

A Tool Kit to Generate 3D Animated CAESAR Bodies

Qiming Wang, Sandy Ressler

National Institute of Standards and Technology

ABSTRACT

The Civilian American and European Surface Anthropometry Resource (CAESAR) database provides a comprehensive source for body measurement in numerous industries such as apparel, aerospace, and automobile. Generating animated CAESAR body sequences from still surface and landmark data will stimulate research and design in these areas. A tool kit has been developed to convert CAESAR bodies to models compliant with the Humanoid Animation specification (H-Anim). It will be helpful to set up a realistic motion capable humanoid library for application environment that can be reused in a wide variety of ergonomic applications.

The process consists of preprocessing the mesh, building a skeleton structure, creating segments of the body, assigning weights for vertices, and integrating motion capture data. Publicly available software is adopted for mesh compression and hole filling. C programs were developed to implement the translation from CAESAR body data to H-Anim. The technical issues involved in the process are discussed, and experimental results are shown in the paper.

INTRODUCTION

The CAESAR project has collected 3D scans, anthropometry landmarks, and traditional measurements on 2400 U.S. and Canadian, and 2000 European civilians. The 3D high-resolution data of U.S. and Canadian human body's surface were scanned using a Cyberware WB4 whole body scanner. The digital information includes range images and color information. The landmark points are pre-marked by pasting small stickers on the body and extracted using landmark software. Each body has three poses: one standing pose and two seated poses as shown in Figure 1.

The CAESAR database provides a comprehensive resource for anthropometry and measurement in the apparel, aerospace, and automobile industries. However, CAESAR characters are static surface areas

without motion. The development of an animation capable human model from CAESAR data will make database more useful and will attract wider interest. The aim of this work is to build an animated humanoid database from the CAESAR database. To achieve the objective, we selected a digital human presentation first, and then developed tools to transfer the CAESAR model to the presentation format.

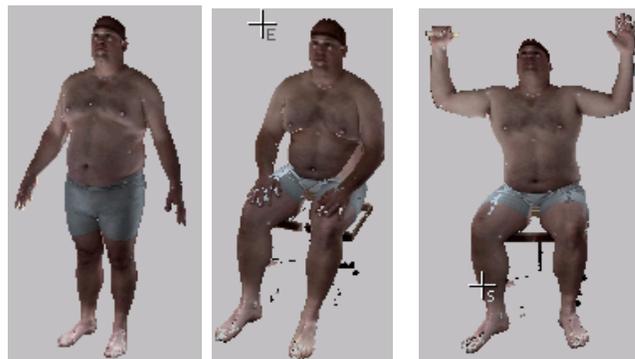


Figure 1. A CAESAR body with three postures.

Humanoid Animation (H-Anim) is an ISO/IEC international standard under development by the Web3D Consortium [9]. It specifies a system for representing humanoids in a network-enabled 3D graphics and multimedia environment. H-Anim figures are articulated 3D representations that depict animated characters. We selected the H-Anim specification as our human animation model because (1) it is a developing international standard; (2) it is a web based model, and supports the creation of interchangeable humanoid, behaviors, and animation; (3) Virtual Reality Modeling Language (VRML) browsers with native implementation of H-Anim exist (Contact developed by Bitmanagement).

The main efforts of this study focus on developing tools to generate H-Anim human body structured data from CAESAR scanned body data to extend the power of CAESAR from a measurement resource to a web based 3D H-Anim library. Only the standing posture of the CAESAR scan body is used in this practice, because it matches the default position specified in H-Anim

standard better than other two seated postures. In this paper, we introduce human animation models of H-Anim specification, describe the whole process from CAESAR to H-Anim, discuss technical challenges and the solutions in the process, show some initial results, and finally provide conclusion and future work.

