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BIOFIDELIC HUMAN ACTIVITY MODELING AND SIMULATION WITH LARGE VARIABILITY

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Interim Report

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14. ABSTRACT

A systematic approach was developed for biofidelic human activity modeling and simulation by using body scan data and motion capture data to replicate a human activity in 3D space. Since technologies for simultaneously capturing human motion and dynamic shapes are not yet ready for practical use, a motion capture system can be used to capture markers on the body during motion and a 3D body scanner can be used to capture the body shape in a pose. Using advanced computer animation software tools, the body scan data and motion capture data are fused to build a dynamic, animation-capable model that can replicate a human activity in 3D space with the true shape and true motion of a human. Using this approach, a model library was built to provide large variability of human activities with respect to anthropometrics and human motions. The 3D body scan data and motion capture data used to build these models were collected from 100 subjects performing nine activities at the 3D Human Signatures Laboratory of the US Air Force Research Laboratory. The model library provides wide range of anthropometric spectrum and motion variation. Given search criteria which include gender, age, height, weight, body build, ethnicity, and activity type, a particular activity model can be found from the library that may be an exact match or a close representation. Efforts were made to ensure that the activity models can be integrated into widely used game engines and image generators.

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Human Body shape and activity modeling, high biofidelity, articulated human body deformation and simulation

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Biofidelic Human Activity Modeling and Simulation with Large Variability

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INTRODUCTION

Human activity modeling and simulation (M&S) has been increasingly used in simulation-based training and virtual reality (VR). However, human M&S technology currently used in various simulation-based training tools and VR systems lacks sufficient biofidelity and variability necessary to describe and demonstrate the key nuances or the variations of human activities and human signatures. This inadequacy becomes crucial when the use of VR or training is human centered, such as human threat recognition training or dismount detection training. Therefore, in recent years, the US Air Force Research Laboratory (AFRL) has been investigating human activity M&S with high biofidelity and large variability.

In this paper, a systematic approach was developed for biofidelic human activity M&S by using body scan data and motion capture data to replicate a human activity in 3D space. Since technologies for simultaneously capturing human motion and dynamic shapes are not yet ready for practical use, data that can be readily used for 3D activity replication are not currently available. Alternatively, a motion capture system can be used to capture markers on the body during motion and a 3D body scanner can be used to capture the body shape in a pose. Using advanced computer animation software tools (e.g., Blender, 3dsMax, and Maya), the body scan data and motion capture data can be fused to build a dynamic, animation-capable model that can replicate human activity in 3D space with the true shape and true motion of a human.

Using this approach, a model library was built to provide large variability of human activities with respect to anthropometrics and human motions. The data sets contain the 3D body scan data and motion capture data of 100 subjects performing nine activities. For each subject, his/her scanned data was used to build a shape model and the motion capture data was used to animate the model, replicating the captured activities in 3D space. As such, large variability is provided in terms of anthropometric spectrum and motion variation. A Graphical User Interface (GUI) with display, edit, and search functions was developed for this human activity model library. Given searching criteria which include gender, age, height, weight, body build, ethnicity, and activity type, a particular model can be found from the model library that may be an exact match or a close representation. Efforts were made to ensure that the activity models can be integrated into widely used game engines and image generators (e.g., Virtual Reality Scene Generator (VRSG), CryEngine, and Night Vision Image Generator (NVIG)).

HUMAN ACTIVITY DATA COLLECTION AND PROCESSING

Data Collection

In a human activity study performed in the AFRL 711th HPW 3D Human Signatures Laboratory (3DHSL) at Wright-Patterson AFB, Ohio, whole body scans and motion capture data were collected on 100 human subjects performing nine activities. During the tests and data collection, a 3dMD (Atlanta, GA) whole body scanner photometric system (Figure 1 (a)) consisting of nine camera pods (five cameras per pod, except one pod with four cameras) captures a 3D image of the subject in several standing, static poses. The scanner produces a 3D point cloud which can be saved in a number of file formats, as shown in Figure 2. The motion capture system (Motion Analysis Corp., Santa Rosa, CA) is a ten-digital camera, passive-optical motion capture system. The subjects performed specified actions (activities) within the capture volume (about 20 ft long, and ten feet wide, as shown in Figure 3). Anatomical segment motion was tracked with small retro-reflective markers placed on the body with adhesive Velcro stickers; a modified "Helen Hayes" marker set was used. Digital 2D reference video was recorded during the motion capture with two cameras 90 degrees apart (side view and front/back view).

About half of the 100 subjects were male and half were female; all were screened by a medical monitor to ensure that they had no health problems precluding their participation in the activities. Subjects dressed in a close-fitting, polyester/elastane blend knitted fabric T-shirt and shorts; hair was covered with a snug cap. The activities performed by the subjects included typical everyday activities such as walking, jogging, throwing a ball, and picking up/putting down a small object. Other activities performed in the study included limping, carrying a heavy object in the right hand while walking, digging with a pickaxe, and walking and jogging while wearing a weighted vest.

