Digital Humans and Electromagnetic Motion Capture

Kyle J. Nebel
Development Business Group, U.S. Army TACOM

Andrew Yee
Advanced Development Group, Delphi Automotive Systems

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
15 MAR 2004	**Journal Article**	**07-01-2004 to 19-03-2004**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Digital Humans and Electromagnetic Motion Capture	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Kyle Nebel; Andrew Yee	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Delphi Automotive Systems,1624 Meijer Drive,Troy,Mi,48084	**; #13987**

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000	**TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **#13987**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This paper discusses the cooperative research and development work between Delphi Automotive Systems (formerly known as Delphi Interior & Lighting Systems) and the U.S. Army TACOM/TARDEC. Discussion will focus on past work and the evolution of the approaches currently being used by TARDEC and Delphi for digital human animation, real-time human interaction (man in the loop), and motion data library development, as it relates to TACOM/Delphi?s electromagnetic motion capture systems and the Engineering Animation Incorporated (EAI)-Jack ergonomic analysis/animation software.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**12**	

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.
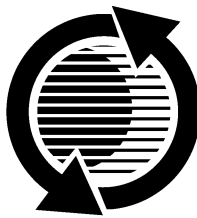
GLOBAL MOBILITY DATABASE

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

Digital Humans and Electromagnetic Motion Capture

Kyle J. Nebel
Development Business Group, U.S. Army TACOM

Andrew Yee
Advanced Development Group, Delphi Automotive Systems

ABSTRACT

This paper discusses the cooperative research and development work between Delphi Automotive Systems (formerly known as Delphi Interior & Lighting Systems) and the U.S. Army TACOM/TARDEC. Discussion will focus on past work and the evolution of the approaches currently being used by TARDEC and Delphi for digital human animation, real-time human interaction (man in the loop), and motion data library development, as it relates to TACOM/Delphi's electromagnetic motion capture systems and the Engineering Animation Incorporated (EAI)-Jack ergonomic analysis/animation software.

INTRODUCTION

TACOM and Delphi Automotive Systems have been working together on a joint research effort where the use of motion capture hardware has been applied towards the scripting of anthropomorphically correct digital humans to evaluate digital mock-ups in a computer generated synthetic environment. The focus of this research was to address the lack of digital human capabilities that are necessary for an operator, maintainer or trainer to accurately evaluate the performance requirements (i.e., human factors, maintainability, etc.) of a digital mock-up using today's state-of-the-art modeling and simulation tools.

The system used by Delphi consists of a one-wall CAVE (CAVE Automatic Virtual Environment), an Ascension motionstar electromagnetic motion tracker, and EAI-Jack ergonomic simulation/analysis software. At the U.S. Army TACOM, the systems include a Virtual Research V8 Head Mounted Display (HMD), an Ascension Flock of Birds (FOB), motion tracker, including 10 position sensors (i.e. birds), and the EAI-Jack software.

Initial discussion will focus on the electromagnetic motion capture hardware setup and configuration at the two organizations. The problems with electromagnetic devices associated with these specific configurations, discovered, as part of this joint research will be discussed. For example, the differences in the optional

Serial vs. Ethernet configurations for communicating with the motion tracker can be a source of problems. This paper will then focus on the digital human, the sites used to constrain/control the human, the minimum number of sites required to generate motion data files, the site orientation/position/offset (i.e., sites selected on the digital human constrained by the position sensor which define the digital human's motion), and the pros and cons of using a minimum number of position sensors. Finally this paper will discuss the motion data file generated as a result of a motion capture session (i.e., the types of files that can be generated, and the associated motion data format.). The conclusion will address areas that need future development and new trends in motion tracking.

DIGITAL HUMANS AND ELECTROMAGNETIC MOTION CAPTURE

THE FOCUS – Manual scripting of digital human avatars has been, and still is the norm, when developing animations of maintenance, manufacturing, and automotive cockpit operations, for both TACOM and Delphi. The problem associated with this approach is that the digital human motion developed through manual scripting, is an approximation of actual human motions required to accomplish the task and results in rigid, robot like interactions of the digital human with the virtual environment. This scripting is very time consuming, with the time required to develop an animation increasing as the number of the human joints involved increases. These animations are able to satisfy the initial, or base requirement, of digitally imitating rough human interaction within a virtual world, but in order to fully analyze the human factors effects of an entirely digital concept on the human as the end user, greater accuracy is needed. How the digital human interacts with the digital model, needs to mimic the actual motions that would be used in the real world, to analyze such human aspects as reach, posture, lifting, comfort, vision, in the digital development of the human interface.

