DEVELOPMENT OF HEADFORMS AND AN ANTHROPOMETRIC SIZING ANALYSIS SYSTEM BASED ON 3D HEAD SCAN IMAGES FOR HEAD-RELATED PRODUCT DESIGNS

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The present study developed a sizing analysis system based on the Civilian American and European Surface Anthropometry Resource (CAESAR) database of North Americans (n = 2,299) for head-related product designs. To find representative heads from a huge amount of 3D human scan database, a sizing analysis system is required for efficient analysis of sizing systems based on anthropometric measurements. The head of the CAESAR 3D scan were manually edited to improve a quality for better use to the product design. Twenty one anthropometric landmarks were marked on the edited 3D heads to measure 40 anthropometric dimensions related to the head product designs. All head and face dimensions were automatically measured by applying a measurement system coded using Matlab. Fifteen representative headforms were generated in terms of 5 ethnic groups (composite group, Caucasians, American Africans, Asians, and Hispanics) and 3 gender groups (composite gender, males, and females). Finally, the sizing analysis system was developed based on the measurement of the CAESAR for analysis of head and facial measurements and generation of sizing systems.

INTRODUCTION

3D human scan images can be usefully applied for ergonomic product designs. Based on the 3D scan image, not only simple dimensions (e.g., length, circumference) also complex dimensions such as section curve, surface shape, and volume which are useful for the product design can be measured (Chang et al., 2007; Lee et al., 2010; Lee et al., 2011; Lee et al., 2013a; Weinberg et al., 2004). For example, based on 3D scan faces of Korean Air Force pilots, Lee et al. (2013a) designed pilot oxygen masks which have better fit for Korean pilots. Also, a large-scale 3D scan database such as the Civilian American and European Surface Anthropometry Resource (CAESAR; Harrison and Robinette, 2002) can be applied for the product design.

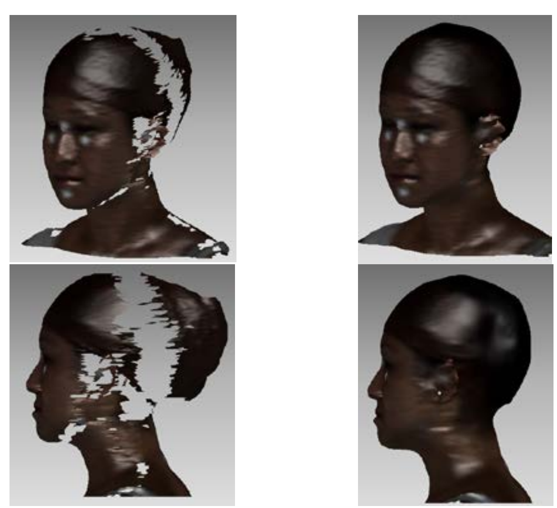
Representative models or sizing analysis systems can be efficiently used for the product design based on large-scale 3D human scan images. A representative model can provide the anthropometric characteristics of the population (Ball, 2009; Jung et al., 2010; Zhuang et al., 2010). A computerized sizing analysis system can be used for statistical analysis of anthropometric measurements designated from sample population (Lee et al., 2013b), and can generate a sizing system of the target product, efficiently. Both representative models and sizing analysis system can derive useful information about the product design to product designers.

The present study edited and measured 2,299 heads from the CAESAR of North Americans. Headforms which can represent North Americans in terms of ethnic and gender groups were generated for the purpose of head-related product (e.g., helmet, mask, goggle, and headphone) designs. Finally, an anthropometric sizing analysis system was developed based on the measurements of the edited CAESAR heads to generate sizing systems of head-related products.