Figure 1: Whole Body Scanner Set-Up

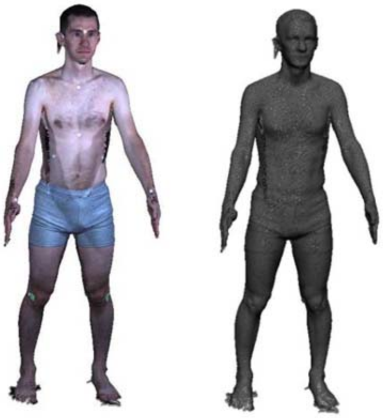


Figure 2: Body Scan Data
(left: image with texture; right: wireframe image)

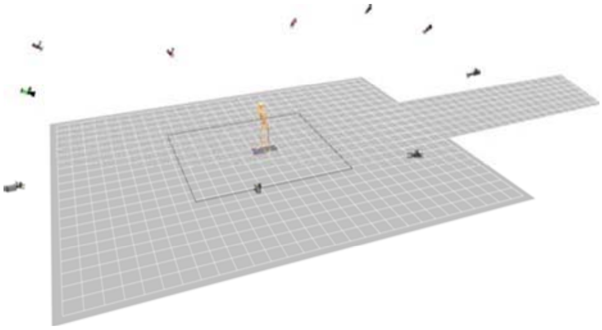


Figure 3: 3DHSL Motion Capture Camera Layout

Data Processing

The scan data usually contains holes and rough edges, and the resolution may be too high for the modeling software. Thus post-processing is necessary. In this study, Polyworks (InnovMetric Software, Quebec, Canda) was used to process 3D whole body scans. The software has the ability to fill holes using different types of methods ranging from a simple hole filling to applying a bridge of polygons to adjust areas with missing data. It also has the ability to apply a smoothing process at any given point to remove sharp edges and to smooth the surface of the scan. Another useful function used in the processing is the polygon reduction. This function provides the ability to take a high resolution model and reduce the polygon count to a manageable number that is appropriate for using the scan data for the modeling and animation. Due to the limitation of capture volume of the 3D whole body scanner, the full body cannot be captured for a tall subject when he/she is in T-pose. The problem was solved by using Polywork's merging tool. This tool provides the capabilities necessary to take various aspects of different scans of a particular individual and merge them together to create a scan that was impossible to capture in one time. By creating macros through command line history recorder and then running the macros, the productivity of scan data process was significantly increased.

Missing frames, excessive noise, and marker swapping are common issues with motion capture data. Post processing of motion capture data was performed using Cortex software (Motion Analysis). Alternatively, missing frames can be recaptured by interpolating; noise can be reduced or eliminated by using a de-noising method (e.g., one based on wavelets); and marker swapping can be corrected using marker (point) registration techniques such as Coherent Point Drift (Myronenko & Song, 2010). A Matlab program was developed to handle all these issues.

HUMAN ACTIVITY REPLICATION VIA 3-D MODELING

Activity replication is replicating a human activity that was captured from a human subject in a laboratory. Using human modeling tools (e.g., Blender, 3dsMax, and Maya), human activity modeling includes character building that creates its shape model and character animation that drives the model with the prescribed motion, both of which are associated with a skeleton model of the character. The shape model is defined by the surfaces attached to the skeleton, and the process of attaching surfaces to the skeleton is usually called skinning. The prescribed motion is given by the gross motion (translation and rotation of the whole body) and a sequence of poses that in turn, is defined by the joint angles for each pose. As the skeleton is driven by the prescribed motion, the attached surfaces will move accordingly and deform in a certain pattern which is controlled by specific blending schemes of the tools used.

The scan data of a subject which contains about 800, 000 polygons can be imported into 3DS Max via a skinning process. While this approach can be applied to each individual subject, it is not efficient when a large number of subjects are to be modeled and the final model may be used in a real-time 3D environment. Therefore, a low-poly "performance" template model was built, as shown in Figure 4, which could be aligned to several major landmarks on each subject to be modeled, shaped to the contours of the subject's body, and animated. Various regions of the template model are colored to aid in landmark alignment. The base template model consists of about 3,500 polygons. Depending on the use of the template model, its resolution can be increased to 15,000 polygons. Since the template model needs to describe the body shape not only in a standard pose (Figure 4) but also in various other poses during animation, efforts were made to ensure the template model could provide realistic surface deformation in various poses, as shown in Figure 5.

Figure 4: Template model in a Standard Pose

Figure 5: Template Model in a Bending Pose

After aligning the height, size and position of the template model to several major landmarks on the subject to be modeled, 3DS Max is used to fit or map the low-poly "performance" model to the scan data (Figure 6). A 3DS Max tool, Fit Tools, was created to assist in this process. As such, a larger number of individualized human models can be quickly constructed from their scan data. Figure 7 illustrates a few examples of them.