HUMAN MODELS IN H-ANIM

H-Anim specifies the human geometry in two ways: skeletal body, and skinned body. The skeletal method presents the geometry as a skeletal hierarchy defining the relationship between the segments, called bones in some human models. The geometry of segments describes the body as separated geometric pieces. When a joint is bent, say the shoulder, then all the segments below it will be moved relative to it, so that the whole arm moves. Skeletal human models are computationally efficient. However, artifacts such as seams or creases near the joints happen in the skeletal body model. Figure 2 shows one H-Anim figure walking with skeletal geometry. The gaps around both knees are obvious.

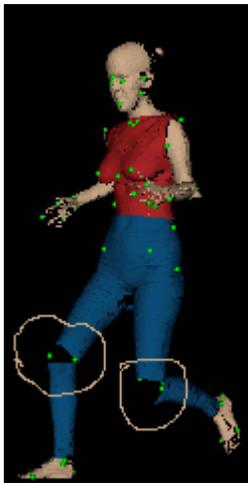


Figure 2. H-Anim figure with skeletal geometry.

The skinned geometry specifies the body surface as a continuous piece of geometry also known as a mesh. It has an underlying skeleton, and a skin. The articulated skeleton is defined as a hierarchy tree of joints, the same as in the skeletal model. The skin is defined as a set of polygons, which surrounds the joint skeleton. When one or more joints move, the vertices on the skin will have transformations and deformations depending on the locations of the vertices. This will insure surface motion without any seams. The problems shown on Figure 2 will not happen.

Comparing these two models, we prefer the skinned model, because it gives a more realistic human shape and motion. The skinned model may not be efficient in rendering if the browser does not have H-Anim native implementation. Fortunately, as mentioned before, the

VRML Browser Contact does have this capability and other browsers are under development.

THE TOOL KIT

The conversion from CAESAR to H-Anim involves technical challenges in various areas, such as mesh reconstruction, 3D human models, and animation of the human body. We will discuss the details in the following sections. In this section, the process structure and data flow is briefly shown in Figure 3. The blocks with bold text indicate input file or output file, and others are the processing procedures.

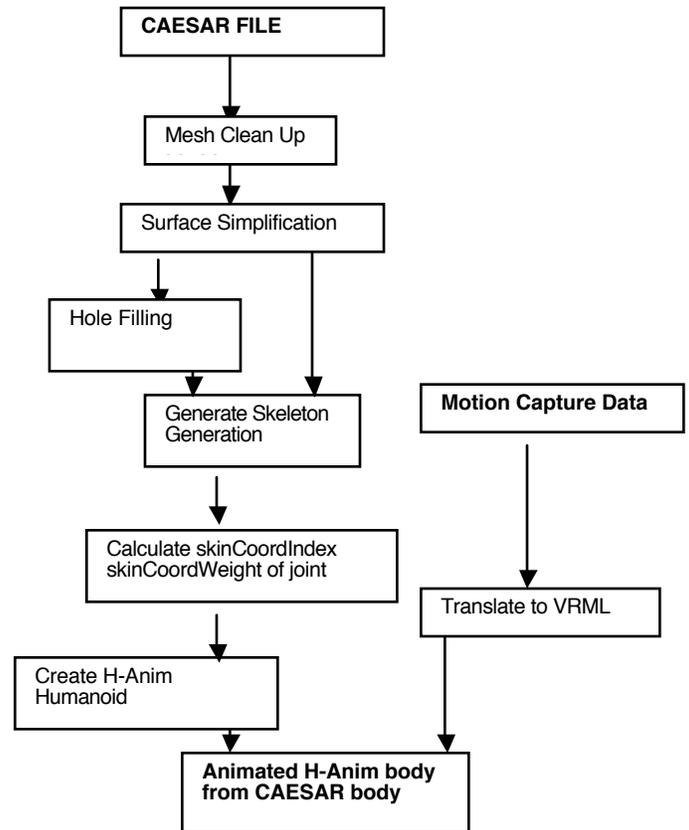


Figure 3. The structure and data flow of the process.