ANALYSIS OF CAESAR 3D SCAN DATA

3D Data Editing

The CAESAR 3D heads were manually edited in terms of hole-filling, arrangement of hair style, and smoothing. All of the original CAESAR scan images have a large misscanned parts on their left side as shown in Figure 1.a. And there were



(a) Before editing (b) After editing

Figure 1. Editing of the CAESAR 3D scan head (illustrated)

unnatural parts (e.g., hair style, beard) with some heads, which can affect mismeasurement of head-related dimensions (e.g., head length, head breadth, head circumference). Out of 2,384 CAESAR scan images, 85 cases (3.6 %) were excluded because they were minority (e.g., Eskimo, American Indian, or mixed race) or they had unacceptable image quality with their 3D heads which were due to huge misscanned area, movement during 3D scanning, or excessive amount of hair or beard. The present study edited those 3D scan images of 2,299 CAESAR heads (1,818 Caucasians, 258 American Africans, 173 Asians, and 50 Hispanics) using RapidForm 2006 (INUS Technology, Inc., South Korea), a 3D point cloud mesh editing software. To save time of manual editing, out of full body image, only head and neck (above shoulder) parts were edited. More than 300 hours were spent for manual editing of 2,299 CAESAR 3D heads.

Landmark Identification

Landmarks for the measurement of head and facial dimensions were manually marked on 3D scan images. Previous researches (Ahn and Suh, 2004; Alexander et al., 1979; Clauser et al., 1988; Hack and McConville, 1978; Han and Choi, 2003; Hughes and Lomaev, 1972; Kim, 2004; Kim, 2005; Kim et al., 2004; KATS, 2004; Oestenstad et al., 1990; Oh and Park, 2010; Yokota, 2005; Young, 1993; Zhuang and Bradtmiller, 2005) which measured facial dimensions were reviewed. Through the literate review, 132 head and facial anthropometric dimensions were identified. Of these facial dimensions, 40 dimensions were selected as those applicable to design of head-related products. And 21 head and facial landmarks (Figure 2) corresponding to those dimensions were identified. All landmarks were marked on all 2,299 heads by one expert on anthropometry by using RapidForm 2006.

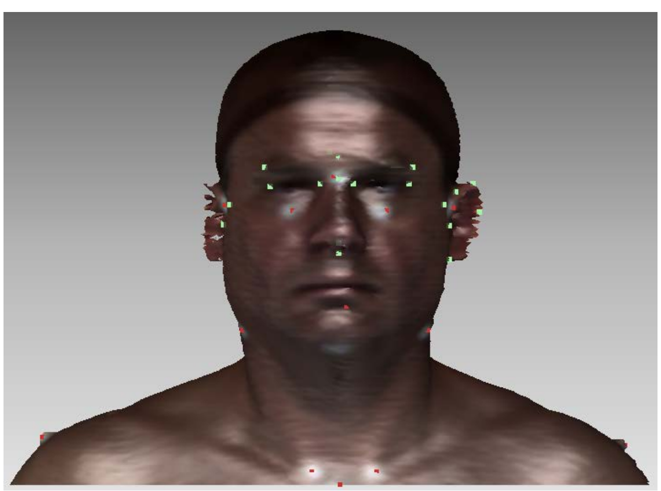


Figure 2. Head and facial landmarks (illustrated)

Anthropometric Measurement

Forty measurement dimensions of 2,299 3D human heads were measured through an automatic measurement system developed using Matlab 2013a. The system measured head and facial dimensions based on landmarks and 3D point clouds of head. Of the facial dimensions, length and width dimensions were measured by calculating Euclidian distances between corresponding landmarks and arc dimensions were measured by creating a virtual plane passing corresponding three landmarks and forming the arc which intersects the plane and the facial image. Measurements of each facial dimension exceeding the range of mean ± 3SD were examined and repeated measurement was made for accuracy.

GENERATION OF HEADFORMS

Based on edited 3D heads and those measurements, 15 representative heads in terms of ethnic group and gender were identified and those heads were reproduced as headforms. Average sizes of head and facial measurements in terms of each ethnic group (composite ethnic group, Caucasian, African American, Asian, and Hispanic) and gender (composite gender, male, and female) were calculated. Based on those measurements per groups, 15 heads which have the most similar sizes from the average were found. Those heads were manually reproduced as headforms through RapidForm 2006. All 15 heads were smoothed and mirrored; all measurements were adjusted to fit the average sizes; and one nicely scanned 3D ear was resized and attached on the average location of the ear (Figure 3). Finally, the headforms were 3D printed and polished for the use of product design and evaluation.

