

ANTHROPOMETRIC PROCEDURES FOR DESIGN DECISIONS: FROM FLAT MAP TO 3D SCANNING

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Anthropometric principles have been applied to many applications in various industries, for reasons of product value, efficacy and safety. This paper presents four anthropometric approaches for product design decisions. A univariate method has been widely used in designing for extremes, such as in determining door heights. A bivariate method has been useful for products that primarily involve dual essential dimensions, such as in shoe-sizing applications. For many other applications, a multivariate accommodation approach is necessary to account for both the body size variance and proportional variability. A 3D shape-quantification approach is advisable for determining sizing schemes and size ranges of personal protective equipment, such as fall protection harnesses. A 3D digital feature-envelope approach is instrumental for placement of control components in workspaces, such as in a farm-tractor-cab accommodation.

Introduction

Anthropometry is the study of human body size and proportions. It contributes to product value, efficacy, and safety in numerous applications. Anthropometric information is traditionally reported as means and standard deviations for various body segments (Roebuck, 1993). While the traditional anthropometric approach is useful for some simple applications, recent literature has shown that the point-to-point anthropometric information currently being used seems to be insufficient for many design applications (Hsiao *et al*, 2003). For instance, dimensions measured and tabulated by traditional methods are not linked to one another; knowing shoulder width would not enable a designer to create an accurate representation of shoulder location related to the cab space for a vehicle-design application. The newly available 3-D scanning and shape-quantification technologies make the assessment of 3D anthropometric information for product-design decision a much more

feasible undertaking. This paper presents traditional univariate and bivariate methods and two emerging 3D anthropometric procedures for design decisions. Examples are provided for better understanding of general anthropometric principles and the specific approaches.

Procedures for design decisions

In product design practices, a six-step anthropometric procedure is typically used for design decisions (Hertzberg, 1972). These steps include (1) determining the body dimension that is of essential importance (e.g., stature, hand width, etc.), (2) determining the population to be considered (e.g., sex, age, occupation etc.), (3) selecting the percentage of the population to be accommodated (e.g., for safety, cost-benefit, or other concerns), (4) obtaining the necessary reference materials to determine the appropriate statistics (users may need to collect their own data.), (5) computing the specific dimensions, and (6) adjusting as necessary for clothing and other equipment.

Design for extremes with univariate analysis

In some design applications, the extreme value of a single anthropometric measurement plays the critical role in design decisions. An example is to specify the height for a doorway to avoid unintentional head injuries in manufacturing plants. The solution can be drawn by following the above-mentioned six steps. The essential dimension is stature. The population to be considered is U.S. civilians. The percentage of the population to be accommodated is 99.9 percent of the male population, reflecting the paramount importance of safety concerns; this will cover almost all females as well. The reference information X (mean stature) is 175.3 cm and S (standard deviation) is 7.1 cm (Webb Associates, 1978). The Z value (a coefficient whose value varies with the percentage of population to be covered) for $Z_{99.9}$ is 3.09. Therefore, $\text{Stature}_{99.9}$ is $175.3 + 3.09 * 7.1 = 197.2$ cm. By adjusting the height for shoes (2.5 cm) and headgear (5.0 cm) (Hertzberg, 1972; Das and Grady, 1983), we find that the desired opening should be $197.2 + 2.5 + 5.0 = 204.7$ cm.

Design with bivariate analysis

In other product design applications, the design decision may involve some dimensions that can be simplified to two critical measurements. Shoe design is in this category. Most people are familiar with typical shoe sizing schemes, which consider foot length and foot width. Some people can find good-fitting shoes easily; others have difficulty in finding even a barely fitting one. Why? Assume that the U.S. population mean for foot length is 27 cm with a standard deviation of 1.6 cm and the mean foot width is 13 cm with a standard deviation of 1.2 cm. Based on the assumption that the data are normally distributed, the ellipse in Figure 1 would cover 95% of the dataset. Assuming that a space of 0 to 1 cm between shoe length and foot length is the comfort range and that a space of 0 to ¼ cm between shoe width and foot width is tolerable, we will have a number of two-dimensional configurations: a 28L by 13.25W, a 29L by 13.25W, and many other shoe sizes (Figure 1). However, we will notice that, based on the dataset, the central size fit only 7% of the persons. Some sizes only fit 2%, or even 0.2%. Comfort tolerance and cost probably dictate the available sizes in the market.

