Use of Geometric Data in Human Factors and Ergonomic Applications

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Abstract Human factors and ergonomics (HFE) studies seek to match capabilities of people to products and task. Typically, emphasis is on product or task design, but understanding user population form is also important. The application of geometric methods in HFE differs from usual explorations in physical anthropology. In HFE, both size and shape differences matter. Analysis seeks to characterize variation *within* a population rather than quantifying differences *between* populations. We used 3D scans from the Civilian American European Surface Anthropometry Resource (CAESAR) dataset to examine female anterior torso form (size *and* shape) for a personal protection application. For a human modeling application, seated torso scans were used to generate models for vehicle driver position analysis. In both examples, scan data were sampled to reduce the number of mesh vertices and to establish correspondence between vertices and anatomy.

Principal component analysis (PCA) was performed on the mesh data. Analysis of anterior torso form found differences along PC1 to be largely in girth, PC2 contrasted girth and torso height, and PC3 found differences mostly in chest/abdomen form. For the seated torso models, PCA scores were regressed against stature and BMI. Stature and BMI were then used to generate synthetic torso models for driver position evaluation.

The use of geometric-based analysis is relatively new in HFE and has the potential to greatly influence the analysis of body form. In the future, we will be investigating differences in body size and shape in more realistic dynamic postures. Approved for public release, NSRDEC PAO U13-126.

Introduction

- Engineering Anthropometry- collection, processing, analysis, and summarization of population-level data on human body size and shape.
- Used in human factors, ergonomic, and other applications related to the design and implementation of things people use.
- Concerned more with user population variation, less with differences between means.
- Data sets from large surveys, typically national or military.
    - NHANES- National Health and Nutrition Examination Survey.
    - CAESAR- Civilian American European Surface Anthropometry Resource.
    - Size-USA, -UK, -Korea, -China.
    - ANSUR- US Army Anthropometric Survey (1988, 2013).
    - MC-ANSUR- Marine Corps Anthropometric Survey (2011).
- Usually contain standard 1D anthropometry, now have 3D scans (e.g. Fig 1).

Figure 1. Cyberware PX head scanner in use.

Defining Torso Geometry for Design of Personal Protective Equipment

Goal

- Create male & female torso shapes for personal protective equipment (PPE) design.
- Accommodate 90% of the population.

Method

- Updated variation of "Boundary Models" or "Extreme Form" approach (Bittner et al, 1986; Meindl et al, 1993).
- PCA of 3d coordinates from whole body scans.
- User population= Joint Strike Fighter CAESAR (Robinette et al., 2002; Hudson et al, 2003).
- Females only, N=722.
- Trimmed whole body scans to torso and decimated to 217 anterior torso points (Figs. 2 & 3).
- Groups of mesh vertices were related to anatomy for later analysis (Fig 4).
- Applied GPA with scale restored (Morpheus).
- Generated residuals.
- PCA of residuals covariance matrix.
- Computed 90% and 30% equal frequency ellipses (EFEs) based on PC Factor 1 & Factor 2 (Meindl et al, 1993).
- Defined 9 models- mean and along major axis intercepts for 90% & 30% EFE (Fig. 6).

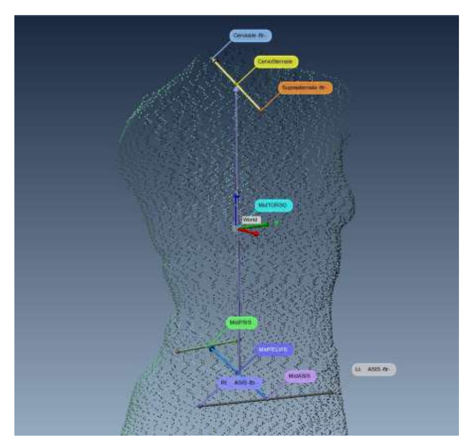

Figure 2. Torso coordinate system.

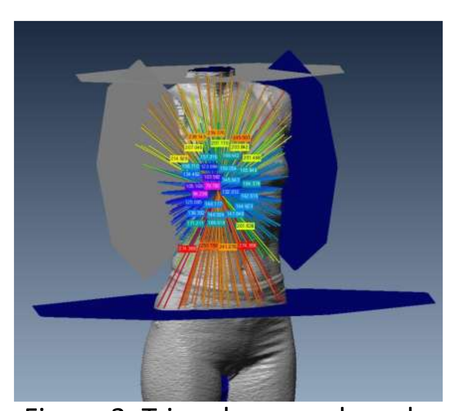

Figure 3. Trim planes and mesh vectors from origin.

