CREATING HUMAN FIGURE MODELS FOR ERGONOMIC ANALYSIS FROM WHOLE-BODY SCAN DATA

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Advances in surface scanning technology have made possible the large-scale collection of body shape data. This paper describes methods for creating whole-body human figure models from the 3D scan data using a semi-automated process. Body surface landmark data are used to calculate joint locations and to segment the point cloud. A surface polygon mesh is fit to the point-cloud data for each segment. The model accuracy with respect to the original scan data can be made arbitrarily high by increasing the polygon model resolution. NURBS surfaces are then fit to the polygon mesh for rendering in CAD systems. The result of this process, which typically requires about five minutes, is a whole-body, articulated model that represents the body shape captured in a whole-body scan. The model posture can be adjusted dynamically in a CAD environment for application to a wide variety of ergonomic analyses.

INTRODUCTION

The CAESAR program is an international effort to gather whole-body anthropometric data from civilian populations. Three-dimensional scanners are being used to record body shapes in the U.S., the Netherlands, and Italy. The U.S. data collection has concluded with measurements of 2374 men and women ages 18 to 65. These data are now available to the companies who have supported the CAESAR partnership, and will soon be available to others through the Society of Automotive Engineers.

In CAESAR, participants are scanned in three postures: standing, erect sitting, and relaxed sitting. The CAESAR research team has produced a landmark file for each scan that contains the three-dimensional locations of 44 body landmarks. The landmarks were extracted from targets visible in the scan data by automated and manual methods. These data are essential for the analysis methods presented in this paper.

Although whole-body scan data have many applications, one prominent use for the data is the construction of human figure models that accurately represent the body shapes of a diverse population. Current human figure models can be configured to represent a wide range of anthropometry, but generally lack realistic body contours and do not represent idiosyncrasies in body shape. The principal challenge in using whole-body scan data with human figure models is creating an articulated, surfaced geometric model that matches the scan data with an acceptable level of accuracy.

There are two general approaches to this problem. One is to create a unique geometric model of the individual scan, then segment the model and attach the segments to a kinematic linkage. This method has been most commonly used to date, particularly in fields such as entertainment animation. With the rapid proliferation of scanning technology have come software packages that facilitate the construction of CAD models from the point-cloud data produced by the scanners. Most are intended to be used in reverse-engineering applications in which the fit of the model to the data is more important than the structure of the model.

Body models constructed using this technique are not easily used with most ergonomic figure models, however, because such tools usually are based on surface geometry having a well-defined and consistent topology. For example, such tools usually have sites defined on the surface of each segment to which constraints can be attached. Some figure models were developed to accept alternative surface geometry, but the geometry must still be segmented in a manner consistent with the kinematic linkage of the figure model. The current tools available for surfacing point clouds also do not provide substantial levels of automation.

An alternative approach is to fit a predefined human body model to the scan data. This approach is promising, but is difficult to implement because differences in body shape and limb orientation necessitate complicated algorithms and operator intervention to obtain an accurate fit. Currently, both of these approaches require substantial operator involvement and require a large amount of time to complete a single model. Creating usable models from CAESAR scan data using the available techniques can require as much as a day's work for each scan, making it impractical to access the entire CAESAR dataset in a human figure model environment.

This paper presents a hybrid approach that fits a generic polygon mesh to the surface point cloud of a standing body scan. The mesh resolution can be set arbitrarily to obtain the desired tradeoff between model complexity and processing speed. Segmentation is performed on the point cloud, prior to surfacing. This method has the advantage of creating models with a consistent topology, given the same input settings. If desired, other human figure models can be fit to the models created by these methods. The process is considerably simpler than fitting a figure model to the original scan data, because the intermediate model surfaces and linkage are well defined. Throughout the process, the desired tradeoffs between accuracy, processing speed, and model complexity can be maintained.