The programs in the procedures shown in Figure 3 constitute a tool kit to generate animated H-Anim bodies from CAESAR bodies. It has three categories of programs or routines.

The first category is translators. The process involves many software packages, which require different file formats. The CAESAR scan data file format is a PLY file. The polygon compressing software “qslim” requires SMF files. The animation file is a BVH file. The H-Anim file itself is a VRML file. Several translators were developed for the translation among different formats. The second category is utility programs for generating seamless H-Anim bodies, such as the original mesh clean up, adding color to the mesh reconstructed with hole filling algorithm, clipping plane generation, seamless H-Anim

body generation, and animated body generation. Most utilities are written in the C program language. The third category of programs is downloaded packages from the Internet. It has a polygon simplification program and hole filling programs.

Two tcl shells could be used to integrate the whole process. One java application was developed for adjusting the clipping planes interactively.

SURFACE SIMPLIFICATION

A CAESAR body scan is a huge 3D polygonal mesh of more than 200000 vertices and 300000 triangles with per vertex color information. These huge models make storage, transmission, computation, and display less efficient. Therefore, surface simplification is a necessary step in our process.

In recent years, the problem of surface simplification has received increasing attention. Several different algorithms have been formulated for simplifying surfaces. We adopted the method using quadric error metrics proposed and developed by Michael Garland [1][2], and downloaded the free software “qslim 2.0” [3] running in a Windows system. This method is efficient, and maintains high fidelity to the original model. Another important feature is that the author developed an advanced version of the program, which can simplify surfaces with color and texture.

Figure 4 shows the images of original body with 300000 triangle polygons and simplified body with 50000 polygons. The results are satisfactory both for quality and performance. The run time is about 15 s for PC of the Intel Pentium 2.40 GHz running in Windows 2000.

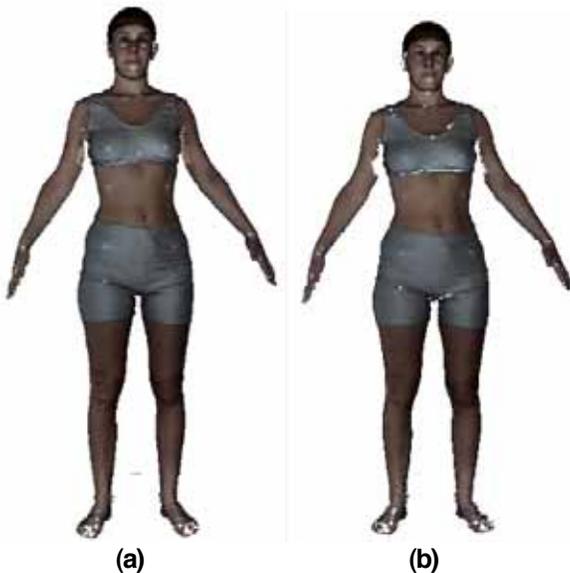


Figure 4. Comparison of original CAESAR body with simplified body. (a) Original scan body. (b) Compressed body.

HOLE FILLING

Modern 3D scan systems can measure the shape of an object’s surface with high accuracy and resolution. However, these systems often cannot observe the entire surface, the resulting 3D models may be incomplete. Occlusion, reflectance, constraints on scanner placement, or missing views are the main causes for the existence of holes. Although an incomplete surface model is acceptable for some applications, it is not satisfactory for our digital human modeling.

CAESAR scanned human bodies often contain many holes. Some of the holes are big and have complicated shapes. The holes in the areas away from the joints, such as in ears, hair areas, do not effect the construction of H-Anim body. However, areas such as under the armpits and around the crotch are critical for our process, because they are close to the shoulder and hip joints. Hole filling becomes an important part of our processing.

