) where the two participants in the same small WHR category, however, differ in buttocks prominence. Therefore, as explained above, adding sub-categories which need only the pattern modifications could improve the customer satisfaction.

(i) First participant (ii) Second participant

Fig.3 Side view of participants in small WHR Category

The questionnaire feedback for 12 samples were analyzed and a column chart was produced by calculating percentages of "agree" and " neither agree nor disagree" answers for 9 questions.

The column chart (Fig.4) showed that more than 80 percent agreed with the fit of the pants they fitted-on while waist, leg and pant length achieved 100 percent fit agreement. The question number 4; “Crotch is loose so that buttock and thigh are not defined”, scored minimum of 83 percent since in two samples, crotch was not loose resulting in the buttock to be defined. However, according to the analysis of questionnaire feedback, it can be concluded that the fit of the samples are acceptable which in turn confirm the accuracy of the new size chart.

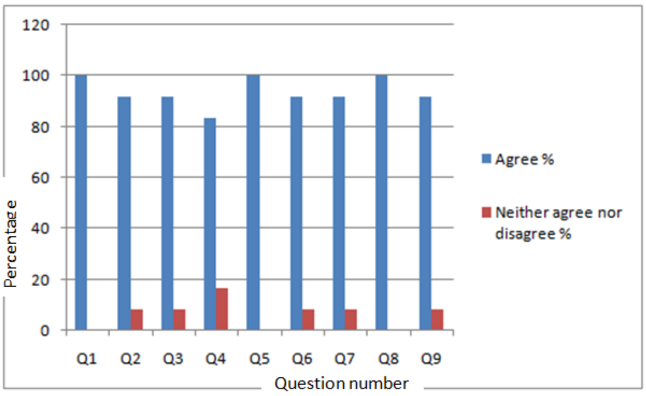

Fig. 4: Column chart of the percentages of “agree” and “neither agree nor disagree” of the questionnaire

IV. Conclusion

Due to the issues incurred in k-means clustering method, global kernel *k*-means clustering, which is a novel approach, was used in this research for anthropometric data clustering. The most important fact is that the approach can handle high dimensional data without variable reduction which is a requirement for anthropometric data clustering. Further, this method facilitates non-linear separation of clusters which is also an important prerequisite in clustering of anthropometric data. In addition, the ability to handle large datasets is also an advantage though the time complexity is high in processing. In this research, it was revealed that different lower body shapes need to be identified for achieving a perfect fit. Although, the researcher could realize three lower body shapes, further development need to be done incorporating width/ depth proportions in defining varied lower body shapes. Validation process of resultant size charts which was done statistically and through live fit assessment session, proved that the new size chart was strongly representing the lower body of Sri Lankan females of aged 20-40 years. Furthermore, the results of the questionnaire survey verified that the participants were satisfied with the fit of the sample pants they fitted-on. Therefore, it was confirmed that categorizing different body shapes available in the population and applying suitable clustering approach separately for the identified categories are very important in developing apparel size charts. Further, the new approach: global kernel k-means clustering approach, with a suitable kernel function and optimized kernel parameters would provide better solution in clustering of anthropometric data.

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