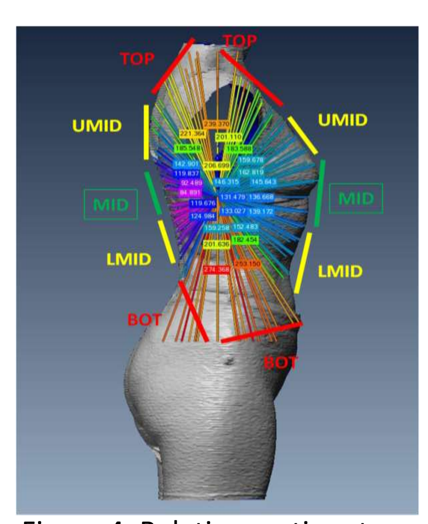

Figure 4. Relating vertices to anatomy.

RESULTS

- Retained 3 factors, explaining 72% cumulative variance (Table 1).
- The first two factors are used to illustrate results. Model forms from PC1 and PC2 are shown in figure 5.
- Variation along PC1 is best described as a robusticty change related to horizontal expansion.
- Variation along PC2 contains more of a size component oriented along the vertical direction.

Table 1. PCA results and descriptor of representative torso forms.

PC	Description	Eigen-value	% Total Variance	% Cumulative Variance	Relevant
1	**Robusticity**	***25833***	**47.6**	**47.6**	Yes
2	**Short/Wide/Round vs. Tall/Narrow/Elliptical**	***9000***	**16.6**	**64.2**	Yes
3	**Girth Ratio: Upper to Lower Torso**	***4471***	**8.2**	**72.4**	Yes
4	Asymmetry: Right vs. Left Shoulder Height	***2510***	4.6	77.1	No
5	Neck Length	1568	2.9	80.0	No
6	Size Ratio: Breast to Belly	***1243***	2.3	82.3	Yes
7	Hour Glass Shape vs. Straight	***11479***	2.1	84.4	Yes
8	Flatter Sternum vs. Cleavage (fabric span?)	***845***	1.6	85.9	No
9	Indentation vs. Protrusion: 10th Rib and Sternum	***649***	1.2	87.1	?
10	Asymmetry: Right vs. Left Breast	***610***	1.1	88.2	No

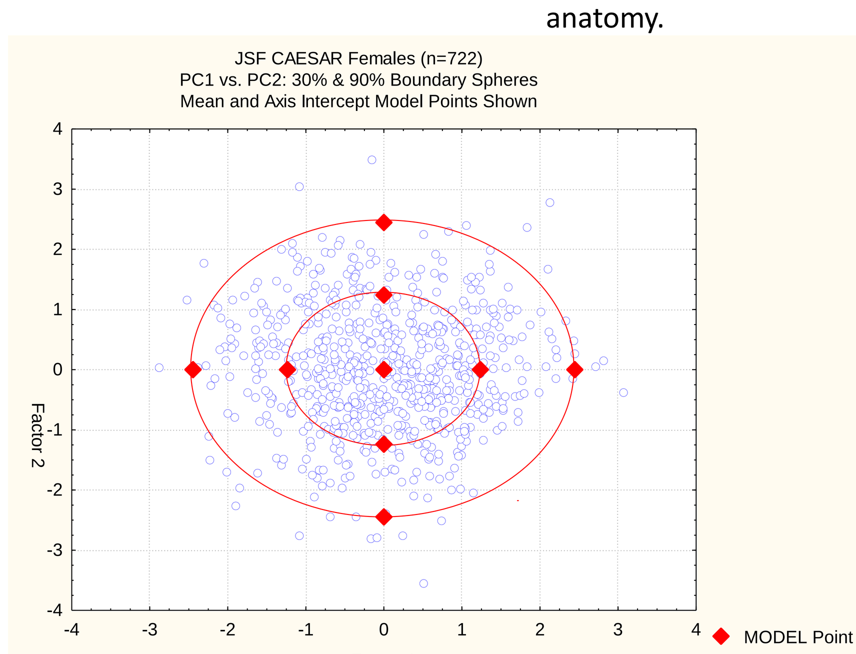

Figure 5. Distribution of representative forms, "model points", defined from 90% and 30% equal frequency ellipses of PCA scores.