ELECTROMAGNETIC MOTION CAPTURE – There are basically two types of electromagnetic motion capture systems available today: the AC magnetic currently

produced by Polhemus, and the pulsed DC sold by Ascension. The discussion will focus on the use of the Ascension system with the EAI–Jack software environment as it relates to this joint research program. Basically an electromagnetic motion capture system consists of a transmitter, a transmitter controller, N number of sensors, and a Central Processing Unit (CPU) (figure 1). The CPU calculates the position and orientation of the sensor or bird, based on the bird's reaction to the electromagnetic field generated by the transmitter, and then passes this data on to the host computer where the motion data is being displayed.

Figure 1.   Ascension MotionStar and Flock of Birds systems

The Ascension Extended Range Transmitter (ERT) is a one-foot square black box, and generates an 8 to 10 foot radius electromagnetic field, that could be categorized as a hemispherical region where motion capture occurs (figure 2).
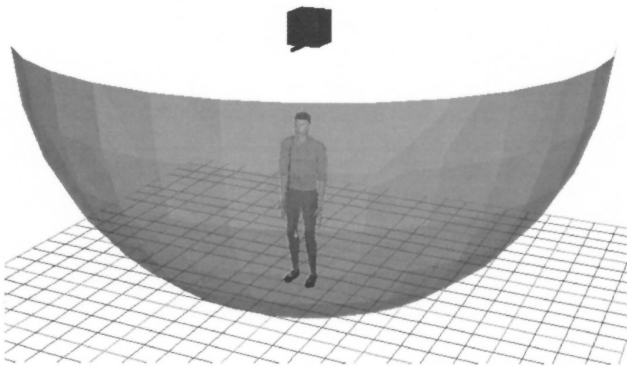

Figure 2.   Lower Electromagnetic ERT field hemisphere

There are six possible hemispheres that you can select for your motion capture region, and this will control how you place your transmitter (i.e., forward, rear, right, left, upper and lower). The default hemisphere for motion capture within the EAI-Jack environment is the front hemisphere (figure 3). The front region should be an adequate configuration for most motion capture sessions. Until recently, there were two modes of operation for the transmitter: normal and extended addressing, with the recent addition of the super-expanded addressing. A little known fact about the first two modes is the mode's effect on the electromagnetic field strength. Under normal addressing mode, the electromagnetic field strength is varied with respect to the proximity of the closest sensor and allows the bird to come right up to the transmitter. The problem is that the field strength is

weaker for the birds farthest away. For the expanded addressing mode, the field strength is a constant but the sensor cannot get closer than a two-foot radius.
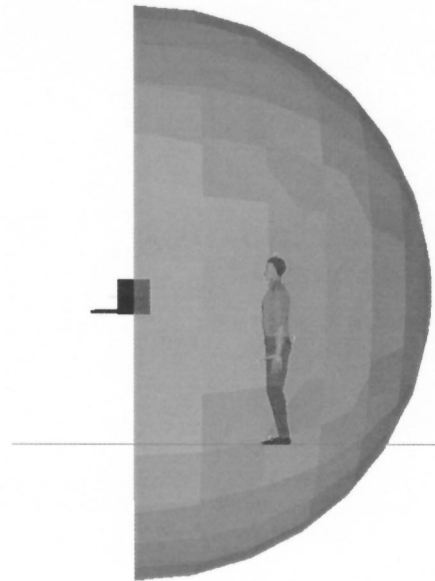