The problem of filling holes in polygon meshes has been a challenging topic in the surface reconstruction field. We did investigation for filling holes in the triangle meshes from the Web in order to find public available hole filling software. In general, there are two kinds of algorithms: point based using Voronoi diagram and Delaunay triangulation; and volume based using volumetric diffusion theory. We selected one method for each category in the public domain for the experiments.

Tight Cocone developed by Tamal K.Dey [4] of The Ohio State University is a point based algorithm that outputs water-tight surfaces from a point set in three dimensions. Tight Cocone software was downloaded from the web site [5] after author’s approval. The program was used to reconstruct some of our CAESAR simplified meshes, and the results for most of the bodies are good in general. Figure 5 and 6 show the results of Tight Cocone hole filling. In the Figure 5 (b), the holes on the arm, face, head, and ear are filled nicely. Figure 6(a) (b) present the results near the armpits.

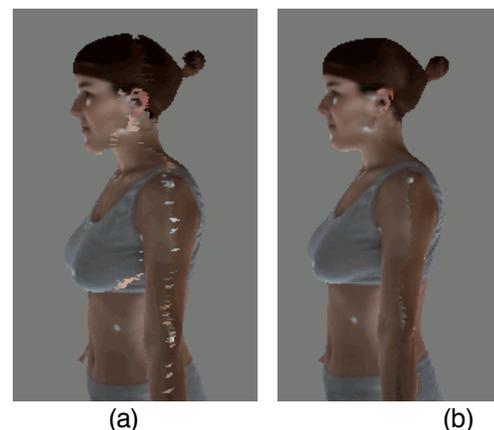


Figure 5. Results of filling holes using Tight Cocone method from side view. (a) Before filling. (b) After filling.

to fill the holes and the processed model will be used for the further refinement.

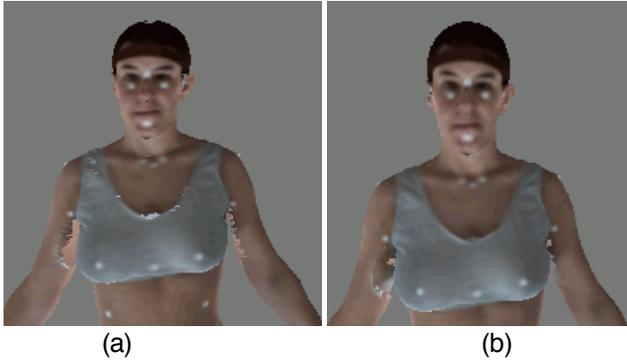


Figure 6. Results of hole filling using Tight Cocone method from front view. (a) Before filling. (b) After filling.

Another method of hole filling we tried is based on volumetric diffusion. Brian Curless and Marc Levoy [6] presented a volumetric method for integrating range images. James Davis presented a paper about filling holes in the complex surface using the volumetric diffusion [7]. We downloaded the software “Volfill” [8] and ran it on one CAESAR body. Figure 7 is the model after filling holes using Volfill method. The vertex color has not been applied. Figure 7 shows the whole body result, it works well for the small holes. However, the areas with complicated big holes have surface protruding with extra polygons, such as near the ears, hair, hands.

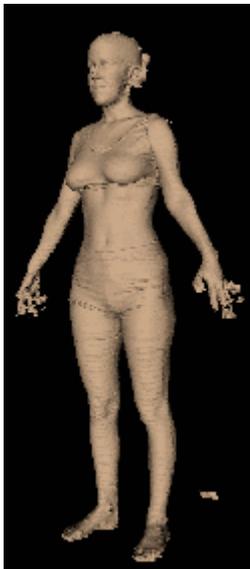


Figure 7. The results of hole filling using volumetric diffusion method.