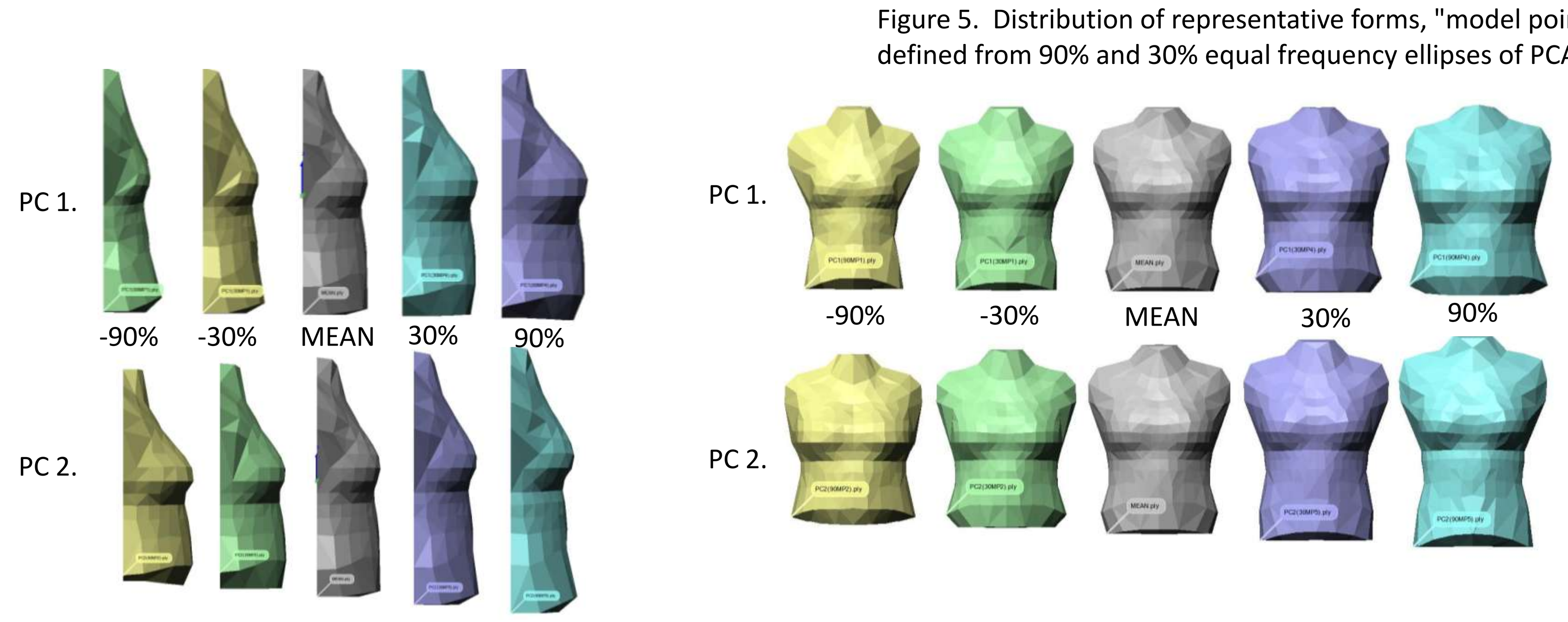

Figure 6. Lateral and frontal views of torso models selected from 90% and 30% equal frequency ellipses of PCA1 and PCA2 scores.

Synthesizing Seated Digital Human Models

Goal

- Create a representative set of digital human models to evaluate chair concepts.
- Capture a range of male and female body shapes and sizes.

Method

- General approach follows Reed and Parkinson (2002). Workflow is given in figure 7.
- Seated 3d scans and landmark locations were obtained (Fig 8).
- Scan mesh was downsampled and splined (Fig. 9).
- Produced a standard mesh by morphing a template to each scan (Fig. 10) (Allen et al., 2003).
- Full geometry data matrix was 3d mesh vertices and 3d landmark coordinates.
- PCA performed on covariance matrix of the centered data matrix.
- Retained PCs to describing 99% of variance.
- Regression of PC scores with body mass and height using BMI and stature (r ~.09).
- Regression provided a means to generate a virtual user population for product design and evaluation (Fig 11).