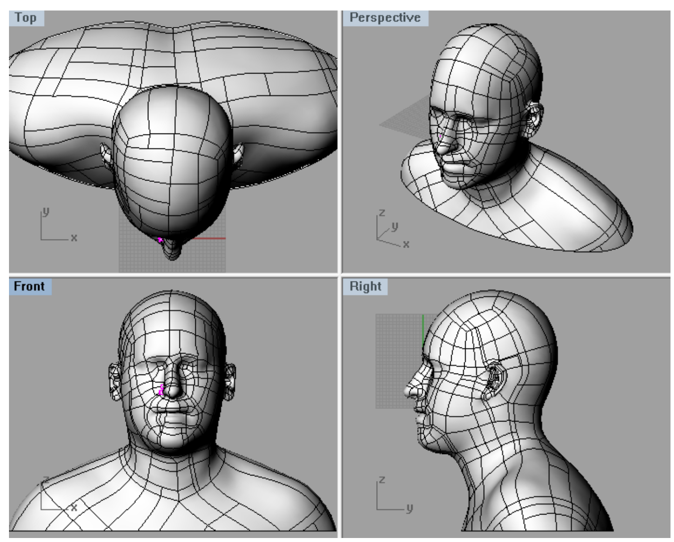


Figure 3. Development of representative heads (illustrated)

DEVELOPMENT OF ANTHROPOMETRIC SIZING ANALYSIS SYSTEM

The present study developed an anthropometric sizing analysis system which can be used by product designers for analysis of head and facial measurements, and for generation of sizing systems. The system can be used through 4-step process: (1) selection of target product, (2) definition of target population, (3) selection of key anthropometric dimensions, and (4) generation of sizing system. First, target head-related product (e.g., helmet, mask, goggle, and headphone) is selected. Second, characteristics of target population are defined in terms of ethnic group, gender, and age group (e.g., 20s, 30s, 40s, 50s, and 60s). Third, one or two key anthropometric dimensions corresponding to design dimensions of the target product are selected. Finally, based on statistical analysis (Lee et al., 2013b), sizing system (Figure 4) is generated by adjustment of a number of sizes, range of coverage sizes, and accommodation percentage.

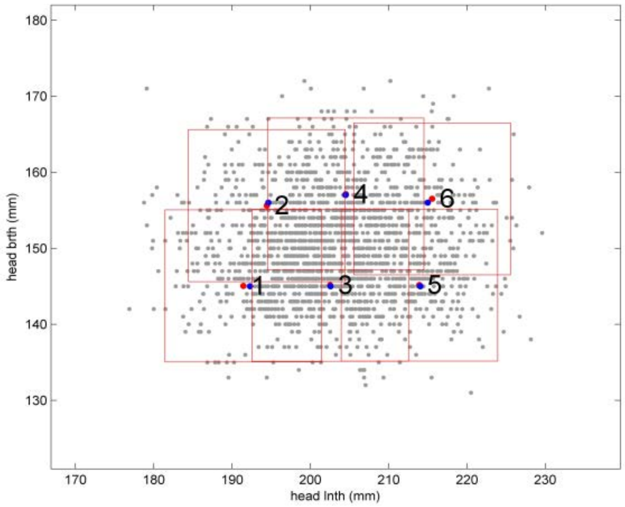


Figure 4. Sizing system having 6 sizes with visualization of location of centroids (illustrated)

DISCUSSION

In the present study, CAESAR 3D scan images were edited precisely by hand, and detailed head and facial dimensions which can be used for head-product designs could be measured. Because of limitations of 3D scanning technology in 1998 when the CAESAR database was established, the CAESAR 3D images have large misscanned part on their left side. Also ears and crotch parts of human body were not scanned accurately. In the present study, the CAESAR images were manually reconstructed by experts on 3D anthropometry for better application of 3D images to the product design. Because the edited CAESAR heads contain not only 3D point clouds but also landmarks and dimensions, these data can be applied to a post analysis of characteristics of additional head and face dimensions in further researches.

The representative headforms and sizing analysis system were developed for product designers who are limited on anthropometry. Both of digital and 3D printed headforms can be applied for efficient design and evaluation of products through product development phases. Also, specialized sizing analysis system can provide necessary information about sizes for head-related product designs. In the system, characteristics of a product (e.g., type of product, number of sizes, key design dimensions) and anthropometric information (e.g., target population, key anthropometric dimensions) were considered to generate a sizing system.

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