In general, two methods improved our models. Both of them could fill the small and simple holes. For the complicated holes, such as on hands, under armpits, around ears, they are not perfect. Therefore, more efforts should be done to improve the hole filling process. At present, we use the Tight Cocone method

Most algorithms of geometry reconstruction do not consider color. We used the original model’s vertex color to estimate the color in new model output from the hole filling algorithms. For each vertex in the new model, look for the closest vertex in the original model and use that color as this vertex’s color. It will generate wrong colors for the big hole areas but is reasonable. The area under left armpit of Figure 6(b) has color more similar to the cloth not to the arm skin.

GENERATION OF H-ANIM BODY

H-Anim figures are described using the nodes in the standard: Humanoid, Joint, Segment, Site, and Displacer. The Humanoid node is the root of an H-Anim figure and provides the attachment framework for all other parts of the humanoid. The Joint node is used to describe the articulations of the humanoid figure. These Joint nodes are organized into a hierarchy that describes the inherent parent-child relationship of Joint nodes in the skeleton and provides a container for information that is specific to each joint of the skeleton.

```

DEF HUMANOID Humanoid {
  name "Humanoid"
  skinCoord DEF hanim_skin_coord Coordinate {point [...]}
  skeleton [DEF hanim_HumanoidRoot Joint {
    ...
    children [
      DEF hanim_sacroiliac Joint {
        skinCoordIndex [...]
        skinCoordWeight [...]
        ...
        children [
          DEF hanim_l_hip Joint {
            skinCoordIndex [...]
            skin CoordWeight [...]
            ...
            children [
              ...
            ]
          }
        ]
      }
    ]
  } # hanim_HumanoidRoot
] # skeleton
skin [
  DEF hanim_skin_color Color {color [...]}
  Shape {
    ...
    coord USE hanim_skin_coord
    color USE hanim_skin_color
    coordIndex [...]
  }
] #skin
} #Humanoid

```

Figure 8. An example of H-Anim Humanoid.

Instead of describing definitions of Humanoid and other objects, we present an example of H-Anim humanoid as shown in Figure 8. The “skeleton” and “skin” are two

important fields to be filled for the skinned human model. For each joint constituting a skeleton, skinCoordIndex and skinCoordWeight are two attributes to be generated. In following sub sections we will explain the concepts and methods for generating H-Anim humanoid.

(1) LANDMARKS OF CAESAR BODY

The CAESAR body with a standing posture has a landmark file with 73 landmarks including the 3D coordinates of the positions and landmark names. The H-Anim body created in our process has landmarks shown as green balls. When the user moves the mouse cursor over a landmark, a text of the landmark name and coordinates will pop up on the screen. This provides a 3D interface for understanding the landmarks of the CAESAR body.

(2) JOINT HIEARACHY USING CAESAR LANDMARKS

Although a CAESAR scanned body surface does not have interior information, we could estimate the locations of joints using the landmarks. For example, we use the average of the landmarks of left Trochanterion and Crotch as an approximate location of left hip joint. Eighteen joints are selected to form a joint hierarchy of the skeleton shown as Figure 9.

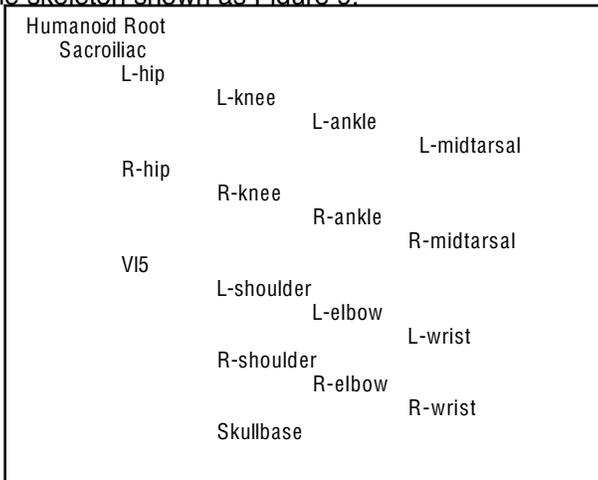
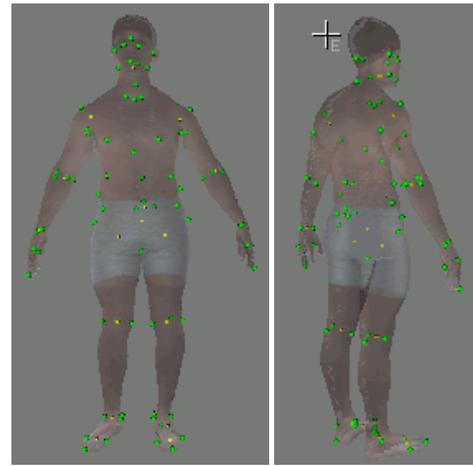


