Modeling People Wearing Body Armor and Protective Equipment: Applications to Vehicle Design

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Abstract. Vehicle interiors are complex human-machine interfaces, posing substantial design challenges, particularly when the vehicle is also a workplace. These challenges are compounded by the wide variability in human size, shape, and preference. For law-enforcement officers, firefighters, soldiers, and other workers, specialized clothing or body borne gear can affect their accommodation, comfort, safety, and ability to perform. Digital human modeling has the potential to provide designers with accurate tools to represent human variability, but current software generally lacks the ability to represent accurate seated body shapes for occupants with body borne protective equipment. This paper presents an overview of research to develop body shape modeling tools for vehicles that incorporate body armor representations. Laser scan data drawn from a large-scale study of men in seated postures was used to develop a predictive model that generates body shape as a function of standard anthropometric dimensions and seat and workspace variables. The model is postured using a data-based approach that incorporates the effects of body armor and gear on posture. Importantly, the space claim for the body armor and body borne gear is validated by reference to laser scan data.

Keywords: Vehicles, Seats, Body Armor, Human Models.

1 Introduction

Vehicles are important workplaces for a large number of people who work in law enforcement, fire-fighting, military, and other occupations. Digital human models (DHM) that represent human body size, shape, and posture in three-dimensional (3D) computer aided engineering (CAE) systems have been useful in improving accommodation and reducing worker stress in these environments. However, few commercial human modeling tools are capable of representing accurately a wide range of seated body shapes and modeling the effects of personal protective equipment (PPE) and body borne gear (BBG) remains a challenge.

This paper gives an overview of a new human modeling system for representing soldiers in vehicles. Data drawn from a large-scale 3D anthropometry survey were used to develop a parametric human body model capable of representing soldiers with a wide variety of size and shape. Posture prediction models, including the effects of body armor and BBG, was developed from landmark data obtained in the same study. Finally, the space claim for PPE and BBG is represented using an automatically configurable geometry model. The resulting space claim was validated using 3D scan data.

2 Methods

2.1 Data Sources

The data for the current work were obtained in the Seated Soldier Study, a large-scale investigation of soldier body shape and posture in vehicle environments [1]. In brief, 315 soldiers were recruited at 3 US Army posts. Using a VITUS XXL laser scanner, each soldier's body shape was captured minimally clad and in up to 24 posture conditions, including some seated and standing conditions with PPE and BBG.

Half of the participants were measured as they sat in a reconfigurable squad seat at a range of seat heights and back angles. Postures were gathered at three ensemble levels: uniform only, uniform+body armor (PPE), and PPE level+BBG. In each condition, a FARO Arm coordinate digitizer was used to record body landmarks, including points describing the position and orientation of the head, thorax, pelvis, and lower extremities.

2.2 Modeling Approach

Body Shape. Figure 1 shows the modeling approach schematically. Laser scan data from a range of seated postures were used to create a parametric, statistical body shape model that is capable of representing a wide range of male soldier sizes, shapes, and seated postures. The model was parameterized by stature, body weight, and erect sitting height. Because the underlying data included a range of lumbar spine flexions and recline angles, the torso posture could be parameterized based on the side-view eye location with respect to the hip joint centers. The modeling method has been described elsewhere [2]. In brief, a template model is fit to each scan using a two-step method involving radial-basis-function morphing to match landmark locations followed by an implicit surface method for fine fitting. A principal component analysis followed by linear regression is used to relate body shape to standard anthropometric variables.

Posture. Seated posture predictions for this squad (fixed-seat) application was based on regression models obtained from landmark data [1]. For the software implementation, two landmark locations were predicted: the position of the mean hip joint center relative to the seat reference point, and the location of the eyes relative to the hips. This effectively gives the position and posture within the seat. In addition to the anthropometric variables, the seat is characterized by seat height and seat back angle. Seat measurements are made using either the SAE J826 H-point manikin or the ISO 5353 seat index point tool [3].

Lower extremity postures can be varied to represent a range of seating configurations. A radial-basis-function morphing method [4] enables changes in thigh, leg, and foot orientation to produce a wide range of postures. The limb shapes in these postures are not validated, but any discrepancies are likely to be smaller than clothing effects.

Body Armor. Because body armor specifications are subject to limitations on public distribution, the research team created simplified geometry that approximates the space claim of a certain set of protective gear without including unnecessary details. Four sizes of body armor vest and helmet were created. The vest geometry was segmented into front, rear, and top components, each connected by reconfigurable geometric elements. In the software implementation, the correct size is first selected based on a sizing formula generated in actual fit tests. The vest is the applied to the human figure using methods designed to produce reliable overall dimensions – accurate representation of the human/armor interface was not an objective.