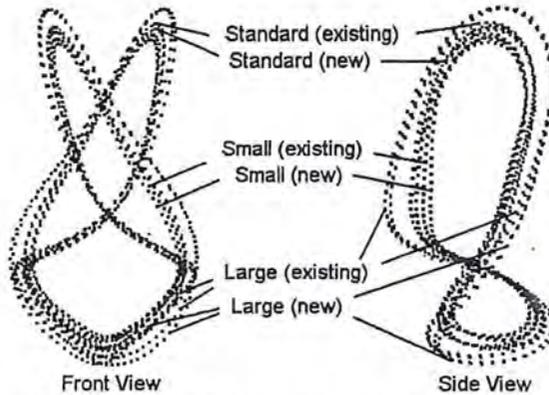


Figure 2 Mean outlines for the three existing and redesigned harness sizes, based on multivariate predictions of Elliptic Fourier analysis coefficients

major challenges as in the harness design case: determining critical body dimensions, obtaining the necessary data, and computing the specific dimensions. In a study on anthropometric criteria for the design of tractor cabs, knee height (sitting) and 8 other parameters were found to affect the accommodation rating (Hsiao *et al*, 2004). A principle component analysis approach was utilized to form a set of 15 anthropometric model variables used in the cab design process, through significant composite variables, derived in a mathematical reduction process of key anthropometric dimensions. These 15 representative models are useful in the design process, especially in using digital human modeling techniques, to ensure that the finished product will accommodate the desired population.

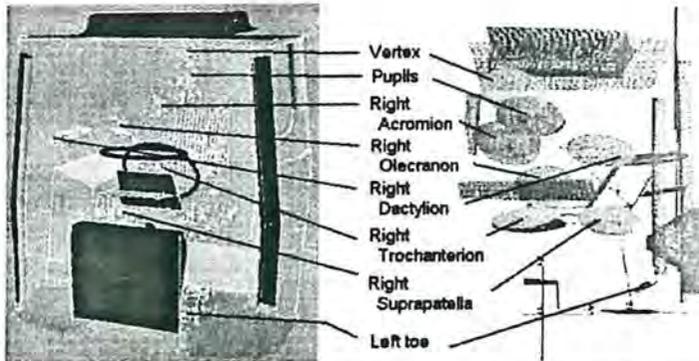


Figure 3 Landmark locations (white dots) of the 15 representative body models related to the tractor workspace (left picture) and the 95% ellipsoid representations of the feature envelopes for some landmarks (right picture; side view of the workspace).

While the identified 15 representative models are useful for examining tractor cab accommodation, the design process is incomplete without considering the use of feature envelopes of body landmarks in optimizing the layout of cab components. For instance, designers need to know where the knees are with respect to the seat, to position the steering wheel. Visually, a feature envelope can be thought of as an ellipsoid enclosing a cloud of three-dimensional data points representing the variability in a landmark location. Figure 3 shows some of the 14 critical landmarks for the 15 representative models for tractor design. Alternatively, designers can digitize the critical landmarks of all subjects in a national 3D survey database. A set of centroid coordinates of the key body landmarks and the 95% confidence semi-axis-length for each landmark location can be developed through a principle component analysis approach to guide tractor designers in their placement of tractor control components to best accommodate the user population.

Summary

In product design applications, a six-step anthropometric procedure is useful for design decisions. This paper presented traditional univariate and bivariate approaches and two emerging 3D anthropometric methods, based on the six-step anthropometric procedure, for various product design decisions. Examples of door, shoe, harness, and tractor designs were provided for better understanding of the general principles and the specific approaches.

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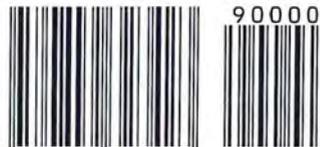
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