Figure 9. Joint Hierarchy.

Figure 10 shows the locations of the landmarks and joints of one CAESAR body from two different viewpoints. The green balls indicate landmarks on the surface. The yellow boxes present the joints inside the body.

(3) SEGMENTS

After creating the skeleton, we will separate the whole body into several parts, called segments or bones. For example, the right upper arm segment is between the right shoulder joint and the right elbow joint. Each joint has one joint separation plane. The segments are generated using the joint separation planes and some



(a) Front view, (b) Side view.

Figure 10. Landmarks and Joints. (a) Front view, (b) Side view.

additional clipping planes in order to insure that the segment distribution is as accurate as possible, and each vertex on the surface belongs to one and only one segment except on the joint separation planes. We will present the procedure in more detail here.

A joint separation plane or a clipping plane is a 3D plane specified by a normal and a point on the plane. The standard equation of a plane is

$$A x + B y + C z + D = 0$$

where (A, B, C) is unit normal. The value of D is determined by substituting in the known point (Px, Py, Pz) on the plane, namely,

$$D = - (A P_x + B P_y + C P_z)$$

For any vertex (Qx, Qy, Qz) on 3D space, the expression

$$side(Q) = A Q_x + B Q_y + C Q_z + D$$

can be used to determine which side of the plane the vertex lies on. If it is positive, the point lies on the same side as the normal. If negative, it lies on the other side, if zero it lies on the plane. This is the fundamental principle used for generating segments.

One or more 3D planes are defined to generate one segment. Figure 11 shows the separation of the body, and some planes, the segments are distinguished with different colors. The **ps** plane is the separation plane for creating the segment head. This plane has normal up and joint point of skullbase joint. However, multiple planes with different normals are necessary for most joints. For example, we use four planes, **p1**, **p2**, **p3**, and **p4**, in Figure 11, to generate the segment associated with right hip joint. The normals and points of the planes

can be calculated from landmark data for most of the segments.

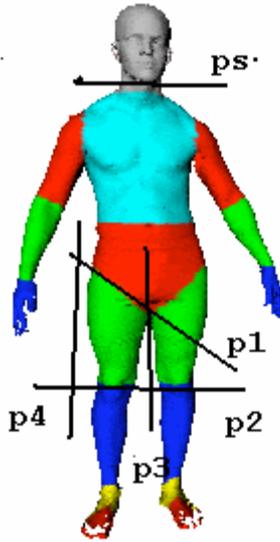


Figure 11. The segments and separation planes.

If the scan body is ideal, which means the areas under armpits and under the crotch are clear, the result of segmentation is satisfied. Unfortunately, for many reasons, the quality of CAESAR scan data is not perfect for our tasks. It is difficult to define the clipping planes to separate the body. For example, if one or two arms are too close to the chest. The separation planes may cut some vertices on the shoulder to the chest, or reverse, so that strange animations may happen. Due to the complexity of the CAESAR data, it is hard to find an automatic way to generate a set of clipping planes from the landmarks working for most of the CAESAR bodies. Therefore, we developed a semi automatic method to define a set of clipping planes for an individual body interactively. This way significantly improves the result. Those details are beyond the scope of this paper.

