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Developing Anthropometric Targets for ATDs using Statistical Body Shape Modeling

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ABSTRACT

We have developed a new paradigm for creating anthropometric specifications for ATDs and other human surrogates based on multivariate modeling of body landmark locations and surface geometry. The first ATD created using these techniques is the Warrior Injury Assessment Manikin (WIAMan) under development by the US Army. In this paper we give an overview of the process, which combines body landmark data obtained from the target population in realistic seating scenarios with whole-body surface data obtained using laser scanners with participants in a range of seated postures. First, to represent realistic occupant posture, we create a regression model using data from the measurements in vehicle seats to predict body landmark locations as a function of the target anthropometric variables (typically stature, sitting height, and body weight). Second, we create a statistical body shape model from scan data from hundreds of individuals in a wide range of supported seated postures. Importantly, the inputs to this model are body surface landmark locations measured in the vehicle seating conditions. Finally, we combine the two models to obtain the target surface shape and landmarks in the desired posture. With this information we estimate internal joint center locations, defining the kinematic linkage of the ATD. Once created, the same statistical models can be used to define other sizes of physical or computational manikins.

INTRODUCTION

Previous ATD development programs have used two general approaches to developing anthropometric specifications. The dimensions of the Hybrid-III family were chosen from tabulations of standard anthropometric dimensions (lengths, breadths, and circumferences) obtained in unrelated studies of civilian anthropometry (Mertz et al. 2001). A small amount of information on seated posture and pelvis geometry was obtained from measurements of a few individuals similar in size to the ATD (Backaitis and Mertz 1994).

The Anthropometry of Motor Vehicle Occupants (AMVO) study, conducted at the University of Michigan Transportation Research Institute (UMTRI) in the early 1980s, gathered anthropometric data specifically for purposes of ATD development (Schneider et al. 1983). Overall reference body dimensions (stature, body weight, and erect sitting height) were identified from the target percentiles of tabulated data for the U.S. adult population. Individuals who were close in size to the three target ATD sizes (small female, midsize male, large male) were recruited for detailed study. In the first phase, driving postures were recorded in real vehicle seats by measuring the three-dimensional locations of body landmarks using stereophotogrammetry. In the second phase, body landmark locations were measured for twenty-five men or women in each category as they sat in a specially prepared rigid seat that allowed access to posterior as well as anterior torso landmarks. A small number of linear body contour measurements were made using a manual contour gage. Photography was used extensively to document body shape.

The means of the body landmark coordinates for each subject size group were taken as the specifications for the associated ATD. Additional manual measurements of the seated subjects taken using standard anthropometric techniques were included as part of the specification. The surface landmarks were used to estimate internal joint locations based on previous cadaveric studies. A set of three full-size surface shells (small female, midsize male, large male) were created based on the landmark measures, standard anthropometric data, linear contour measurements, and photographs. These surface shells formed a critical part of the specification, filling in the gaps between the landmarks with contour information. The AMVO data have been used for the development of several ATDs, notably the midsize-male and small-female THOR and WorldSID ATDs (Moss et al. 2000, McDonald et al. 2003).

The current analysis is similar to the AMVO approach except that modern measurement methodology and advances in statistical methods have allowed a more general and complete analysis. As with AMVO, target values for reference dimensions (stature, body weight, and erect sitting height) were obtained from previous studies of the relevant population. However, instead of measuring only individuals similar in size to the ATD, posture measurements were made for a diverse sample of individuals with a wide range of body size in a range of vehicle-seat conditions. In addition to three-dimensional surface landmark measurements, whole-body surface coordinate data were obtained using a VITUS XXL whole-body laser scanner (Human Solutions). Skeletal joint locations were estimated from surface landmarks using techniques similar to AMVO, except that more complete data on pelvis geometry from medical imaging data were used. The target configuration of landmarks and joints was computed using linear regression analysis with the reference anthropometric dimensions as predictors.