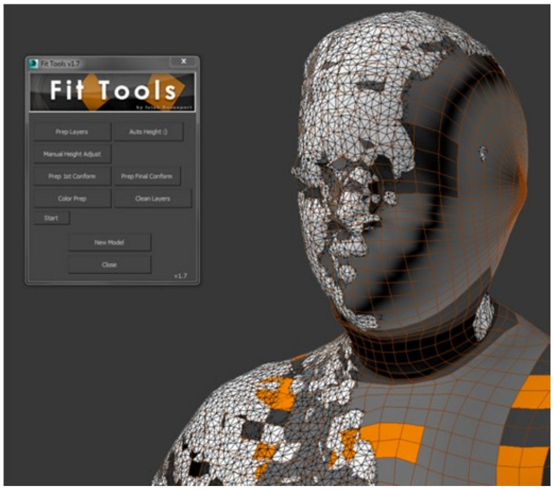


Figure 6: Mapping the Template Model to Scan Data

Figure 7. Individualized Model Constructed via Fitting

The replication of a specific subject's activity is achieved through a character mapping process. The motion capture system records the x-y-z position of each marker placed on the subject's body in a TRaCe (TRC) file format. In MotionBuilder the subject model's limbs, represented as a basic skeletal structure, are mapped to the corresponding marker positions during the initial starting pose of the motion capture session, as shown in Figure 8. As the motion capture markers change position their corresponding mapped limbs move accordingly to create motion in the skeletal structure which creates motion in the subject model.

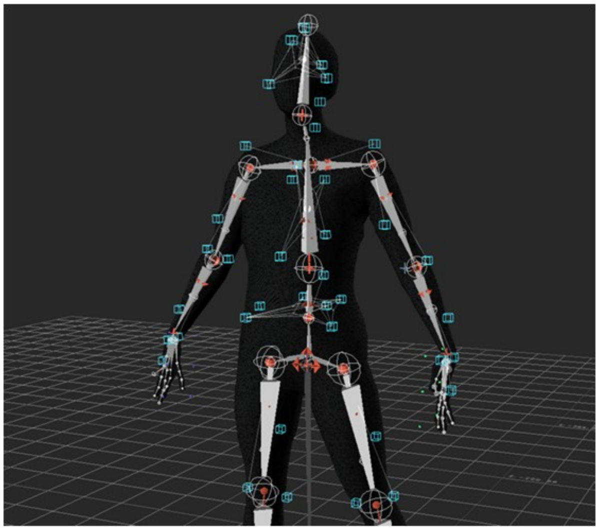


Figure 8: Marker Positioning

In the testing, each subject performed many different activities. During replication, as soon as the shape model is constructed, the same model will be animated using the motion capture data for each different activity. Figure 9 illustrates the replication of a subject in several different activities.

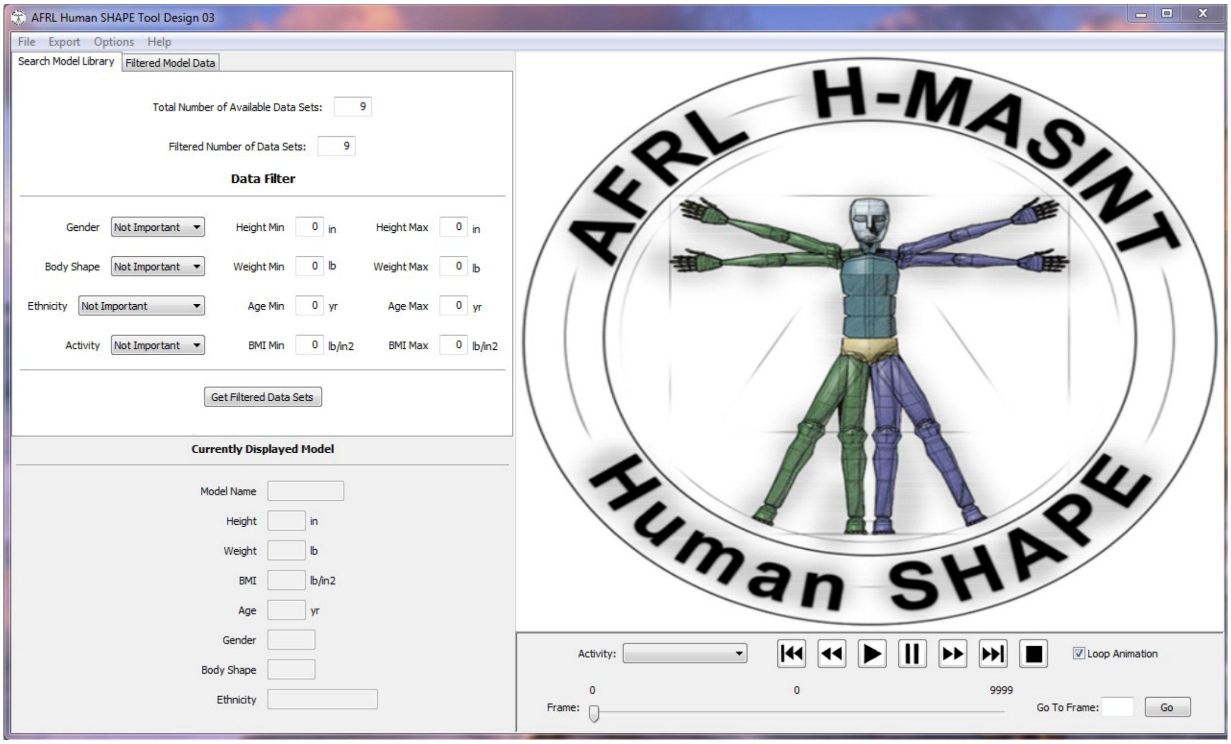
Figure 9: Replication of a Subject in Five Activities

AN ACTIVITY MODEL LIBRARY

Based on the human activity data sets collected at the AFRL's 3DHSL, nearly 100 subject models were built with nine animations for each subject (nine activities). This provides a large collection of human activity models. In order to manage this model collection, a model library with a GUI and basic functions was developed.

