DEVELOPMENT OF A DISTRIBUTED REPRESENTATIVE HUMAN MODEL GENERATION AND ANALYSIS SYSTEM FOR MULTIPLE-SIZE PRODUCT DESIGN

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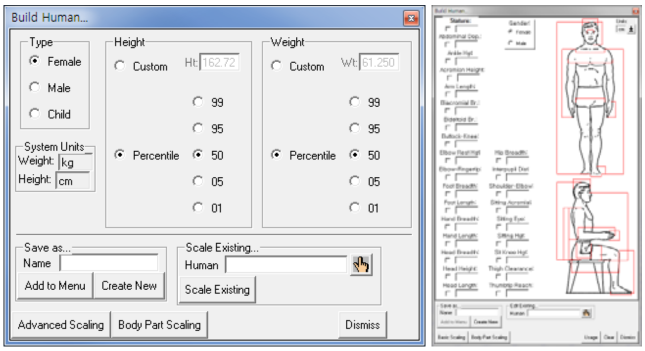
The aim of the study is to develop a distributed representative human model (DRHM) generation and analysis system. DRHMs are used for a product with multiple-size categories such as clothing and gloves. It is not easy for a product designer to explore an optimal sizing system by applying various DRHM generation methods because of their complexity and time demands. The existing studies related to DRHM generation protocols and RHM generation methods of three digital human model simulation systems (Jack®, RAMSIS®, and CATIA Human®) were reviewed in the study. The DRHM generation protocol was implemented by providing sophisticated interfaces which offer various statistical and visualization techniques. The system can analyze the multivariate accommodation percentage of a sizing system, provide body sizes of generated DRHMs, and visualize generated DRHMs. The DRHM generation and analysis system can be of great use to efficiently determine an optimal sizing system for a multiple-size product by comparing various sizing system candidates with each other.

INTRODUCTION

Multiple-size products such as clothing and gloves have more than two sizes. A sizing system for multiple-size products has been used to fit groups in various sizes (Winks, 1997; Ashdown, 2003). A product design based on anthropometric data can fit the human body with effectiveness (KATS, 2006); therefore, a sizing system of the multiple-size product needs to be properly designed to accommodate the anthropometric characteristics of a target population.

Distributed representative human models (DRHMs) have been applied traditionally for the design and evaluation of the sizing system for multiple-size products. A distributed method generates one DRHM in each grid formed to accommodate a designated percentage (e.g., 90%) of the target population (Jung, 2009). The previous studies designed sizing systems of gloves (Robinette and Annis, 1986; Rosenblad-Wallin, 1987; Kwon et al., 2004), lower body clothing (Moon, 2002), women's underwear (Zheng et al., 2007), protective clothing (Laing et al., 1999), and apparel (McCulloch et al., 1998) through distributed methods; however, it is not easy for a product designer to generate DRHMs and analyze the performance of an applied distributed method due to the systems' complexity, multiformity, and time demands (Lee et al., 2011).

Digital human simulation systems such as Jack® generally provide two interfaces (percentile and custom-built) for generating RHMs in a virtual environment; however, these interfaces do not provide multivariate RHM generation functions. The percentile method only provides three or five stature percentile-based RHMs (1st, 5th, 50th, 95th, and 99th percentiles, Figure 1.a). The custom-built method is accessed through its interface that requires a user to directly input pre-calculated RHM's body sizes (e.g., Jack®: 26, Figure 1.b); however, computing body sizes of RHMs by the distributed method is complex and time demanding. In addition, performance indices such as the accommodation percentage, which is a percentage of the target population that the generated RHMs accommodate (Jung, 2009), are not provided.



(a) Percentile (b) Custom-built

Figure 1. An example of RHM generation interfaces of Jack®

The present study developed a DRHM generation and analysis system for multiple-size product design. First, a literature review related to the DRHM generation process and method was conducted, and characteristics and limitations of RHM generation interfaces of existing digital human simulation systems were investigated. Second, sophisticated interfaces in regards to each DRHM generation step were provided with the performances of generated DRHMs in the system. Finally, an optimal sizing system of a men's flight suit was determined using the system for validation.

LITERATURE REVIEW

The DRHM generated by distributed methods has been applied to the design and evaluation of multiple-size products. The distributed method generates a DRHM at the center of each grid formed to accommodate a designated percentage of the target population (Jung, 2009). The DRHM generation process was classified into three steps (S1: extraction of key dimensions, S2: determination of distributed method, and S3: determination of DRHM's body sizes), and various statistical techniques such as factor analysis and optimization method (McCulloch et al., 1998) were used in each step (Figure 2).

