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A quantile-based anthropometry synthesis technique for global user populations

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ABSTRACT

Detailed anthropometric data are valuable in making well-informed and responsible design decisions. However, such data are available only for a few user populations around the world. More widely-available information is in the form of summary statistics (e.g., means and standard deviations) and the values of body measures at certain key percentiles (e.g., 5th, 50th, 95th). Such information, while useful, is not suitable for in-depth analyses of a population's variability, since it does not allow for the consideration of correlations between different body measures, does not describe irregular distributions of body dimensions, etc. This paper presents a new method that utilizes values of body measures at different percentiles in synthesizing a detailed anthropometric database for a virtual population of users. The procedure is demonstrated in the context of Japanese civilian youth and U.S. military, and is shown to be simple, accurate, easy to use, and applicable across these two anthropometrically dissimilar populations. The case study shows that the virtual population is statistically equivalent to the actual target population in a number of ways. In addition to achieving statistical equivalence with the actual population's body dimensions, the method also ensures that the synthesized individuals are composed of appropriate and realistic body proportions and combinations of anthropometry.

1. Introduction

Anthropometry (i.e., body measures) are known to be influential in determining users' preferred styles of physically interacting with products (Strasser, 1995). Information about anthropometry is vital to satisfying product performance objectives such as safety, comfort, ease of use, and visibility. This paper presents a methodology for the synthesis of detailed databases of anthropometry for "virtual populations" that are comparable to the actual target populations. The method is based on readily-available information about the required body measures for the population. The resulting databases allow for in-depth analyses of the variability of relevant body dimensions in the target population; doing so is key to developing ergonomic designs that efficiently *accommodate* the desired percentage of users.

1.1. Sources of information about population anthropometry

Anthropometric databases contain the values of body dimensions measured for a surveyed population of individuals. Such databases are available for certain user populations; examples include ANSUR (Gordon et al., 1989), which is representative of the U.S. military in the late 1980s, NHANES (U.S. Centers for Disease Control and Prevention, 2008), which provides limited data about the civilian U.S. population, and CAESAR (Blackwell et al., 2008), which is a convenience sample of North American and European populations. However, due to the resources and effort entailed in the compilation of such databases, they are few in number. Additionally, data collected from studies are often not made publicly available. A compounding complication for the designer is the uniqueness of the anthropometric characteristics of distinct populations. This uniqueness renders inaccurate the substitution of other populations' data in place of the target users' anthropometry.

Numerous studies through the years have resulted in concise statistical information about a variety of populations. This statistical information is usually in the form of summary statistics—the mean and standard deviation of different body measures—and can also include the values of these body measures at key percentiles. For example, Gite et al. (2009) provides the means and standard

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deviations of body measures, which are assumed to be normally distributed, of Indian farm workers. The State Bureau of Technical Supervision (1989) and Instituto Nacional de Tecnologia (1995) are sources of values of anthropometry at certain percentiles (e.g., 1st, 5th, 10th, 50th, 90th, 95th, and 99th in the former) for Chinese and Brazilian civilians, respectively. Barroso et al. (2005) provides both summary statistics as well as percentile-wise information of anthropometry for the Portuguese worker population.

Many surveys have been directed at more specific groups of users, including Algerian date palm farmers (Mokdad, 2002), Bahraini school children between 6 and 12 years of age (Mokdad and Al-Ansari, 2009), female maquiladora (i.e., assembly plant) workers located along the Mexico-U.S. border (Liu et al., 1999), Taiwanese workers (Wang et al., 1998), and U.S. truck drivers (Guan et al., 2012). Some of these surveys have involved three-dimensional body scans of populations such as adult wheelchair users (Paquet and Feathers, 2004). A few studies have examined the impact on anthropometric variability of human laterality (i.e., left- or right-handedness) and gender (Mohammed, 2005), age (Annis, 1996; Jarosz, 1999; Pennathur and Dowling, 2003; Hu et al., 2007), and race/ethnicity (Imrhan et al., 1993).

