

A Generation Method of Representative Human Models at the Boundary Zone of a Designated Accommodation Percentage

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Abstract. Representative human models (RHM) for the target population are used for anthropometric product design and evaluation in virtual environments. The existing RHM generation methods such as boundary approach use multivariate data reduction techniques such as factor analysis to reduce the original set of anthropometric dimensions. Due to the limitation of the data reduction techniques the lack of representativeness of RHMs by the existing methods has been reported. The present study developed and evaluated a boundary zone method. The proposed boundary zone method generated representative human models at the boundary zone statistically accommodating a designated percentage of the population without any data reduction technique. The evaluation results showed that the accommodation percentage of the boundary zone method was 91%, which was higher than those of square (41%) and circular method (82%) and similar to that of rectangular method (92%). Furthermore, the representative human models by the boundary zone method were within the size ranges of the target population.

Keywords: Representative human model, Anthropometric design, Digital human simulation, Accommodation, Computer workstation.

1 Introduction

Representative human models (RHMs) for the target population are used for anthropometric product design and evaluation in virtual environments. RHMs are a small group of digital human models which statistically represent a designated percentage (e.g., 90%) of the target population. These human models give designers a way to efficiently utilize the body sizes of the target population in product design and evaluation. For example, the interior layouts of a bus [15] and an overhead [9] can be efficiently evaluated by a small group of human models in terms of posture, visibility, and reach.

Existing generation methods of RHMs can be grouped into two categories (boundary approach and distributed approach) according to the characteristic of

design application. The boundary approach generates RHMs at the boundary enclosing a designated percentage of the target population; and the human models can be applied to design and evaluate a one-size product (one-size fits all) such as workstation [2], car interior [4], and cockpit [16]. On the other hand, the distributed approach generates RHMs at the centroid of the scattered grids which accommodate a designated percentage of the target population; the human models can be used for design and evaluation of a multiple-size product such as clothing [8, 10, 13].

The boundary approach can be further classified into three methods (square, rectangular, and circular methods) according to the determination of a boundary. The square method [1, 2] generates RHMs at the corners and a centroid of a square formed in the space of factors identified by factor analysis on anthropometric dimensions under consideration. Next, the rectangular method [7] generates RHMs by the procedure similar to that of the square method except that the boundary is determined to statistically enclose a designated percentage and consider the relative importance of each factor. Lastly, the circular method [12] generates RHMs at the every 45 degree of the circumference of the circle which encloses a designated percentage of the target population.

Limitations of the boundary approach using a data reduction technique have been reported [11]. Data reduction techniques such as factor analysis and principal components analysis can reduce the original set of anthropometric dimensions to a smaller set, although most of the body size variability (e.g., 80% of the total variability) is accounted. This information distillation greatly simplifies the generation process of RHMs; however, some of the body size variability (e.g., 20% of the total variability) is omitted in the generation of RHMs. Furthermore, conversion from sizes of RHMs defined in the space of common variables to the space of anthropometric dimensions may cause estimation error if there is a low correlation between a factor and corresponding anthropometric dimensions.

The present study developed a generation method of RHMs at the boundary zone statistically accommodating a designated percentage of the target population for one-size design. The boundary zone enclosing a designated percentage can be identified by the normalized square distance of anthropometric dimensions without using any data reduction technique. The present study compared the performances of the boundary zone method to those of the exiting boundary methods through the generation of RHMs for a computer workstation design.

2 Boundary Zone Method

The present study proposed a two-step generation method of RHMs at the boundary zone which accommodates a designated percentage. First, the values of anthropometric dimensions under consideration are converted into normalized square distances to identify the boundary zone which statistically accommodates the designated percentage. Second, clustering analysis is conducted on the cases within the boundary zone to minimize the number of RHMs satisfying the accommodation percentage requirement.