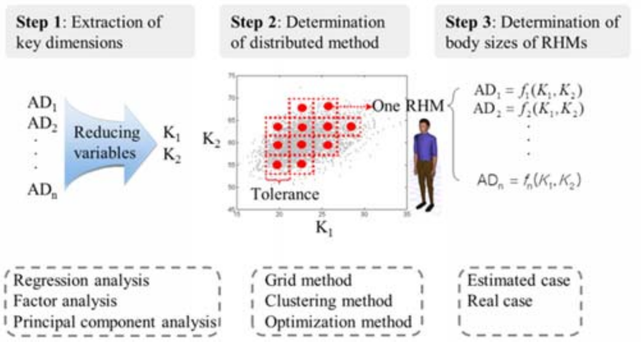


Figure 2. DRHM generation process
(AD: anthropometric dimension, K: key dimension)

The present study investigated the characteristics and limitations of three representative digital human model simulation systems: Jack® (SIMENS, Germany), RAMSIS® (Human Solutions, Germany), and CATIA Human® (Dassault Systemes, France) as shown in Table 1. For example, Jack has an RHM generation interface that consists of gender (female and male) and percentile selection (1st, 5th, 50th, 95th, and 99th) based on a US Army anthropometric database collected by Gordon et al. (1988); however, it does not provide for functions such as composite gender, various age groups that could be applied to each group ratio, and diversified anthropometric databases.

Table 1. Characteristics of RHM generation interfaces of DHM simulation systems

Factors	Jack® (SIMENS)	RAMSIS® (Human Solutions)	CATIA Human® (Dassault Systemes)
Database /Nation	US Army (1988)	Germany etc., 17 nations (1984-2020)	America etc., 5 nations (*N.S.)
Gender	Female, Male	Female, Male	Female, Male
Age groups	**N/A	Fixed 4 groups (e.g., 30-49)	N/A
# ADs	26	24	N/A
RHM generation method	Percentile Custom-built	Percentile Custom-built	Percentile

* N.S.: not specified, ** N/A: not applicable

SYSTEM DEVELOPMENT

The present study developed a DRHM generation and analysis system using Microsoft Visual Studio C# 2010 and MATLAB 2011a (MathWorks, Inc., USA). The system provides input interfaces which reconstruct the existing three-step process of DRHM generation into a five-step process, and visualizes performance analysis results of generated DRHMs as shown in Figure 3.