Figure 3.   Forward hemisphere configuration

Field Integrity and Virtual World Interaction – There are many factors that can affect the field integrity of an electromagnetic motion capture system. The most obvious is the presence of ferrous metal within the field envelope. As a result of this handicap, physical mock-ups must be fabricated using alternative materials, like wood, composites, or nonferrous metals. These mock-ups are only necessary when attempting to develop motion files for a specific process that will later be used as a basis for a digital human factor case study. Another alternative is to digitally mock up the devices in a virtual world and use an HMD to view the virtual environment. The problem with this scenario is that it is not possible to realistically interact with (i.e., grab and release), the virtual objects associated with the process being studied. One approach that has been used successfully consists of the instrumentation of the actual object with a position sensor that constrains the digital model with the associated sensor icon, such that the position and orientation in the virtual world mimics that of the real world. By paying close attention to the placement of the electromagnetic transmitter and its relationship to the objects in the virtual world, one can minimize distortion, resulting in extremely accurate motion capture data. Other factors that can affect field integrity are: the proximity of fluorescent lighting to the transmitter, power distribution boxes within the field, steel-reinforcing rods in the floor if it is a concrete slab, and performing motion capture at the limits of the electromagnetic field. An example of where you would see problems with the electromagnetic field limit would be with a CAVE (figure 4), where the transmitter is elevated as a result of system requirements.
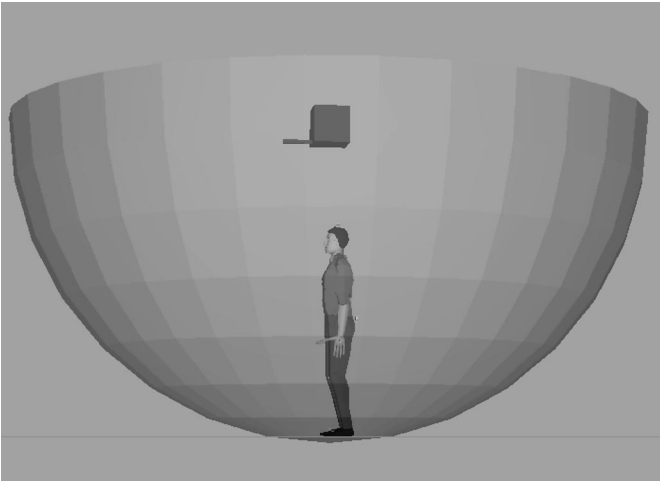
Figure 4.   Electromagnetic field within a CAVE environment

The major problem with this configuration is that the lower human extremities are already at the field limits, and as you move out from under the transmitter, the sensors are outside the maximum radius for the field. Factors like steel-reinforcing rods can be a major factor for field distortion, for these configurations, when built directly on concrete slabs. Distortions in actual position have been observed (figure 5), for this type of configuration, where the birds drift to one side as you move from the head down to the feet.
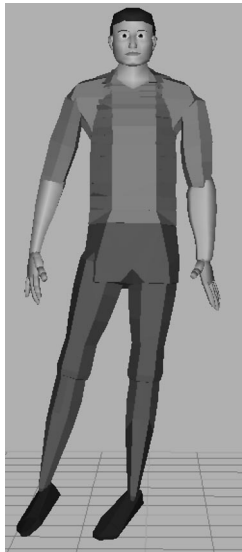

Figure 5.   Sensor position distortion at the feet closest to the field radius

Using an elevated floor with a two-foot height, when possible and using the materials mentioned earlier can minimize this distortion. Also, selecting areas for motion capture with high bay ceilings can reduce the effects of fluorescent lighting. Another option is just turning the lights off over the transmitter.

IMMERSION – By using the resources at the two organizations it was possible to evaluate the differences in viewing the digital human in a CAVE configuration, as opposed to that of an HMD. It needs to be mentioned here that EAI-Jack does not run in a CAVE, but the Delphi system allowed the evaluation of motion capture in this type of motion capture configuration, by using the back wall as a large monitor.

CAVE Automatic Virtual Environment – As mentioned previously, the CAVE configuration has problems with distortion of the position and orientation for the sensors closest to the maximum radius of the electromagnetic field. These problems can be ignored when the motion capture scenarios are only concerned with the digital humans' upper torso, as would be the case for processes where the digital humans' tasks were fixed at one location or station. When viewing a task in a CAVE configuration, there are two potential modes of operation. The first mode is that of first person perspective. Virtual objects in this mode appear life size and are positioned around you, as you would expect in the actual environment. The problem is the alignment of the digital human appendages, as in putting on a virtual suit. One solution is to turn the digital human display off, and capture the motion for later playback/analysis. The next mode is that of viewing the virtual world from a third person perspective. This approach has been the primary method used during motion capture sessions onsite at Delphi. The benefit here is in the ability to step back from the scene and view the digital environment as a whole during a capture session. By looking at the virtual environment in this manner it is immediately possible to judge the success or failure of the capture session, and visually identify problem areas with the motion data. This mode has the added benefit of allowing multiple people to view previously recorded sessions for case studies like a design review, or Integrated Process/Product Teams (IPT).