The GUI for the library (as shown in Figure 10), named Human Simulated High-Fidelic Activity Production Environment (SHAPE), was built in wxWidgets using a tool called DialogBlocks. WxWidgets is an open-source cross-platform C++ library designed to build applications, and specifically for building graphical user interfaces. DialogBlocks is a commercial off the shelf tool built to design wxWidgets GUIs, for the layouts, spacing, size and types (buttons, text box, etc.) as well as automatically writing code stubs for the GUI framework (such as initialization, callbacks, event handling, etc.). A screen capture of the tool inside DialogBlocks is shown in Figure 11.

The displaying of the models is handled by OpenSceneGraph (OSG), and open-source scene graph Application Programming Interface (API). OpenSceneGraph is a C++ library written to use OpenGL for drawing. In order to get the model out of 3ds Max into the tool, the max model was exported to Cal3d. Cal3d is a skeletal based 3d character animation library written in C++. It is standalone but a NodeKit was written for OSG to load Cal3d models in an osgPlugin. A graphics library was written on top of OSG for SHAPE to handle all of the OSG functionality (creating an OSG window, loading models, changing state, etc.) needed inside of the tool. It was written as a library to separate it from the GUI code. A screen capture of some of the graphics controls is shown in Figure 12.

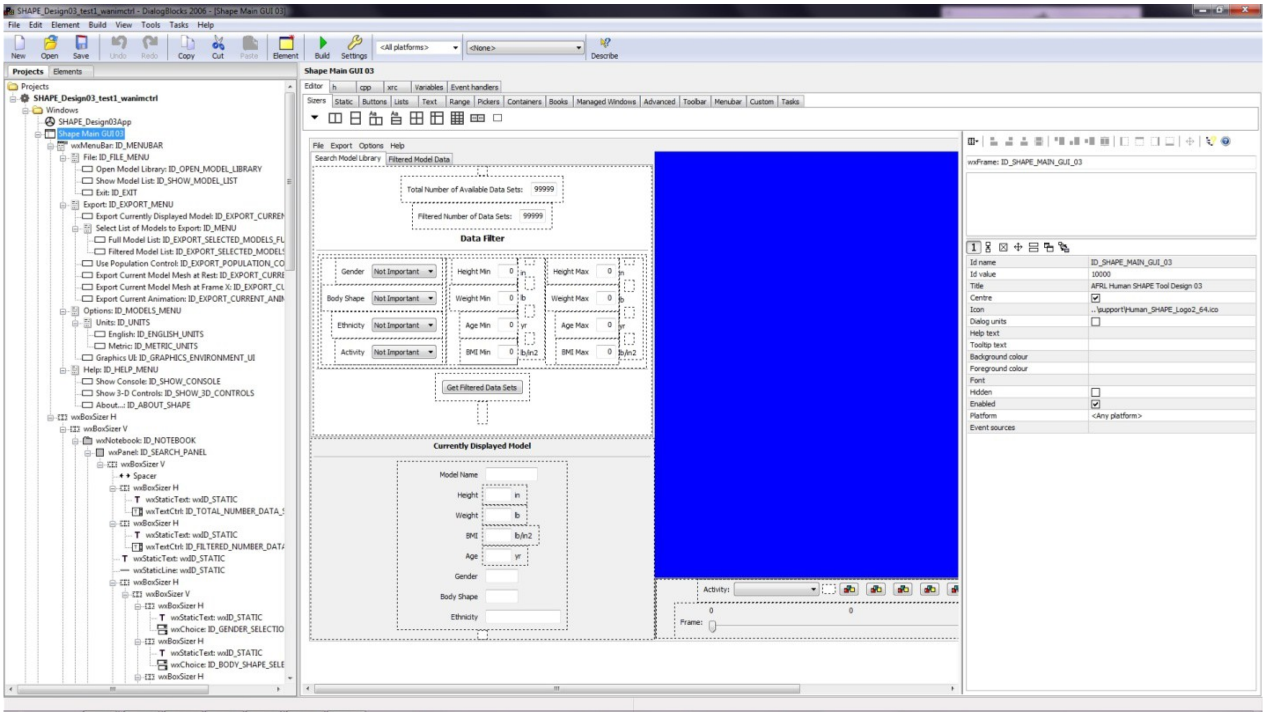


Total Number of Available Data Sets: 9

Filtered Number of Data Sets: 9

Gender	Not Important	Height Min	0 in	Height Max	0 in
Body Shape	Not Important	Weight Min	0 lb	Weight Max	0 lb
Ethnicity	Not Important	Age Min	0 yr	Age Max	0 yr
Activity	Not Important	BMI Min	0 lb/in2	BMI Max	0 lb/in2