A statistical model of the whole-body surface was generated by fitting a homologous template mesh to each body scan, conducting a principal component analysis on the mesh vertices to reduce the dimension of the data, and creating a linear regression model to predict mesh vertex locations from standard anthropometric variables and body landmark locations. The body surface target for the ATD was created by using the reference body dimensions and landmark locations predicted from the vehicle-seat data as input to the body shape model. The resulting shape and landmark data were adjusted for use as the WIAMan specification by articulating the lower extremities using non-rigid morphing techniques.

Following completion of the anthropometric specifications for the ATD, a broader set of data from the squad conditions in the Seated Soldier Study were analyzed to provide guidance for biomechanics testing in support of the WIAMan program. Soldier posture data from four conditions were analyzed using regression methods to estimate the effects of seat back angle change on the orientation of torso body segments. Medical imaging data were analyzed to estimate spine segment orientations from the surface landmark data and to calculate pelvis size and shape. This workshop paper presents a high-level overview of the methods. For more details, see Reed (2013).

METHODS

Data Source

The data for this analysis were drawn from the Seated Soldier Study (Reed and Ebert 2013), the first large-scale study of soldier posture and body shape in vehicle seating environments. A seated posture analysis was conducted with body landmark location data from a single squad seating condition. The body shape analysis was based on laser-scan data obtained with minimally clad subjects in a range of symmetrical unsupported and supported seated postures.

Posture Analysis

Data from 100 men were used for the posture analysis. This is a subset of the data from the Seated Soldier Study, because not all data were available at the time of this analysis. Stature ranged from 1602 to 1965 mm (mean 1759 mm) and body mass index from 18.2 to 38.3 kg/m^2 (mean 26.7 kg/m^2).

Soldiers were instructed to sit comfortably in the seat. Lower and upper extremity postures were required to be approximately symmetrical. A FARO Arm coordinate digitizer was used to record body landmark locations defining the seated posture. The posture data for the current analysis were extracted from Condition C01, in which the padded seat back was nominally vertical, the padded seat cushion was nominally horizontal, and the seat height above the floor (measured from SAE J826 H-point) was 450 mm (for more details, see Reed and Ebert 2013). The current analysis was conducted using data from conditions in which soldiers wore their Advanced Combat Uniform (ACU), including boots. No other protective equipment or gear was worn. The soldier donned a five-point harness in each condition after selecting a comfortable posture. Figure 1 shows a soldier in condition C01 with the ACU garb level.

Body landmark locations were recorded using a FARO Arm coordinate digitizer. Landmarks on the head, pelvis, spine, and extremities were used for the current analysis.

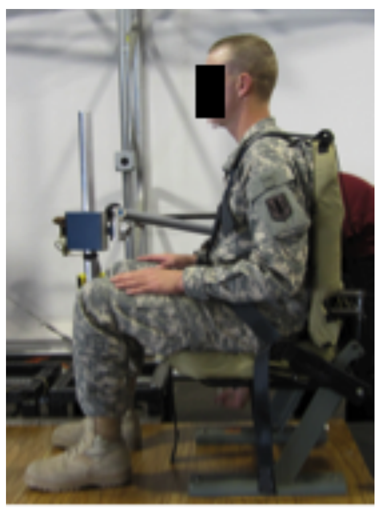


Figure 1. Soldier in Condition C01 and the ACU garb level.

Body Shape Analysis

Laser scan data obtained from minimally clad soldiers were obtained in the Seated Soldier Study. A total of 338 scans from 126 male soldiers were used, with up to four scan postures per soldier (not all soldiers were scanned in all conditions). Due to the study design and limitations in data availability at the time of analysis, this is a different subset of the participants than was used for the posture analysis. Note that the analysis techniques are robust to differences in the samples. Stature ranged from 1584 to 1965 mm (mean 1754 mm) and body mass index from 18.3 to 38.9 kg/m^2 (mean 26.7 kg/m^2). Figure 3 shows the four postures. Surface body landmark locations were extracted from the scan data, as described in Reed and Ebert (2013).