METHODS

Whole body models are created in five steps:

1. Joint locations are calculated from surface landmarks, defining the kinematic linkage of the model.

2. The point cloud is segmented, using the locations of landmarks and joints.

3. Polygon meshes are fit to the point clouds for each segment.

4. NURBS surfaces are fit to the polygon meshes.

Joint Locations and Kinematic Model

The CAESAR body scan data include the locations of 44 landmarks, most of which were identified prior to scanning with markers placed on the subject's body. Joint locations are calculated using methods developed for use in quantifying the posture of vehicle drivers (Reed et al. 1999). The source data for these methods includes cadaveric and radiographic studies. A seventeen-link kinematic model is created, as shown in Figure 1. This process is fully automated. Note, however, that this type of automated segmentation is only feasible because the CAESAR research team carefully digitized and verified the locations of the key body landmarks. Automated segmentation of body scans lacking the needed surface landmarks would be considerably more difficult.

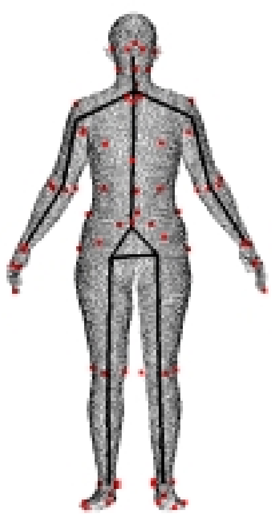

Figure 1. Point cloud from a standing scan with landmarks, calculated joint locations, and kinematic linkage (only 1/10 of sampled surface points are shown).

Segmentation of Point Cloud

The segmentation of the point cloud is the most difficult part of the model fitting process to automate. Although a human can readily identify the segment appropriately associated with each surface point, automated algorithms have difficulty in areas where segments abut, particularly where the arms contact the torso. A semi-automated method is used to ensure that the segmentation is accurate. Algorithms based on joint locations and landmark locations are supplemented by analogs of the visual search process human operators use to detect, for example, the gap between the thighs or between the upper arm and torso. The results of the automated segmentation process are presented to the user graphically for verification, as shown in Figure 2. If necessary, the operator can interactively adjust the segmentation planes to properly section the point cloud. With the current algorithms, adjustment is necessary for about 25 percent of the CAESAR standing scans, but requires only a minute or two. Further advances in segmentation algorithms might reduce the percentage of scans requiring human intervention, but visual verification of the model processing results will always be useful.

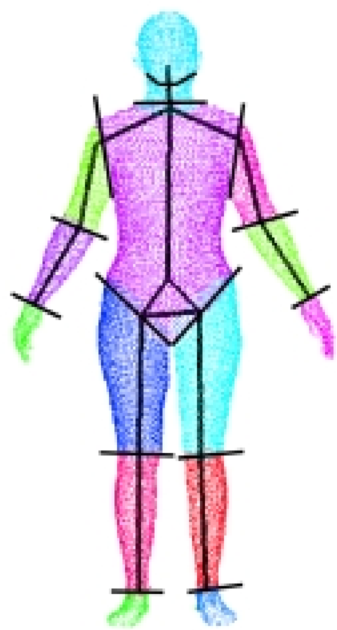

Figure 2. Scan data and skeleton with schematic illustration of segmentation planes. Actual segmentation uses multiple surfaces for some joints.

Polygon Mesh

A rectangular grid of vertices defining a quadrangle mesh is calculated for each segment. The algorithm slices the segment point cloud into a predefined number of segments using planes oriented at specified angles with respect to the segment axis. The slicing plane specifications for each segment are predefined in the segment coordinate system, but can be adjusted as desired. For example, the default procedure is to use 15 slice planes for each arm segment, but a larger number of planes can be used to create a higher-fidelity model. A radial point-sampling method is applied in each slicing plane to create an equal number of surface vertices at even radial increments. The result is a rectangular mesh of surface vertices for each segment.

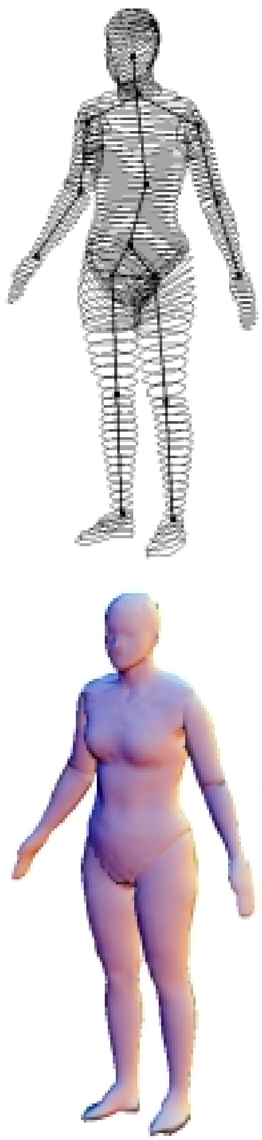

Figure 3. Slice planes used to create quadrangle meshes on each segment (above) and the resulting whole-body model (below).