Figure 10: Human SHAPE - A GUI for the Model Library



```
Projects
  SHAPE_Design03_test1_wanimctrl
    Windows
      SHAPE_Design03App
      Shape Main GUI 03
        wxMenuBar: ID_MENUBAR
          File: ID_FILE_MENU
            Open Model Library: ID_OPEN_MODEL_LIBRARY
            Show Model List: ID_SHOW_MODEL_LIST
            Exit: ID_EXIT
          Export: ID_EXPORT_MENU
            Export Currently Displayed Model: ID_EXPORT_CURREN
            Select List of Models to Export: ID_MENU
              Full Model List: ID_EXPORT_SELECTED_MODELS_FU
              Filtered Model List: ID_EXPORT_SELECTED_MODELS
            Use Population Control: ID_EXPORT_POPULATION_CO
            Export Current Model Mesh at Rest: ID_EXPORT_CURRE
            Export Current Model Mesh at Frame X: ID_EXPORT_CU
            Export Current Animation: ID_EXPORT_CURRENT_ANIN
          Options: ID_MODELS_MENU
            Units: ID_UNITS
              English: ID_ENGLISH_UNITS
              Metric: ID_METRIC_UNITS
            Graphics UI: ID_GRAPHICS_ENVIRONMENT_UI
          Help: ID_HELP_MENU
            Show Console: ID_SHOW_CONSOLE
            Show 3-D Controls: ID_SHOW_3D_CONTROLS
            About...: ID_ABOUT_SHAPE
        wxBoxSizer H
          wxBoxSizer V
            wxNotebook: ID_NOTEBOOK
              wxPanel: ID_SEARCH_PANEL
                wxBoxSizer V
                  Spacer
                  wxBoxSizer H
                    wxStaticText: wxID_STATIC
                    wxTextCtrl: ID_TOTAL_NUMBER_DATA_S
                  wxBoxSizer H
                    wxStaticText: wxID_STATIC
                    wxTextCtrl: ID_FILTERED_NUMBER_DATA
                  wxStaticText: wxID_STATIC
                  wxStaticLine: wxID_STATIC
                  wxBoxSizer H
                    wxBoxSizer V
                      wxBoxSizer H
                        wxStaticText: wxID_STATIC
                        wxChoice: ID_GENDER_SELECTIO
                      wxBoxSizer H
                        wxStaticText: wxID_STATIC
                        wxChoice: ID_BODY_SHAPE_SELE
                      wxBoxSizer H
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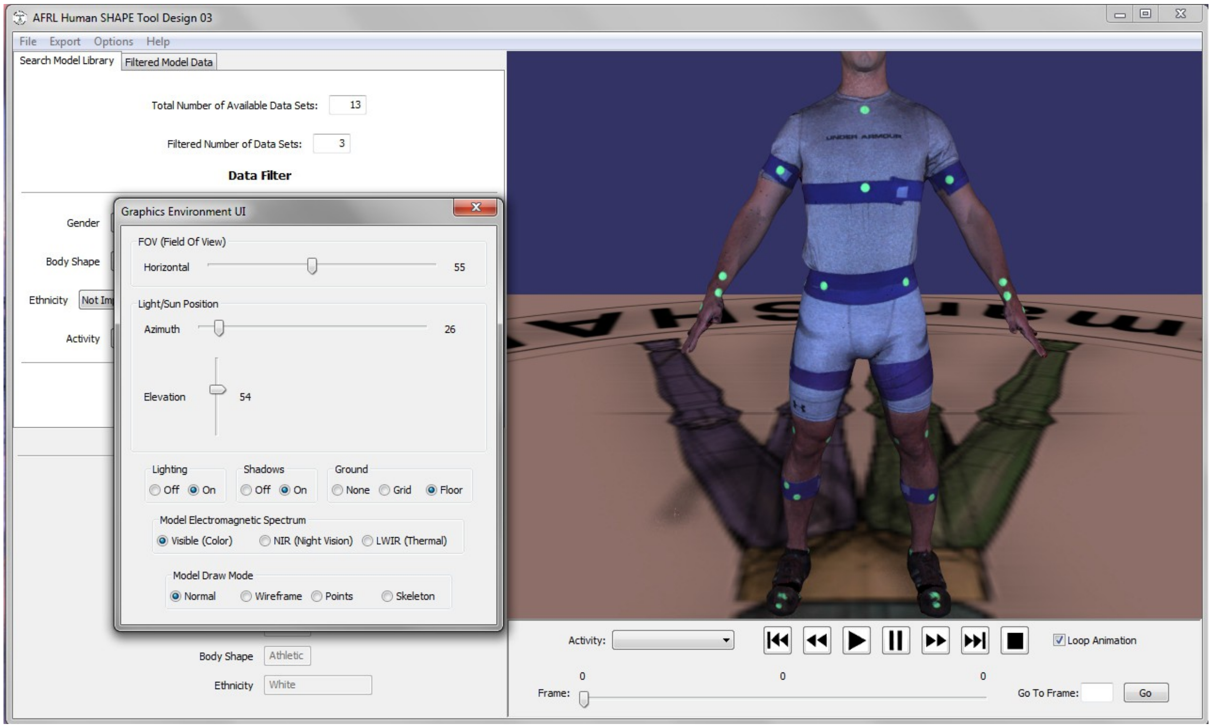
Id value	10000
Title	AFRL Human SHAPE Tool Design 03
Centre	☑
Icon	..\support\Human_SHAPE_Logo2_64.ico
Dialog units	☐
Help text	
Tooltip text	
Background colour	
Foreground colour	
Font	
Hidden	☐
Enabled	☑
Platform	<Any platform>
Event sources	

Figure 11: DialogBlocks Screen Capture



Total Number of Available Data Sets: 13

Filtered Number of Data Sets: 3

Body Shape

Ethnicity Not Im

Horizontal 55

Azimuth 26

Elevation 54

Lighting ○ Off ● On

Shadows ○ Off ● On

Ground ○ None ○ Grid ● Floor

Model Electromagnetic Spectrum ● Visible (Color) ○ NIR (Night Vision) ○ LWIR (Thermal)

Model Draw Mode ● Normal ○ Wireframe ○ Points ○ Skeleton

☑ Loop Animation

Body Shape Athletic

Ethnicity White

Frame: 0 0 0

Go To Frame:

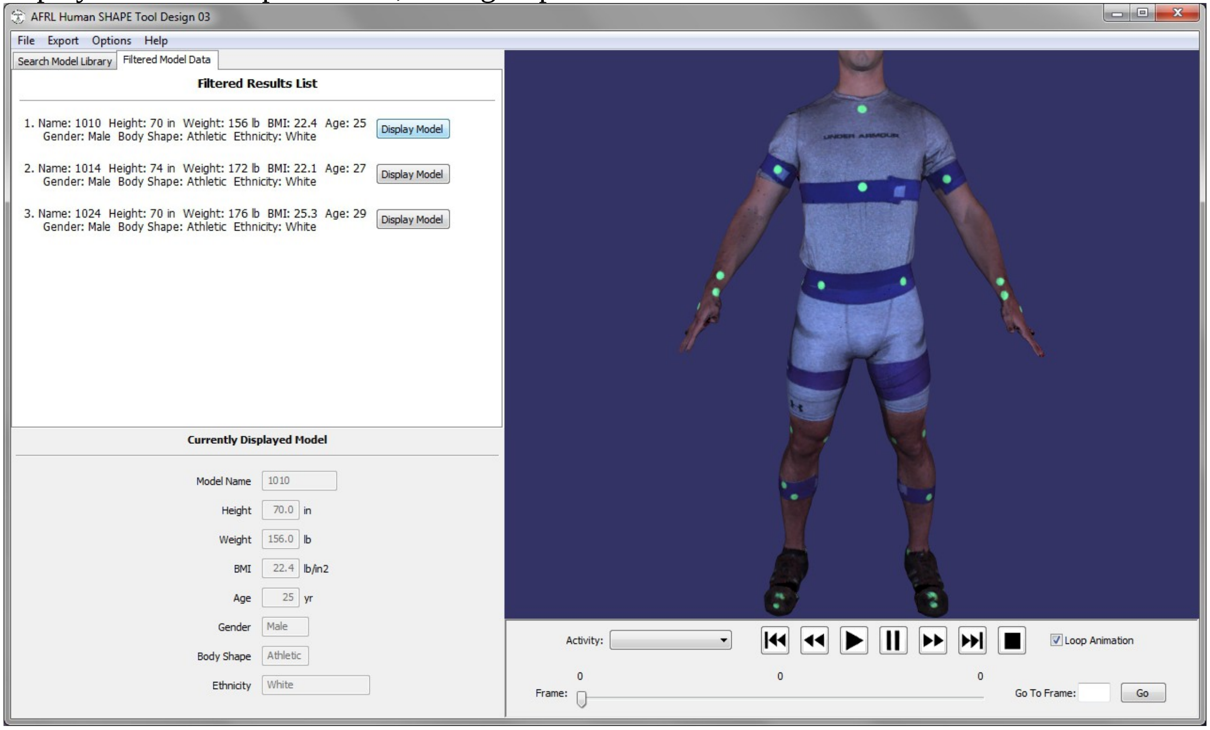
Figure 12: Graphic Controls within the GUI