A uniform template mesh developed for this project from a typical scan was fit to each scan so that each scan was represented by a homologous set of 30,004 vertices. (Reed et al. 2014). Figure 4 shows the template, example data with landmarks, the template initially morphed to match the data at a subset of the landmarks, and the result after final template fitting. A principal component analysis (PCA) was conducted on the vertex coordinates. For the subsequent regression analysis to predict body shape, 60 of 126 PCs representing over 99 percent of the variance in the coordinate data were retained.

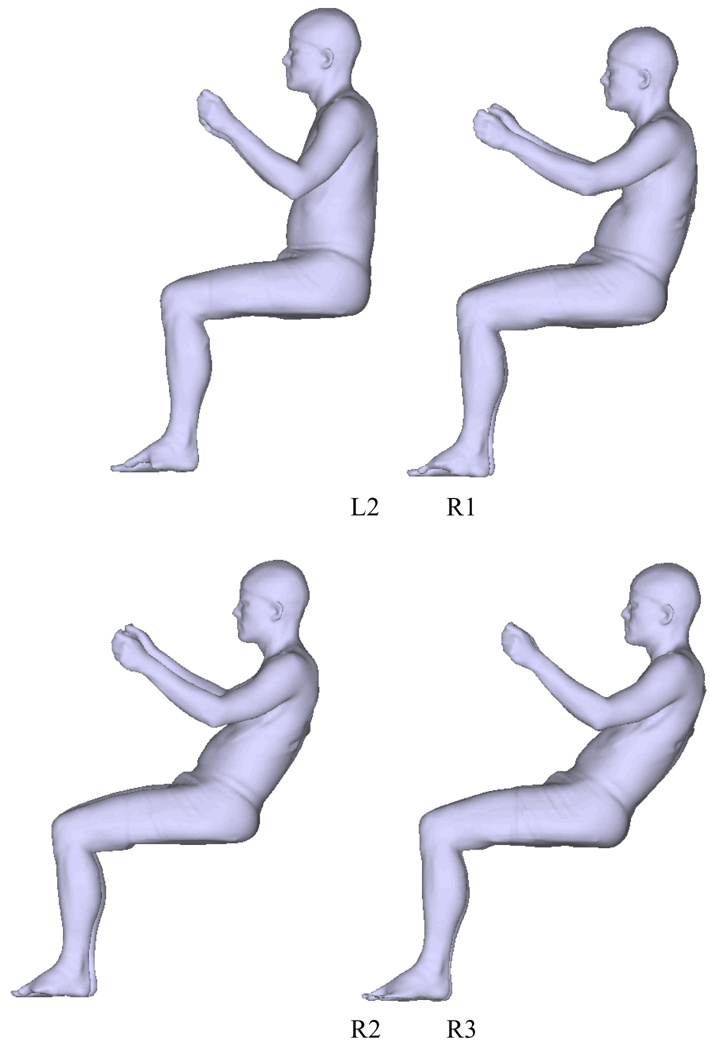
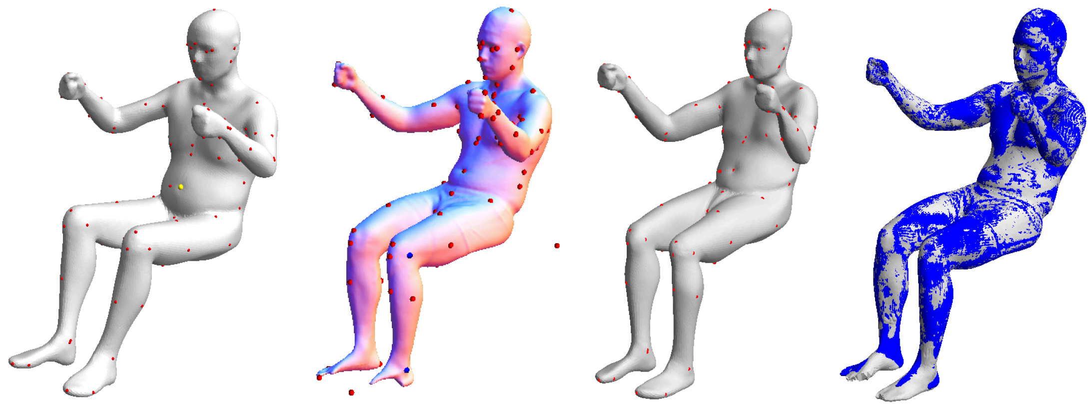