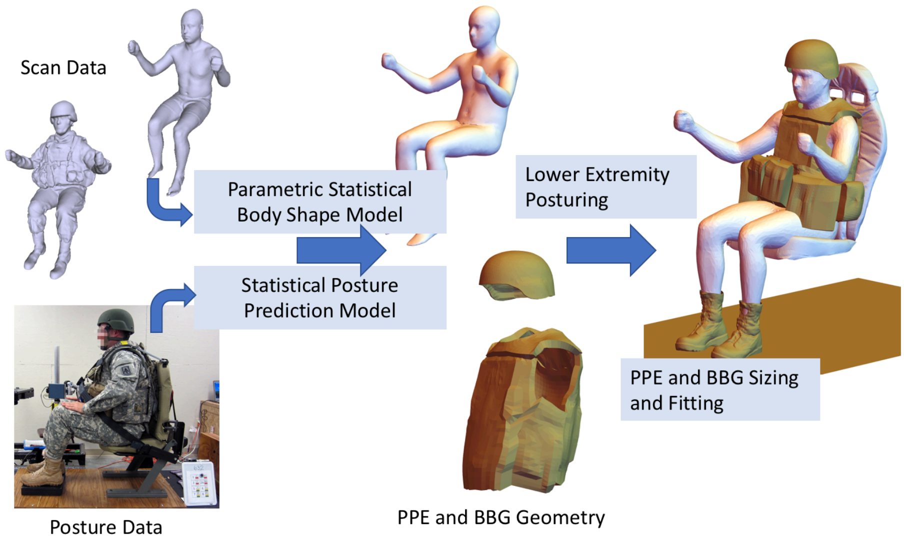

Fig. 1. Schematic of modeling approach.

3 Results

3.1 Representing Posture and Body Shape

Figure 2 shows a range of body shapes and postures. The figures were obtained by manipulating stature and body weight over a wide range, along with variation in seat height and seat back angle.

Fig. 2. Outputs from the body shape and posture models.

3.2 Body Armor and Gear

Figure 3 illustrates the simulation of body armor and BBG. The DHM is placed in a seat using the posture prediction model, demonstrating how the simulated figure scan be used to assessing accommodation by the seat and surrounding environment.

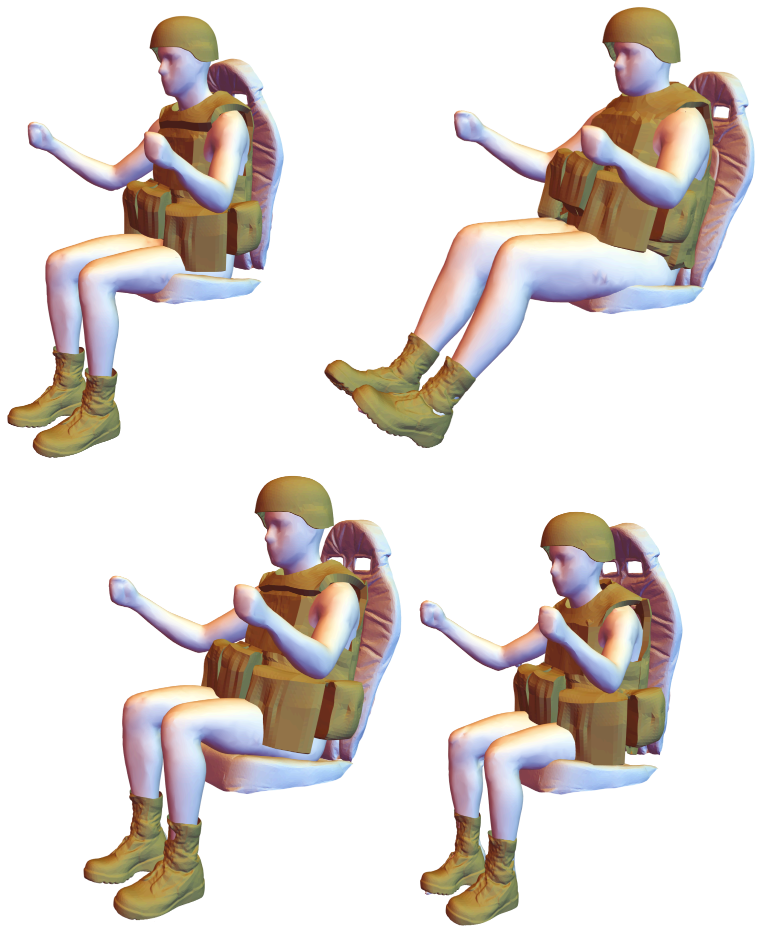

Fig. 3. Model outputs including body armor and body borne gear.

4 Discussion

4.1 Achievements

To our knowledge, this is the first parametric body shape model of seated adults based on an extensive database. The integrated posture-prediction capability is also the first to take into account the effects of PPE and BBG. Finally, the space claim of the simulated ensembles has been validated with reference to detailed scan data from over 200 individuals. The models presented here are currently in use for seat design and assessment. A wider range of statistical body shape models for civilian applications is available online at http://humanshape.org/.

4.2 Limitations

The body shape and posture data were gathered from a diverse group of young soldiers, and hence the model may not be appropriate for other populations. Currently, only a male model is available. The posture manipulations of the limbs are not validated, although the data needed to do so are available. The simulated PPE and BBG represent only a small number of configurations. The posturing model is based solely on statistical relationships; the physical interaction between the sitter and seat is not modeled. This enables a highly efficient simulation that is validated in important ways (for example, reliable prediction of hip and head location). However, the effects of unusual seat configurations cannot be simulated by this method; additional data on posture and shape would be needed to generalize to other seats and PPE ensembles. The relationship between the body surface and the PPE and BBG geometry is not physically realistic. For example, the BBG may intersect the body surface, as visible in Figure 3. Because the purpose of the simulations is to provide guidance for vehicle design, rather than for PPE design, only the overall positioning and space claim is validated. A more complex simulation is needed to apply the body shape model to PPE design and evaluation.

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