(4) skinCoordIndex, skinCoordWeight of JOINTS

As shown in Figure 8, each Joint node in H-Anim specification has two fields, skinCoordIndex and skinCoordWeight, which are associated with creating continuous and smooth deformations. The skinCoordIndex field indicates what vertices will articulate when the joint node rotates. The skinCoordWeight presents the weights of vertices defined in the skinCoordIndex.

As a first step of experiment, we assumed one joint is referenced to only one segment between it and its child joint. In addition the weight is 1 for all the vertices belong to the segment. Such as the right elbow joint is only related to the right forearm segment, and the weight is 1 for all the vertices in the right forearm. The resulting animation is continuous but not smooth, especially in the areas of elbows, knees.

To improve the smoothness of the deformation, we adjusted the skinCoordIndex and skinCoordWeight for each joint. Suppose one joint links two segments, S1 and S2. S1 is between this joint and child joint, S2 is between it and its parent. Suppose the joint is right elbow, S1 is right forearm segment, and S2 is right upper arm segment. We divide the whole area to two regions: a deformable region, shaded area in Figure 12, and an undeformable region, un-shaded area in Figure 12. If a vertex has a distance to the joint less than $\frac{1}{2}$ of the segment length, it belongs to deformable region. Otherwise it is in the un-deformable region.

For the vertex on the separation plane, the weight is 0.5. In the deformable region of S1, the vertex has weight linearly changing from 0.5 to 1.0. In the undeformable region of S1 side, the weight is 1. In deformable region of S2, the vertex has weight linearly changing from 0.5 to 0. the weight is 0 for undeformable area. skinCoordIndex of the joint covers the indices of vertices of the two segments, and the skinCoordWeight will be the weights described.

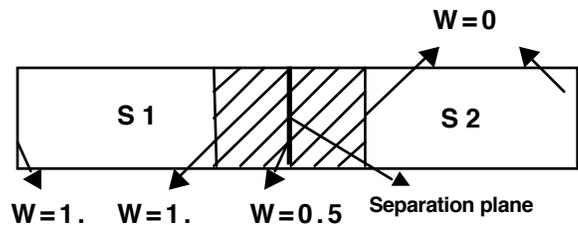


Figure 12. The illustration of the weight assignment.

Figure 13 shows a posture generated with above weight adjustment. The smoothness of the motion has been improved, especially in the areas of the knees and elbows. However, this is in experimental stage, how to distributing the weight factors for different joints to achieve best results still is a research topic for our process.



Figure 13. The image of a walking model.

(5) H-Anim HUMANOID

After filling the skinCoordIndex and skinCoordWeight for all joints, we can integrate them according to the H-Anim specification [Figure 8], and joint hierarchy [Figure 9] to form a seamless H-Anim body. A C program has been developed to generate an H-Anim body. The input for the program is a simplified mesh either with holes filled or not, landmark data, and clipping plane data. The output is an H-Anim body in VRML 2.0 format, which can be viewed in a VRML Browser preferably with native H-Anim implementation. If the browser does not have a native H-Anim implementation, some VRML Script nodes can be added to fulfill the same functions with very slow rendering.

ANIMATION OF H-ANIM BODY

H-Anim bodies generated from the steps described in the previous section are able to move after the motion information is embedded. The use of existing motion capture data is a suitable way to animate H-Anim bodies. We adopted some motion capture data from the software package Poser as experiments. They have a similar joint hierarchy with Figure 9. The file format is Biovision's BVH. Figure 14 shows two snapshots of the dance motion of a CAESAR body.



Figure 14. Snapshots of dance motion.