Figure 2. Four subjects in the four scan postures used for the current analysis. Postures R1, R2, and R3 were supported by a small, padded backrest.



A B C D

Figure 3. Template with landmarks (A), sample scan with landmarks (B), the template morphed to match the data at individual landmarks (C), and the result of template fitting to the scan (blue, D).

RESULTS

Figure 4 shows examples of the range of body shapes that the statistical model can produce. Stature and body mass index were varied to produce these figures. The figure illustrates that the model is capable of simulating a wide range of body shapes, with the WIAMan target lying close to the center of the underlying data.

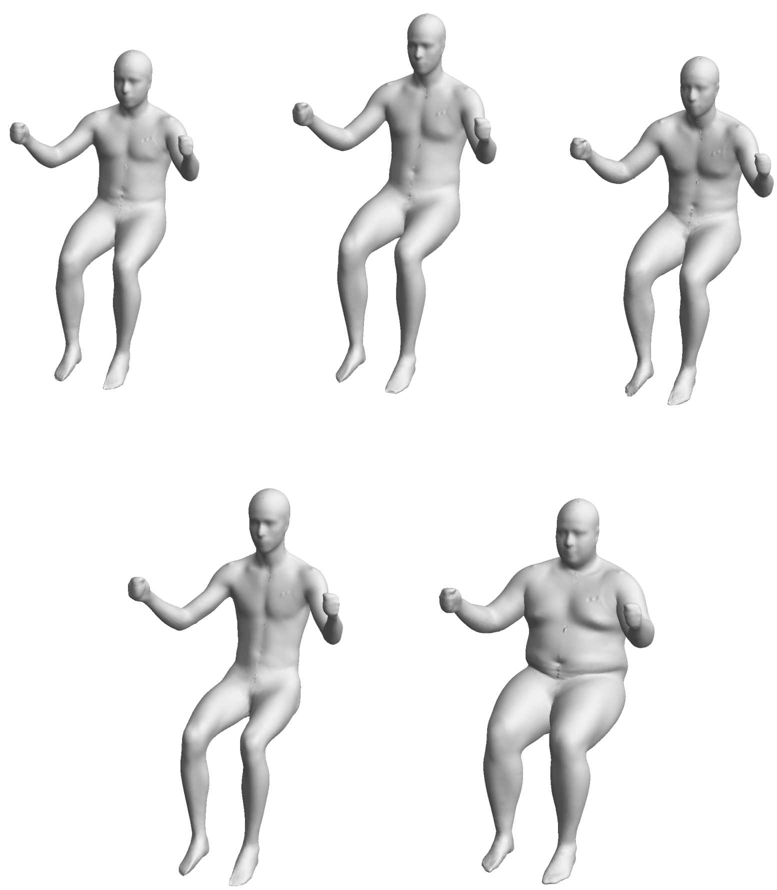


Figure 4. Some of the body shapes that can be produced by the statistical model. The upper right figure is the midsize male body shape obtained using the reference body dimensions (see Figure 5).

Figure 5 shows the body shape and surface landmarks output from the regression model after inputting the WIAMan reference body dimensions, before any adjustments. Figure 8 shows the final body shape, landmarks, and joints following the posture and buttock-shape adjustments. Note that due to limitations of the scanning methodology, the foot geometry is not well represented. The feet depicted in Figure 7 are somewhat smaller than the true foot dimension. Consequently, a separate study was conducted to develop target foot geometry for WIAMan (Reed et al. 2013).