Head Mounted Display – The use of an HMD (figure 6) provides the ability to literally look at the world through Jack's eyes. In order to accomplish this you may use the Multi Channel Option (MCO) installed for a Silicon Graphics (SGI) ONYX, or have the newer SGI ONYX-2. The SGI ONYX-2 provides the ability to selectively identify and output regions of the monitor to specific graphic ports. Having met these constraints, cameras can be attached to sites located on both the right and left eye of the Jack figure, moving with the Jack figure in the virtual environment, generating the view perspective for each eye in two separate windows. By controlling the output display of these windows to the different projectors in an HMD, realistic stereo images can be generated, only limited by the resolution of the HMD used, and the texturing capabilities of the software.

Figure 6.   Virtual Research V8 Head Mounted Display

Extreme caution needs to be exercised when using an HMD for a full body motion capture session. This is primarily due to the potential for tripping and/or falling, resulting from the tethers used to attach the sensors to the CPU catching or snagging on sharp objects. Therefore, the use of an HMD is recommended for situations where the operator is fixed or stationary, as in crew-station evaluations.

Communication: Ethernet vs. Serial in EAI-Jack – The rate at which you can capture motion data, i.e., frames per second (fps), is directly related to the available baud rate. Under the Serial configuration, for a standard Unix operating system the maximum baud rate for the Serial port is 38,400 bits per second (bps). Frame rates around 4 fps have been seen using this configuration at both TACOM and Delphi. Comparing this to the standard frame rate for animation of 30 fps one can see that a considerable amount of data is being dropped. Ethernet has the potential to increase the frame rate, with the baud rate limited only by the network bandwidth. This has not been tested due to hardware constraints. One potential problem is that by increasing the capture frame rate you also increase the size of the motion data file, to be discussed later. Also, when using a Serial configuration within the EAI-Jack environment, Ascension treats the Transmitter as bird 1, even though there is no position sensor attached to this station. In Jack this can cause confusion, for example in a ten-bird setup, you must specify 11 birds in the FOB Graphic User Interface (GUI). What this means is that birds 2 through 11 are the only birds generating position and orientation data. Therefore, care needs to be exercised in the placement of the bird on the digital human, making sure that the real bird placement corresponds to the virtual world placement. This problem does not exist with the Ethernet configuration in Jack.

DIGITAL HUMAN SETUP WITHIN THE VIRTUAL ENVIRONMENT

Electromagnetic Transmitter Location – The electro-magnetic transmitter, as well as the motion sensors (or birds), explained previously, have corresponding icons representing them in the virtual environment. The rela-tive distance between the physical transmitter and the physical motion sensors corresponds to the relative dis-tance between the virtual transmitter icon and the virtual motion sensor icons in the virtual environment. When the virtual transmitter icon is moved in the virtual environ-

ment, the virtual motion sensors also move, but the rela-tive distance between them remains the same. The lower portion of figure 7 shows that the location of the electromagnetic transmitter (black cube in lower left) remains fixed, however, the virtual electromagnetic trans-mitter icon (red cube on left side of upper portion of figure 7) can be moved within the virtual environment.

Figure 7.   Sensor Relationship to Transmitter,
                  Real vs. Virtual

This movement of the virtual transmitter icon is useful because motion capture for different environments can be done without physically moving to different locations. The virtual transmitter icon can be moved to any position in the virtual environment and motion capture can take place because the virtual sensor (or virtual bird) icons move in relation with the virtual transmitter. In this case, when the physical sensors are attached to the object to be tracked, the virtual sensors are in the appropriate location in the virtual environment, as determined by the location of the virtual electromagnetic transmitter icon. When the virtual electromagnetic transmitter icon is moved to another location within the virtual environment, the virtual motion sensor icons, or bird icons, also move to their respective new location. In the case of motion capture, the digital human model and virtual objects which represent the physical human and physical parts being tracked with the motion sensors also move to a new location within the virtual environment. This essentially accomplishes a digital human movement from one location in the virtual world to another location without making the motion-tracked human move in the physical world.