Several technical issues have to be solved for embedding motion to H-Anim body. At first, we have to translate the BVH file to VRML format so that it can be connected with our H-Anim body. We downloaded the translator of BVH file to VRML file developed by Matt Lewis in Motion Capture Lab of Ohio State University [10], and modified the translator to be suitable for our purpose. The second problem is the original posture. The H-Anim body generated from the CAESAR body has an original posture with two arms hanging down. Some motion capture data from Poser has an initial pose with two arms placed horizontally. Therefore we rotated the two arms of H-Anim body around the shoulders about 60° in order to have the initial pose as close as possible to match the motion capture data. Figure 15 shows the initial pose of a body after rotating the two arms.

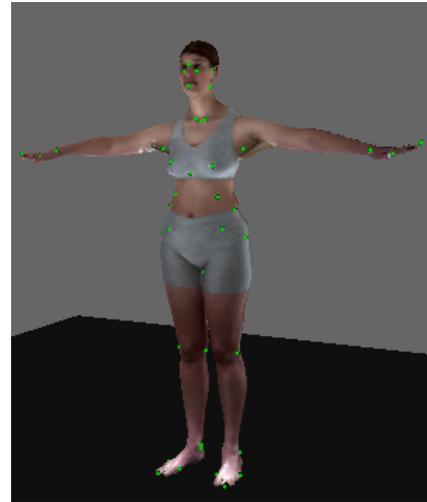


Figure 15. The initial pose with two arms lifted horizontally.

More than ten H-Anim bodies have been generated using the toolkit. Figure 16 shows the image of several bodies walking. The animation used here is walking, which has initial posture very close to the standing posture of CAESAR data.



Figure 16. Snapshot of bodies walking.

CONCLUSION AND FUTURE WORK

The process of converting from a CAESAR body to an H-Anim body still has many technical issues to be solved to make the process successful and simpler for most of the bodies. (1) Improve polygon mesh of CAESAR bodies to generate usable H-Anim bodies with less and smaller holes. (2) Improve performance of the processing without compressing original CAESAR body. The development of hardware shading program by some companies will provide excellent opportunities to improve the performance. (3) Investigate the methods to adjust the weights of vertices for joints so that the motion will be smooth. (4) Scaling motion capture data to be suitable for different size bodies is an important topic, so

called retargeting, an active area of research in the computer graphics community. (5) Investigate more accurate mesh deformation that corresponds acutely to real human skin deformations.

Our process indicates that converting CAESAR scan bodies to H-Anim bodies using our toolkit is feasible. Most of the work can be done automatically except one step in which human inference is necessary. The realistic animated human body inserted into web based virtual environments will be useful and helpful to research and design for a variety of applications. Based on these improvements it is likely that the CAESAR scan database can be a rich resource for industries not only as a static anthropometry measurement resource but also as a movable dynamic human body resource.

ACKNOWLEDGMENTS

We would like to thank Kathleen Robinette and Dennis Burnside of Wright Patterson Air Force Base for their help with the CAESAR data.

REFERENCES

1. Michael Garland and Paul Heckbert. Surface simplification using quadric error metrics. Proc. SIGGRAPH'97.
2. Michael Garland and Paul Heckbert. Simplifying surface with color and texture using quadric error metrics. IEEE Visualization 1998.
3. <http://graphics.cs.uiuc.edu/~garland/software/qslim.html>
4. Tamal K.Dey and Samrat Goswami. Tight Cocone: A watertight surface reconstructor. Proc. 8th ACM Symposium. Solid Modeling Application, 2003, 127-134.
5. <http://www.cis.ohio-state.edu/~tamaldey/cocone.html>
6. Curless Brian and Marc Levoy. A volumetric method for building complex models from range images. Proc. SIGGRAPH'96, ACM 1996.
7. James Davis, Stephen R. Marschner, Matt Garr, and Marc Levoy. Filling holes in complex surfaces using volumetric diffusion. Proc. First International Symposium on 3D Processing, visualization Transmission, 2002.
8. <http://graphics.stanford.edu/software/volfill/>
9. <http://www.hanim.org/>
10. <http://accad.osu.edu/~mlewis/Mocap/>