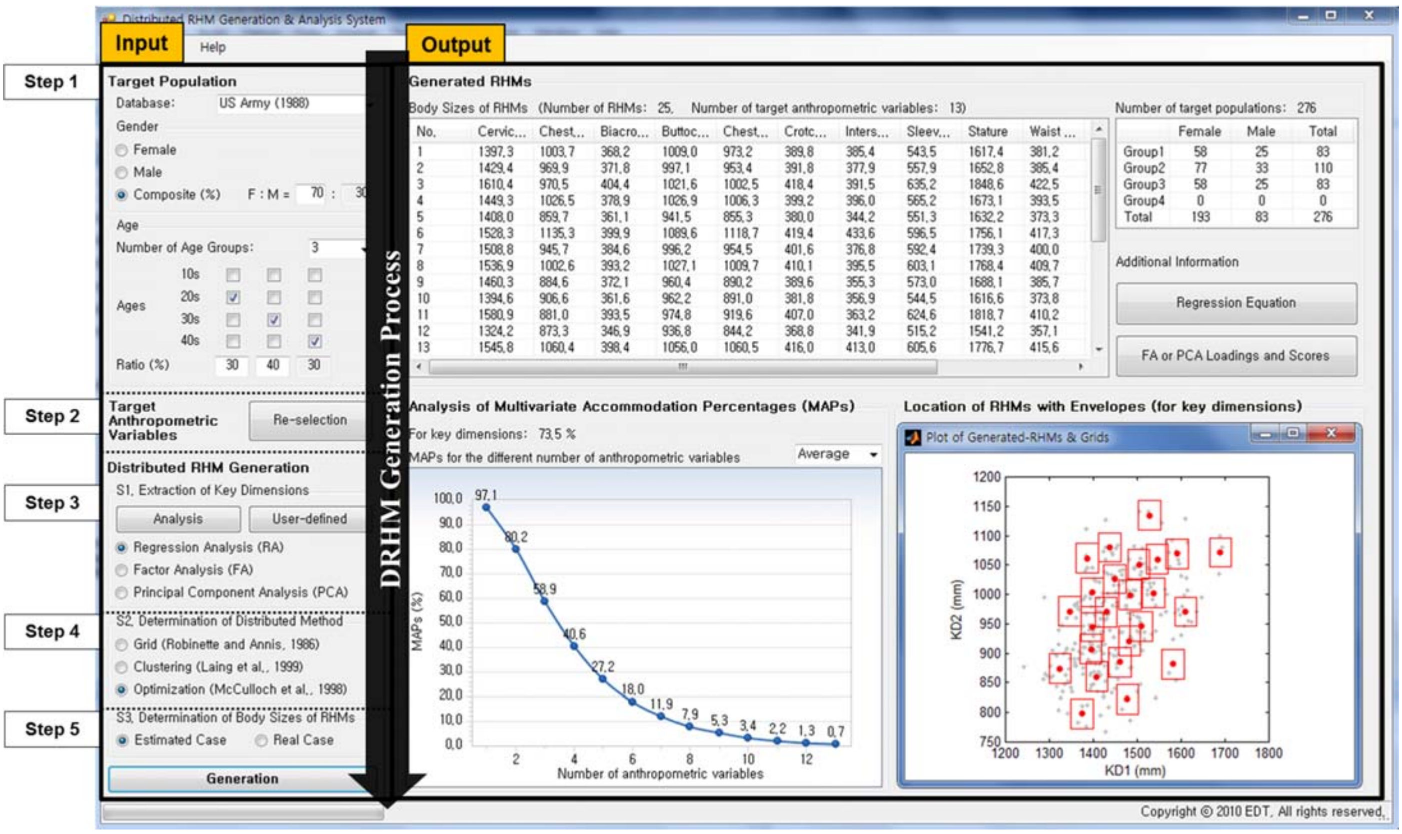


Figure 3. System overview

DRHM generation

Step 1: Target population selection

A target population is determined based on selected gender and age groups from an anthropometric database. The system established various anthropometric databases (e.g., US Army and US Army Pilot collected by Gordon et al., 1998; Korean Pilots collected by Jung et al, 2008), and provides a DRHM generation interface which can be applied to each gender ratio and each age group ratio from 10s to 40s for a formation of various target populations.

Step 2: Target anthropometric variable selection

The system provides a target anthropometric variable selection interface. Anthropometric variables are classified into three categories for systematic and efficient search referring to You et al. (2004): (1) major body segment, (2) sub-body segment, and (3) anthropometric measurement type. For example, the chest circumference can be selected in the order of trunk (major body segment), chest (sub-body segment), and circumference (anthropometric measurement type) as shown in Figure 4.

Step 3: Extraction of key dimensions

The system provides separate interfaces which can be applied to the data reduction techniques of regression analysis, factor analysis, and principal component analysis. For example, eigenvalue and percentage of variance explained need to be decided in order to determine the number of key dimensions at the interface for factor analysis. It is recommended that the user choose the number of key dimensions which refer to the factor selection criteria (eigenvalue > 1 and percentage of variance explained > 80%; Lattin, 2003) as shown in Figure 5.

Step 4: Determination of a distributed method

The system provides separate interfaces which can be applied to three distributed methods: grid method (Robinette and Annis, 1986), clustering method (Laing et al., 1999), and optimization method (McCulloch et al., 1998). For example, the interface for the grid method provides eight descriptive statistics (e.g., mean, percentile; Kwon et al., 2009) with regards to extracted key dimensions for determining the size of the grid (design fitting tolerance; e.g., 50 mm; ANSI, 2007). The user can determine the design fitting tolerance as a single value or multiple values considering descriptive statistics provided, and the target accommodation percentage (e.g., 95%; Jung, 2009) or the minimum population coverage percentage for each grid (e.g., 2%; Lee et al., 2011).

Step 5: Determination of DRHM's body sizes

The system provides two DRHM's body size determination methods (estimated and real case) which can be representative of generated grids within extracted key dimensions. The estimated case method determines a DRHM location at a centroid of a generated grid (Jung, 2009), while the real case method determines a DRHM location as a real case by the Euclidian distance which has the smallest distance from the centroid (Lee et al., 2011).