2.1 Identification of the Boundary Zone

To determine the boundary which accommodates a designated percentage, the values of anthropometric dimensions are converted into normalized square distances by Equation 1. Since the normalized square distance of multivariate normally distributed data follows chi-square distribution with the degree of freedom = n (the number of variables) [6], the boundary which encompasses a designated percentage can be identified by using the normalized square distance. For example, since the chi-square distance of the 90% (p) accommodation boundary for stature and weight is 4.61 ($\chi^2_{2}(1-p) = \chi^2_{2}(0.1)$), the normalized square distances of 90% of the target population are smaller than 4.61.

$$D(S,W) = (S - \mu_s \quad W - \mu_w) \Sigma^{-1} \begin{pmatrix} S - \mu_s \\ W - \mu_w \end{pmatrix} \tag{1}$$

where: D = normalized squared distance

S = stature

W = weight

μ_s = average of stature

μ_w = average of weight

Σ = variance-covariance matrix of stature and weight

The boundary zone as shown in Fig. 1 consists of two boundaries. The boundaries of the boundary zone are determined by a designated accommodation percentage plus and minus a tolerance (e.g., 90% \pm 1%). For example, the chi-square distances for each boundary are 4.41 ($\chi^2_{2}(0.11)$) and 4.81 ($\chi^2_{2}(0.09)$) for the boundary zone which accommodate the 90% of the target population with the 1% tolerance.

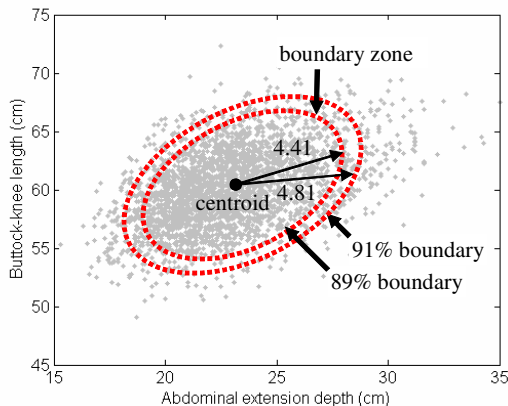


Fig. 1. Illustration of a boundary zone defined by two boundaries

2.2 Clustering Analysis for the Cases Within the Boundary Zone

Clustering analysis is applied to the cases within a boundary zone to minimize the number of RHMs generated. Some of the cases within the boundary zone may be similar in body size so that the cases are grouped into clusters to minimize the number of RHMs. The optimal number of clusters by clustering analysis should be determined while satisfying the designated accommodation percentage. After clustering analysis, RHMs are generated at the centroid of each cluster.

3 Results

The anthropometric database of the US Army [5] and 10 anthropometric dimensions related to the design of computer workstation were used to generate RHMs. The anthropometric database (males = 1,774; females = 2,213) of the US Army were used in the study. The anthropometric data were divided into two subsets (training set: 2,982; testing set: 1,000) to avoid biased evaluation. Then, the anthropometric dimensions for a computer workstation design were selected by referring to a draft standard for computer workstation design [3].

The boundary zone method generated more RHMs than the existing boundary methods (square method, rectangular method, and circular method). The boundary zone method generated 34 human models to accommodate 90% of the target population. On the other hand, the square, rectangular, and circular methods generated 9, 9, and 20 human models.

The accommodation percentage of the boundary zone method was 91% which is close to the target percentage (90%). The boundary zone and rectangular method generated RHMs who accommodated 91% and 92% of the population. But, the accommodation percentages of the square and circular method were 41% and 82% that were lower than the target percentage.

The accommodation percentage decreased as the number of anthropometric dimensions increased. The accommodation percentages for one anthropometric dimension were 87, 99, 97, and 99% for the square, rectangular, circular, and boundary zone methods, respectively; those for three dimensions decreased to 70, 97, 93, and 97% for the square, rectangular, circular, and boundary zone method, respectively. This decreasing tendency was greatest with the square method and lowest with the rectangular and boundary zone methods.

Although the accommodation percentage of the rectangular method was satisfactory, some RHMs generated by the rectangular method were smaller and/or larger than the size ranges of the target population. The sizes of RHMs should be in the ranges of the population; however, the rectangular method generated RHMs smaller than the target population. For example, the size range of forearm-to-forearm breadth for the rectangular method was from 33 cm to 68 cm, of which lower bound is smaller than that of the target population (37 cm). This might be caused from the large boundary which was determined to statically accommodate the target percentage of the population.

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