The information inside the library for different models was written as a simple American Standard Code for Information Interchange (ASCII) text configuration file. The configuration file contains all the model paths, and the anthropomorphic data for that model (such as height, weight, age, etc.). Each model has a simple configuration file that lists the models activities (animations) as well as a simple name and the actual Cal3d model name.

The Human SHAPE tool allows for the existence of multiple model libraries, and through the GUI different model libraries can be loaded. Once a model library is loaded all of the anthropomorphic data is loaded into a map so that searching and filtering can be done on the data. The search criteria available are: gender, body shape, ethnicity, activity, height (min and max), weight (min and max), and age (min and max), and Body Mass Index (BMI) (min and max).

Any combination of the criteria can be entered (from one item to all items) and the tool searches based on whatever is entered. If all data is entered, each criterion is searched for and the data is filtered in the following order (from first to last): gender, body shape, ethnicity, activity, height, weight, age, BMI. For the first four items it is an exact match only, the rest are ranges for the data to fall in (and in the case of just a min entered, then anything greater than that min, the opposite with just a max entered). The matching model or models are then displayed in the “Filtered Model Data” tab, along with all of the corresponding anthropomorphic data for the model(s). A screen capture of filtered data is shown in Figure 13.

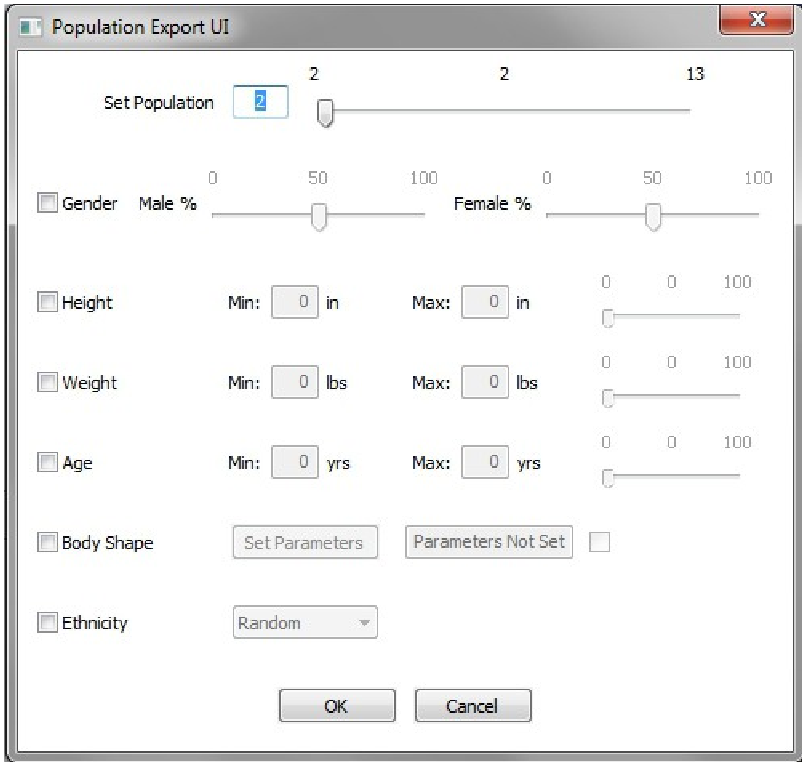
A selected model, or a set of models, can be exported out to different Image Generator (IG) formats. The IG formats available are SubrScene, NVIG, CryEngine, and MetaVR. Unfortunately at this time, the exported data is not created on the fly, rather it is all exported out of 3dsMax ahead of time with plugins from the respective IG developer companies. However SubrScene and NVIG natively support Cal3d so they require the least amount of time and effort to export and prep for SHAPE. The selection of the model or models to be exported can be done in several ways. The single model being displayed can be exported out, or a group of models can be selected from a model list for export, or the population control can be used, which is similar to the data filter to select a group of models based on the anthropomorphic data (instead of just model names). The Population Control GUI is shown in Figure 14.



1. Name: 1010 Height: 70 in Weight: 156 lb BMI: 22.4 Age: 25
Gender: Male Body Shape: Athletic Ethnicity: White
2. Name: 1014 Height: 74 in Weight: 172 lb BMI: 22.1 Age: 27
Gender: Male Body Shape: Athletic Ethnicity: White
3. Name: 1024 Height: 70 in Weight: 176 lb BMI: 25.3 Age: 29
Gender: Male Body Shape: Athletic Ethnicity: White

Model Name 1010
Height 70.0 in
Weight 156.0 lb
BMI 22.4 lb/in2
Age 25 yr
Gender Male
Body Shape Athletic
Ethnicity White

Figure 13: Illustration of the Searching Results



Set Population 2

☐ Gender

☐ Height Min: 0 in Max: 0 in

☐ Weight Min: 0 lbs Max: 0 lbs

☐ Age Min: 0 yrs Max: 0 yrs

☐ Body Shape ☐

☐ Ethnicity Random