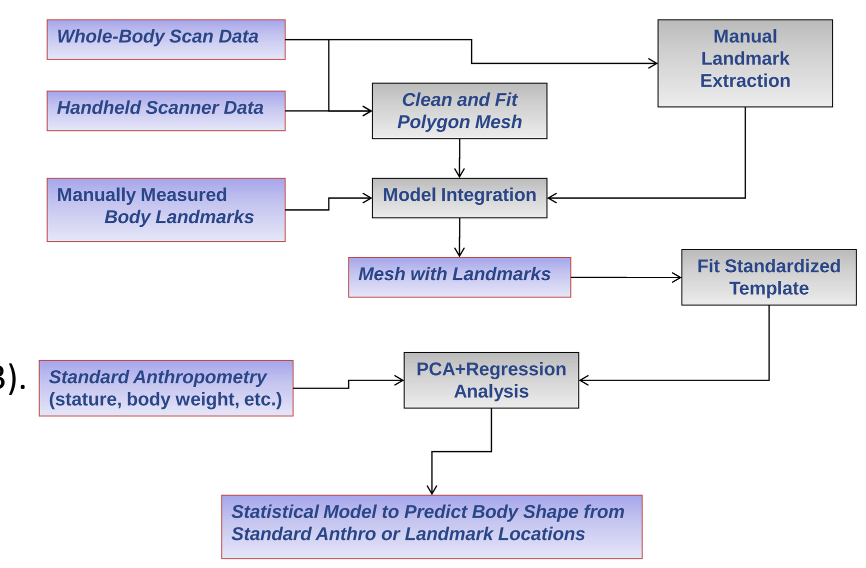

Figure 7. Data collection and processing workflow.

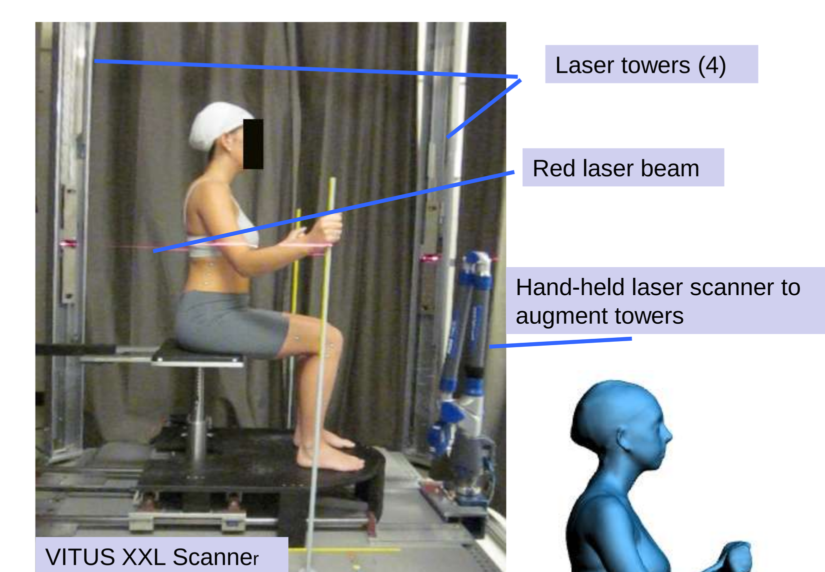

Figure 8. Whole body and handheld scanner set-up.

Figure 9. Extracted 3d scan.