Summary statistics and the values of anthropometry at a few key percentiles are not directly usable in detailed accommodation analyses and design decision-making. There are four main reasons for this. First, as discussed in the previous paragraphs, this information describes a population's body dimensions at only a few percentiles; well-informed decision-making requires the availability of "higher-resolution" information for the entire population. Second, actual distributions of a population's body measures are likely to be non-Gaussian (Vasu and Mital, 2000), which disallows the use of Gaussian tools (e.g., z-scores) in conjunction with this information to calculate the values at different percentiles. Third, summary statistics describe the state of a population's anthropometry at a certain point in time; secular trends could significantly alter these characteristics over a period of time (Drury, 2008). Fourth, separate sets of information for each body dimension fail to capture the correlations between different body measures; the direct use of this information in multivariate analyses can result in lower-than-desired accommodation of the user population (Moroney and Smith, 1972).

1.2. Anthropometry synthesis

The aforementioned problems associated with the dearth of comprehensive anthropometric data for populations may be overcome through the use of anthropometry synthesis techniques. A number of techniques have been put forth over the years. These include methods based on proportionality constants, linear regression, regression with residual variance, and principal components analysis. The foundations of these methods are the correlations between body dimensions. This knowledge can be used along with data about a few basic body measures (e.g., stature and BMI—body mass index, a normalized ratio of weight for stature) to generate databases of the anthropometry that is relevant to the design effort. Each of these methods assumes that relationships between measures in one population (e.g., the ratio of sitting height to stature) will exist in another.

Anthropometry synthesis methods adopt different approaches to utilize these correlations in synthesizing body measure data. Proportionality constants-based techniques such as the ones proposed by Drillis and Contini (1966, cited in Clauser et al., 1969) involve ratios of all body dimensions to stature; the anthropometry generated for every individual in the user population adheres to the fixed set of proportionality constants. Fig. 1 shows some proportionality constants calculated for the ANSUR population. Despite their inherent simplicity, proportionality constants-based approaches are limited by certain invalid assumptions, including: a) all individuals are similarly proportioned, b) all body measures of an individual are of the same percentile, and c) independently accommodating for each body measure yields the desired accommodation level for the user population.

Body proportions are known to vary across individuals in a population (Ruff, 2002). Furthermore, the body dimensions that comprise an individual in a population are likely to represent different percentile values in their respective anthropometric distributions (Roebuck, 1995). The regression-based method presented by Nadadur and Parkinson (2009) is capable of overcoming these limitations through the reincorporation into the synthesis model of the component of anthropometric variability that is unrelated to the predictor variable. This is represented by the residual variance (i.e., the squared value of standard error of variance) of the regression model relating the required body measure to the predictors, which are usually stature and BMI.

Regression-based methods require comprehensive data about the predictor variables—usually stature and BMI—for the target population. However, only descriptive statistics about anthropometry are available for a vast majority of possible target populations. A means to overcoming the unavailability of detailed predictor data involves first using descriptive statistical information to estimate the underlying stature and BMI distributions, then sampling from these distributions to create stature and BMI datasets for the population. This was the approach adopted by de Vries et al. (2011) to generate the requisite stature and BMI dataset of a U.S. truck driver population. This procedure is one of the bases for the anthropometry synthesis approach that is proposed in this paper.

1.3. Anthropometric databases in virtual fitting

References have been made in the preceding subsections about the value of accurately synthesized anthropometric databases for improved design decision-making capability. The widely applied practice of virtual fitting is an illustrative example to this point.

Virtual fitting allows for the simulation of user-product interactions (Chapman, 2011). The process involves formulating design constraints between various product specifications and their corresponding relevant body dimensions and postures (Godwin et al., 2007). When utilized in conjunction with detailed anthropometric data for the population of interest, these constraints help to evaluate the impact of different design specifications on the accommodation level afforded by the product. Efficient virtual fitting techniques make for the selection of product specifications that will achieve the desired accommodation level of the target

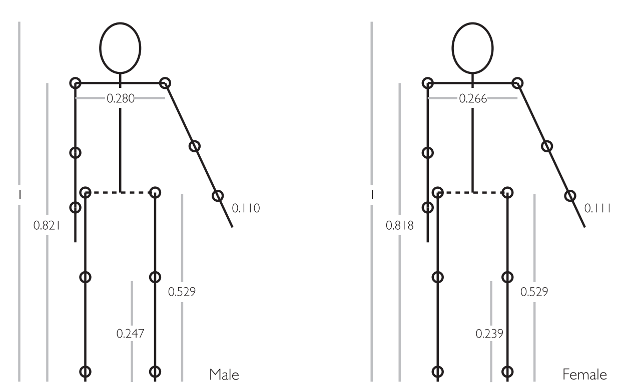

Fig. 1. Some proportionality constants calculated for the female and male ANSUR populations.