As an example, suppose a human needs to work on a part at three different workstation areas. In the case where motion capture is used to track a human and a physical part, three separate physical workstation areas would have to be designated to accommodate human movement between each work area. If, however, we take advantage of the fact that the virtual electromagnetic transmitter icon can be moved within the virtual environment, then each motion capture session at each workstation can be accomplished without physically

4

moving in the real world. By relocating the virtual transmitter icon, the virtual motion sensors, which are attached to the virtual human and virtual part, also move. Again, maintaining the real world position and orientation relationships of the transmitter to the sensors. The virtual human and virtual part can now be relocated to each workstation area, while the motion-tracked human in the physical world stays stationary. The physical human can now perform the operations on the physical part while standing in the same physical location for all three workstation areas. The virtual human and virtual parts are repositioned at each of the three virtual workstation areas simply by relocating the virtual transmitter within the virtual environment. When the motions of the human and part are captured, the motions applied to the virtual human and virtual part in the virtual simulation environment take place at the desired locations. In this example, the captured motions, applied to the virtual human and virtual part, will playback at each of the three workstation areas, even though the physical human did not physically move to another workstation area during the separate motion capture sessions.

Site Position & Orientation, Constraining vs. Constrained – From doing simple motion capture, in EAI-Jack, just controlling the head for viewing the virtual world using an HMD, to generating data for the whole digital human body, there are just two sites to be concerned with for each segment controlled. These are the base sites associated with each segment, the base site for the sensor (Constraining) and the base site associated with the controlled segment (Constrained). For example, figure 8 displays both the base site for the FOB sensor and the base site for the controlled right palm segment.
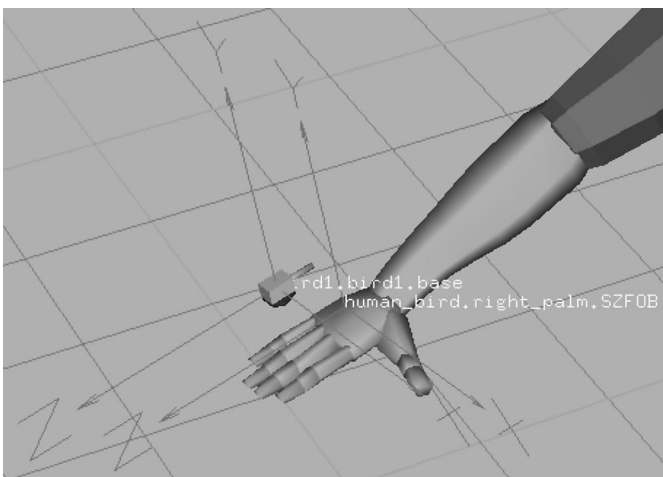

Figure 8.   Position Sensor (Constraining) vs. Digital Human Hand Site (Constrained)

Notice that the coordinate systems for both sites are identical in orientation. If this were an actual motion capture session the position for both would also be identical, the position has been offset for the purpose of clarity. The key point here is that the site controlling each segment should duplicate as close as possible the actual relationship of the attachment of the FOB sensor on the

real human appendage for which motion data is being generated. At this point it should be obvious that the sites provided on the Jack digital human should be adjusted to reflect the positioning that results from the different harnesses used to attach the sensors. By doing this the researcher can control the site positions, specifying key ergonomic markers, increasing data accuracy and worth for later model validation.

Site Placement, How Many Sensors Do You Need – The EAI-Jack digital human currently provides 11 sites as attachment points for motion sensors (figure 9), with the sensors attached as per the discussion in the previous section (i.e. two on the feet, two on the knees, one on the pelvis, two on the hands, two on the elbows, one on the base of the neck, and one on top of the head). All of these sites, while available, do not have to be used when capturing motion data, due to the fact that Jack has the ability to generate postures for those segments not constrained by sensors. It is also possible to create more sites to be used during a capture session, but at present there does not appear to be a need. For the ten sensor configurations used at both organizations, a minimum of six sensors has been used successfully. By attaching sensors to the feet, the pelvis, the hands, and the head, motion data files have been captured where the position data for each segment is within ± 3 inches, for those segments not constrained.