Figure 14: Searching Criteria Selection

☑ Loop Animation

Figure 15: Animation Control

Also built into the Human SHAPE tool is an animation control. The animation control has Video Cassette Recorder (VCR)-like controls with buttons such as play, stop pause, fast-forward, etc. Once the activity is selected a slider bar with numbers displays the number of frames in the animation, as well as the current frame being displayed. This slider bar is updated as an animation is played, as well as when the mode is fast-forward, rewind, or pause. The control also has a go to frame function, which jumps to a specific frame in the animation. The animation control is illustrated in Figure 15.

BIOFIDELITY AND VARIABILITY

Biofidelity

The biofidelity of human activity modeling relies on true body shape and true body motion. Software tools such as MakeHuman (http://www.makehuman.org/, a free software tool) are now available to create various generic human shape models with input parameters for gender, height, weight, etc. While these human shape models provide a realistic, graphical description of human body shape, they are often not able to depict the unique features that are associated with an individual or with a particular racial or ethnic group and thus lack the desired biofidelity.

With advances in surface digitization technology, a 3-D surface scan of the whole body can be acquired in a few seconds. Whole body 3-D surface scans provide a very detailed capture of the body shape. Based on body scan data, human shape modeling with high biofidelity becomes possible (Allen et al., 2002 & 2003; Azouz et al., 2005). The model built from a human body scan data provides highly bio-fidelic, detailed body shape information of the individual.

One method of motion creation is to create several key poses (frames) and then to fill the gaps between those key poses via interpolation. This approach is often used by game developers. The created motion is based on human imagination and thus lacks realism and biofidelity. Alternatively, using motion capture system to record a human motion and then using captured motion to animate the model of same subject, the true motion is fused with the true shape, thus providing high biofidelity to the activity modeling.

Variability

The model library built on the data sets collected at the AFRL's 3DHSL provides a larger variability of human activity modeling in both human shape and motion. The variability can be further expanded by human shape morphing and human motion mapping.

- ***Morphing***

As soon as the point-to-point correspondence is established among shape models (which have been attained in this study), one shape can be gradually morphed to another by interpolating between their vertices or other graphic entities. In order to create a faithful intermediate shape between two individuals, it is critical that all features are well-aligned; otherwise, features will cross-fade instead of move. Figure 16 illustrates an example if shape morphing from one male subject to a female subject (Cheng et al, 2009). Using morphing, new models can be created that resemble to the models being morphed and still provide high biofidelity.