NURBS Surface

A parametric surface is often more useful than a polygonal model for CAD applications. A rapid iterative procedure is used to create a single NURBS (Non-Uniform Rational B-Spline) surface in IGES 128 format for each body segment with a one-to-one mapping between spline control points and quadrangle vertices. The NURBS surface interpolates the surface vertices with arbitrarily high accuracy (typically set to 0.1 mm). Several commercially available software packages create NURBS surfaces on polygon meshes derived from point clouds, but none are known to allow the a priori determination of the number of surfaces and control points. The current procedure ensures that each model has the specified number and arrangement of control points for each segment, simplifying the storage and manipulation of models.

In addition to being much more useful in a CAD environment than the original point cloud data, the segmented NURBS model is extremely compact. When compressed using standard encoding techniques (e.g., gzip), the ASCII IGES file representing a whole body model is less than 30 kB, even when landmark and other descriptive data are included.

Simplifications and Modifications

The cylindrical approach to surfacing segments is inadequate for surfacing of the hands and feet. However, since the detailed characteristics of these segments are seldom needed for ergonomic applications of human figure models, externally generated hand and foot models are fit to the measurement data using linear scaling. The models shown in Figures 3 and 4 have simplified hands and feet. Similarly, the details of the facial features require a large number of polygons to represent well. Yet, since facial features are not important for most ergonomic analyses, an externally generated head model can be used effectively. (Analyses of the fit of protective eyewear or masks would require a more complete head surfacing approach.)

RESULTS AND APPLICATIONS

This modeling process produces an articulated, surfaced model that captures the body shape of the study participant. The model can be imported into any CAD system, or used in an ergonomic modeling environment. Figure 4 shows one model used in geometric analysis of an office chair.

Figure 4. Whole-body model created from a standing body scan used to evaluate office chair dimensions.

The near-term application of models created using these techniques is the assessment of new office chair designs. Prior to the CAESAR program, little three-dimensional information on human back shape was available. The CAESAR scans were obtained in only a few postures, but torso articulation methods have been developed as part of the current research to allow the models created from scan data to be placed in a wide range of realistic postures for chair dimensional assessment. Another area of ongoing research is the modeling of flesh deformation. Models created from standing scan data must be modified to produce realistic buttock and thigh contours when a person is seated. Considerable progress has been made on efficient algorithms for simulating buttock/thigh deformation under interaction with an office chair.

DISCUSSION

Although whole-body models have been created from scan data for some time, the process is generally very time consuming and ad hoc. The accuracy of such procedures can justify the time investment if the goal is to create a small number of models (for entertainment applications, for example). However, making the entire CAESAR database of thousands of scans available as articulated whole-body models requires a more automated approach. The methods described in this paper are automated as fully as possible, with minor operator intervention for quality control. Since human verification would be required even for a fully automated modeling process, the current procedures are believed to represent a near-minimal investment of operator time for model creation. Operator time per model is currently about two minutes, which makes model creation for the full database feasible. Alternatively, the model-creation process can be integrated into ergonomic assessment tools, so that models of any desired fidelity can be created directly from scan data in about five minutes.

The delivery of the U.S. CAESAR scans to the sponsoring companies this year should spur the development of many more tools to work with the data. Already, several human figure model companies are working on methods of fitting their models to scan data. As scanning technology becomes less expensive and easier to use, turn-key systems that create an articulated human body model as they scan a person will become available. These tools will greatly simplify the process of including realistic human body shapes in computerized ergonomic analyses.

REFERENCES

Reed, M.P., Manary, M.A., and Schneider, L.W. (1999). *Methods for measuring and representing automobile occupant posture*. Technical Paper 990959. Warrendale, PA: Society of Automotive Engineers, Inc.

For more information on CAESAR, see: U.S. Air Force Computerized Anthropometric Research and Design Laboratory (CARD Lab) at http://www.hec.afrl.af.mil/cardlab/ and SAE International at http://www.sae.org.