Figure 5. Body shape output from the regression model prior to posture and shape adjustments.

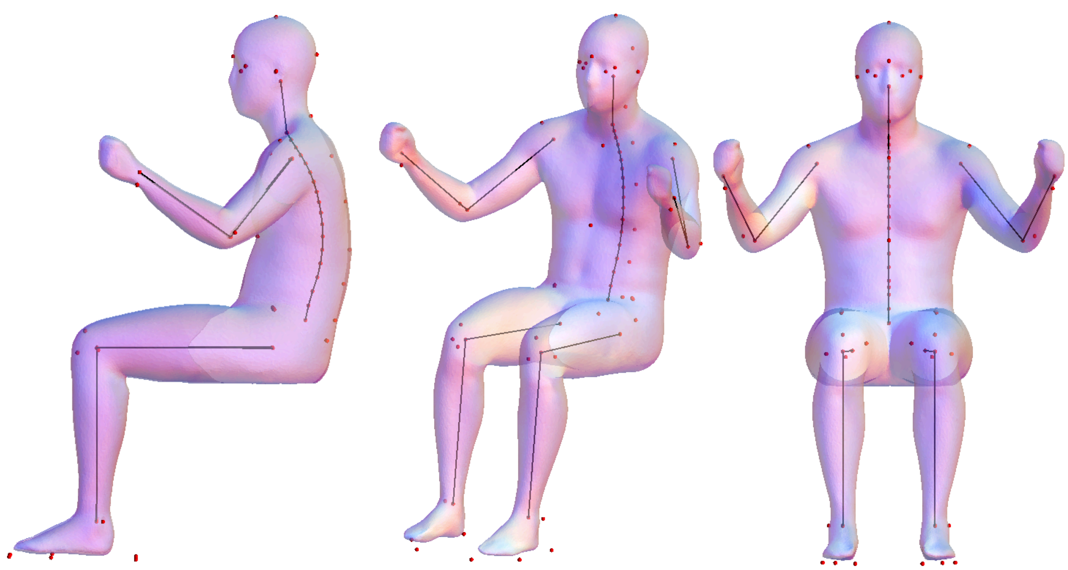


Figure 6. Final body shape with landmarks and joints following posture and contour adjustment. Note that foot landmarks are on perimeter of boot.

DISCUSSION

The current analysis is the first known application of a three-dimensional regression approach, as opposed to simple averaging, to generate anthropometric specifications for an ATD. The method has strong advantages over simple averaging. For example, it is not necessary that the distribution of anthropometric variables in the study population(s) match the target population. The current analysis used two populations drawn from the Seated Soldier Study for the landmark and body shape analyses that differed somewhat in the means and variances of body dimensions. However, the regression analysis requires only that the underlying data span a reasonable range around the target values, which both data sets do. The models developed for this analysis are most accurate near the center of the distribution (i.e., for the current target values) and would be less accurate for extreme targets (e.g., for creating a "95th-percentile" manikin).

It is also the first known application of a shape model based on whole-body laser-scan data to ATD development. One strong advantage of this approach is that it allows data from subjects with a wide range of body dimensions to be used, simplifying the experimental approach. The method also combined data from landmark measurements on clothed individuals in a realistic seat with whole-body scan data obtained with minimally clad individuals on a test seat. The statistical model linking body shape with landmark locations enabled a realistic body shape to be created for a test condition in which scanning was not feasible.

One important advantage of the current methodology is that the posture and shape models can be exercised to generate accurate predictions for other male body sizes. For example, a "large male" model with 95th-percentile stature and body weight could be readily created. The same methodology could be applied to developing anthropometric specifications for a female manikin, although more data than the 53 women available in the Seated Soldier Study would be needed.

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