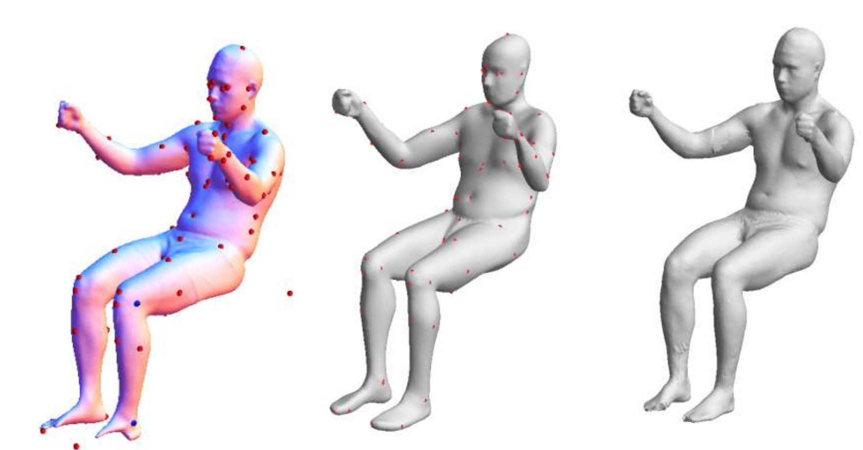

Figure 10. Template matching to produce standard mesh for analysis. Scan and landmarks (left). Landmark template match (center). Final morph (right).

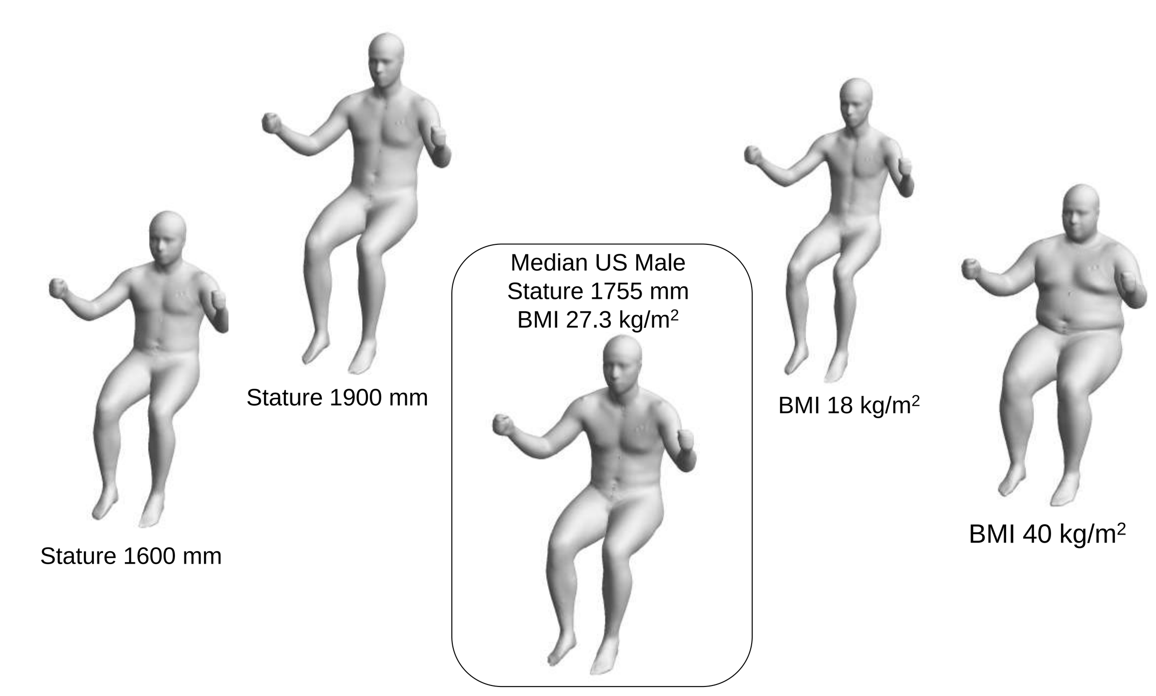

Figure 11. Output of regression model to predict seated body shape (based on 338 scans from 126 men).

Discussion

- Overall goal is to faithfully represent body size/shape of a user population.
- Two approaches to equipment and design and evaluation base on geometric analysis were presented.

Many open questions remain-

- How does PCA of standard 1d anthropometry data compare to results using 3d meshes?
- How different is different within population? How far from the mean?
- How many PC scores to keep? Does the ~90% variance rule-of-thumb apply?
- Can we mix 1d & mesh data?
- Is there an optimal mesh construction?
- How best to achieve vertex correspondence across a population?
- How to relate mesh vertices to anatomy?
- More work is required to better understand the differences between original and synthesized digital models.

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