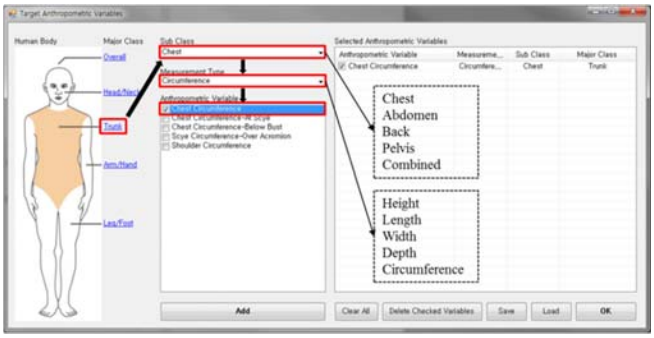


Figure 4. Interface of target anthropometric variable selection

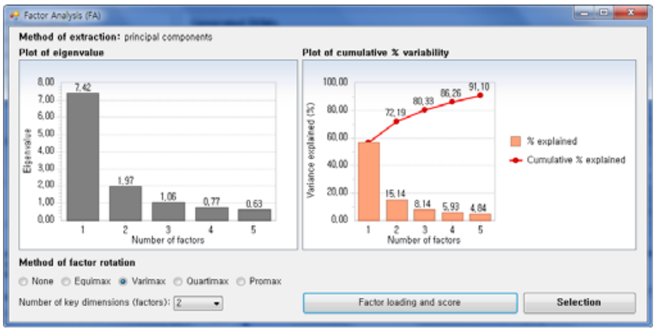


Figure 5. Interface of factor analysis

DRHM analysis

The system provides body sizes of generated DRHMs, the accommodation percentage, and visualized DRHMs on the grid (Figure 3). First, body sizes regarding the target anthropometric variables are provided in a table format. Second, the system provides five analysis results (mean, SD, minimum, maximum, and median) of univariate and multivariate accommodation percentages according to the number of anthropometric variables. Finally, the system provides visualized results of generated grids and DRHMs which represent the characteristics of the applied distributed method.

SYSTEM APPLICATION

The present study compared 18 sizing systems for a men's flight suit as they were applied to possible DRHM generation methods (3 extraction methods of key dimensions × 3 distributed methods × 2 DRHM's body size determination methods) within the developed system, and selected an optimal sizing system which had the highest performances.

Methods

The US Army pilot anthropometric database (Gordon et al., 1988) for ages 20 ~ 40 (n = 485) was selected for the men's flight suit design. Thirteen anthropometric variables for the flight suit design were chosen based upon the existing flight suit design study by Jeon et al. (2009) as shown in Table 2.

The present study generated 18 sizing systems for the men's flight suit design through a possible combination of each step's methods as shown in Figure 6. For example, the P-

Table 2. Anthropometric variables selected for design of the men's flight suit (unit: mm)

Code.	Anthropometric variables (AV)	Descriptive statistics		
		Mean	SD	Range
AV01	Biacromial breadth	400.6	17.5	105.0
AV02	Buttock circumference	991.5	55.0	351.0
AV03	Cervicale height	1531.8	60.0	341.0
AV04	Chest circumference	1009.2	59.6	344.0
AV05	Chest circumference – at syce	1035.8	55.3	309.0
AV06	Crotch length	772.0	47.3	339.0
AV07	Interscye distance	408.7	28.2	164.0
AV08	Sleeve outseam	601.4	29.9	154.0
AV09	Stature	1771.0	64.8	362.0
AV10	Waist back length	421.6	21.2	130.0
AV11	Waist circumference	856.4	65.7	375.0
AV12	Waist height	1131.4	48.1	274.0
AV13	Waist hip length	184.0	19.6	118.0

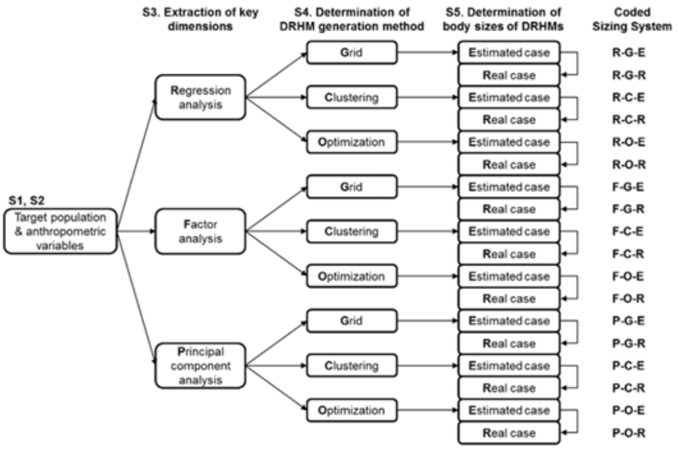


Figure 6. 18 sizing systems having the same target population & anthropometric variables within the system

O-R sizing system means the following criteria: principal component analysis for the extraction of key dimensions; optimization method for distributed method; and real case for DRHM's body sizes determination method. For the comparison of performances among designed sizing systems, the target accommodation percentage with regard to the extracted key dimensions was controlled as 95% in the determination of distributed method step.