- ***Motion Mapping***

It is desirable to map the motion from one subject to another, because it is not feasible to do motion capture for every subject and for every motion or activity. By assuming that different subjects will take the same key poses in an action or motion, one approach is mapping joint angles from one to another, as shown in Figure 17 where motion is mapped onto 3dsMax biped models (Cheng et al, 2012). Note that since the pelvis is usually treated as the reference segment, the hip joint center vertical location needs to be adjusted to reflect the variation of subject size in order to ensure appropriate contact between the feet and the ground. While motion mapping may be fairly natural and realistic, it may not be able to provide sufficiently high biofidelity, because the differences between human bodies and the interaction between human body and boundaries are ignored.

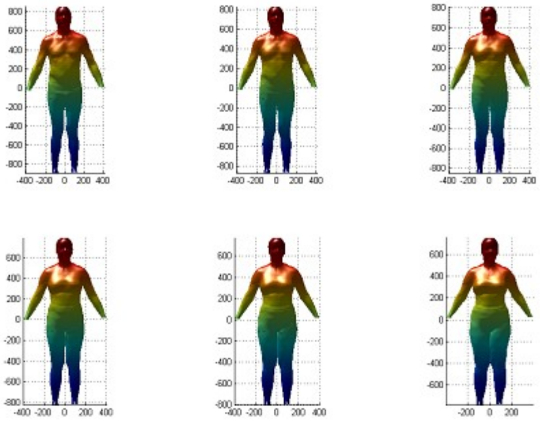


Figure 16: Morphing from One Subject to Another

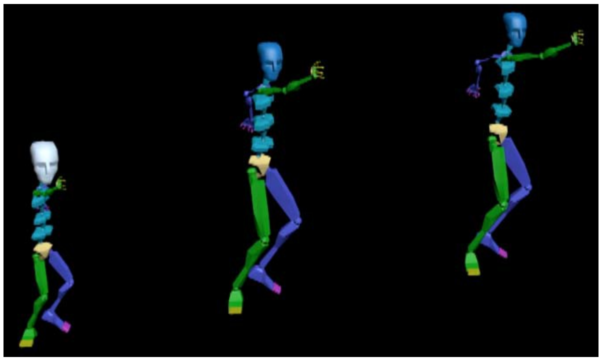


Figure 17: Mapping the Captured Motion into a Group

CONCLUSIONS

Biofidelity is a critical factor when human activity M&S is used in a virtual reality or training system that is human centered. In order to attain high biofidelity, a concerted effort was made in this paper from human shape and motion data collection and data processing to shape modeling and animation. The data-driven human activity models created in this paper can be incorporated into highly fidelic 3-D scenario models to provide natural and realistic exposure and experience to trainees/users.

Variability is often desired by the user community to meet their particular needs for the M&S of human subjects and human activities. Based on the data sets collected from 100 subject performing nine activities at the AFRL's 3DHSL, the model library built in this paper provides a large variability of both human shape and human motion. The variability can be further expanded by shape morphing and motion mapping.

While data-driven modeling allows us to create human activity models with high biofidelity and large variability, it is not feasible to collect data for every subject and for every activity. Therefore, it is necessary to develop technologies for creating activities. Activity creation relies on dynamic shape modeling and motion creation, for which further investigations are needed to overcome technical obstacles.

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ACRONYMS

3DHSL	3-D Human Signatures Laboratory
AFRL	Air Force Research Laboratory
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BMI	Body Mass Index
B.S.	Bachelor of Science
GUI	Graphic User Interface
H-MASINT	Human Measurement and Signature Intelligence
IEEE	Institute of Electrical and Electronics Engineers
IG	Image Generator

MBA	Masters of Business Administration
M&S	Modeling and Simulation
NVIM	Night Vision Image Generator
OSG	OpenSceneGraph
SHAPE	Simulated High-Fidelic Activity Production Environment
TRC	TRaCe
VCR	Video Cassette Recorder
VR	Virtual Reality
VRSG	Virtual Reality Scene Generator