Key dimensions were extracted by applying the determination criteria recommended by the existing studies related to each method (regression analysis, factor analysis, and principal component analysis). For example, the number of key dimensions of the regression analysis was determined as a number which had a decreasing trend of average adjusted R^2 between key dimensions and other dimensions according to an increase in number of key dimensions (Jung, 2009). Considering average adjusted R^2 with practicality, stature and chest circumference were selected as real key dimensions (average adjusted R^2 = 0.577) in the study.

Results

The present study analyzed four characteristics (generated number of DRHMs, multivariate accommodation percentage, cover rate, and number of outliers) to compare performances

Table 3. Performances of generated 18 sizing systems (AP: accommodation percentage, KD: key dimensions)

No.	Sizing system	AP for KD (%)	Number of DRHMs	Real KD (2)	Real non-KD (11)	
				AP (%)	Cover ratio (%)	# outliers
1	R-G-E	95.3	29	95.3	62.2	0
2	R-G-R	87.4		83.3	63.0	0
3	R-C-E	95.3	34	95.3	65.9	0
4	R-C-R	90.9		92.4	65.0	0
5	R-O-E	95.1	35	95.1	61.9	0
6	R-O-R	92.8		91.8	62.8	0
7	F-G-E	95.1	26	50.3	54.8	1
8	F-G-R	86.8		38.2	42.7	0
9	F-C-E	95.3	24	35.5	42.1	1
10	F-C-R	92.8		33.5	42.4	1
11	F-O-E	95.3	26	37.2	43.5	1
12	F-O-R	92.8		34.3	40.5	1
13	P-G-E	95.3	26	50.7	84.0	4
14	P-G-R	92.4		70.6	70.0	0
15	P-C-E	95.1	20	78.9	57.1	0
16	P-C-R	93.4		79.3	58.3	0
17	P-O-E	95.9	23	74.1	58.9	0
18	P-O-R	92.6		75.4	57.0	0

* Cells shaded: controlled sizing systems for accommodation of 95%
** CR: cover ratio of ranges of dimensions

of the 18 generated sizing systems (Table 3). For example, the F-G-E sizing system had 26 sizes, a 50.3% accommodation rate for real key dimensions (AV04 and AV09), and a 54.8% cover ratio with 1 outlier for real non-key dimensions (AV01 ~ AV13 except for AV04 and AV09). The cover rate is calculated by comparing the sum of ranges of the generated sizing system against that of original dimensions and the presence of an outlier means that the ranges of the generated sizing system exceed those of original dimensions (Lee et al., 2011).

The present study selected the R-G-E (regression analysis - grid method - estimated case) sizing system as the optimal sizing system for the men's flight suit design. A sizing system having a small number of sizes and a high accommodation percentage can be most practical and effective (Rosenblad-Wallin, 1987); therefore, the present study selected the R-G-E as the optimal sizing system due to the fact that it has the smallest number of sizes (29) of three candidates and has a high accommodation percentage for stature and chest circumference (R-G-E: 95.3%; R-C-E: 95.3%; R-O-E: 95.1%).

DISCUSSION

The present study developed a specialized system for DRHM generation and analysis for multiple-size product design. The system consists of five DRHM generation steps (S1. target population selection, S2. target anthropometric variables selection, S3. key dimensions extraction, S4. distributed method determination, and S5. DRHM's body sizes determination) for ease of use and reduction of development time. The system provides sophisticated interfaces regarding statistical manners used in the DRHM generation step so that the user can design a customized and desirous sizing system. The system specializes in generated DRHM analysis for DRHM's body sizes, performance results such as the accommodation percentage, and visualized information; therefore, the system can be of significant help in the design of an ergonomic product sizing system.

The system can be used as a tool which analyzes designable sizing systems easily and quickly, since the user can choose various alternatives for an optimal sizing system. The present study selected the optimal sizing system (regression analysis - grid method - estimated case, R-G-E) through the comparison of 18 possible sizing systems. The existing studies regarding DRHM generation have designed product sizing systems applied to designer-oriented methods without systematic comparison among DRHM generation methods; whereas, designers who use the developed system which provides various DRHM generation techniques at every step can make a variety of technical alternatives and choose an optimal sizing system.

For future studies, a development of a boundary representative human model (BRHM) generation and analysis system and a linkage with the custom-built interface of digital human model simulation systems may be needed. The BRHMs are applied to an ergonomic one-size product design such as a vehicle seat (Jung, 2009); therefore a specialized system similar to the DRHM generation and analysis system is needed for easy and efficient BRHM generation. In addition, the development of an interoperability method between RHM (DRHM or BRHM) generation methods and the custom-built interfaces of the digital human simulation systems will be required for ergonomic evaluations (e.g., reachability, clearance).

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