Figure 9.   Digital Human Motion Sensor Attachment Points

While these postures do not exactly match the human motion, it has been close enough for the work being done. The benefit from reducing the number of sensors used to capture the human motion is that these sensors are now available to attach to physical parts where interaction in the virtual world is desired. Attempts have been made to capture, first, the human motion for a specific process and/or task, then the object motion for the part being manipulated, and then combining this motion in the final animation. Anyone that has ever attempted this can verify the difficulty of duplicating three-dimensional paths during two separate motion capture sessions. The resulting animation is like a race with the objects leaving and arriving at different times, speeding up, slowing down, while following slightly different paths. On the other hand, by using more sensors to control the digital human motion, the calculations required to determine postures are reduced if not entirely eliminated. This increases the accuracy of the digital human motion data and reduces the latency seen between the actual digital motions as compared to the real motion. Latency is the difference between the digital human motion and the real human subject's motion, when viewed simultaneously, with the digital motion lagging behind the real motion by a fixed amount. This problem tends to be more apparent when using an HMD configuration over that of a CAVE. Both approaches have their benefits and the decision of which approach to use should be based upon the ultimate goal of the motion capture session. The ultimate goal for a motion capture session can fall into two possible categories: either greater digital human motion accuracy, required for human factors studies, or digital human interaction with virtual objects, when realistic process animations are required.

Controlling the Head – In the early phase of the program, problems were encountered that involved how the head reacted to being directly constrained by a sensor. Usually the reaction of the head produced postures where the head rotated 90 degrees about the vertical or lateral (side to side) axis. Needless to say the motion generated during these initial sessions was humorous but not very productive. One approach developed as an alternative to constraining the head was to use the ability to force the Jack figure to fixate on an object. To accomplish this, a script file was developed that placed an object in space relative to the sensor at a specified offset in front of the Jack figure, attached the object to the sensor, and forced the figure to fixate on the object (figure 10). It needs to be mentioned that the sensor that the cube was attached to, is the sensor attached to the head, thus tracking where the head looks. This approach solved all problems previously experienced in constraining the head during a motion capture session. The object used as the fixation goal can also be turned on and off during a motion capture session, providing a realistic viewing experience. The resulting head motion only has one problem, this is when

the subject attempts to look straight down, as in looking at your feet in a standing posture. The problem seen is that the head tends to lean on the right shoulder while looking down.

Figure 10. Digital Human Head Set to Fixate on One-Inch Cube

MOTION DATA FILE FORMAT, CHANNELSETS – As discussed in the document "JACK/TTES: A System for Production and Real-time playback of Human Figure Motion in a DIS Environment" [2], a channel is defined as storage for any time-varying parameter. A channelset and a sharedchannel hold the same data as a channel, except they are not bound to a specific object. A channelset organizes a set of sharedchannels together, giving them a name and three other parameters we will discuss later. A sharedchannel, which is subject to the channelset parameters, introduces three more parameters and contains the entire motion data, in a frame format (i.e., N number of frames at a frame rate of so many frames per second).

Channelset File Naming Convention – Channelset files in the EAI-Jack environment are one method of storing motion data resulting from a motion capture session. The problem with the channelset file is the naming convention, specifically the file extension required when saving the data to your hard drive. Channelset motion data files use the ".env" (environment) extension. Anyone that is familiar with EAI-Jack file types knows that the ".env" file is primarily used when building the virtual world (i.e., locating objects, attaching textures, defining colors, etc.). This can be confusing, if the user does not include "motion" in the file name when saving motion data, and should be used as a standard operating procedure for naming motion data files.

Channelset Motion Data File Types – There are three basic types of channelset motion data files that can be saved when doing a motion capture session. They are: human motion data, object motion data, and a combination of both human and object motion data. The difference between the human and the object motion data is that besides capturing the position and orientation for the root site, the digital human file also contains all of

the joint angles for the 68 joints defined in the EAI-Jack digital human. These 68 joints are included in the channelset file as 68 sharedchannels, which will be discussed later.

Channelset Motion Data File Syntax – Channelset Motion data files are ASCII text based. The benefit here is that the file can be viewed, edited, and position data can be extracted, by using a standard ASCII text editor. The first line of a channelset file defines the channelset name. Later, during animation development, in the EAI-Jack animation system module, this is the name that appears on the pull-down menu for "select channelset", when using the "creating channelset motion" (1) command. The open bracket ({) defines the beginning of the channelset data, with the close bracket placed after the last line of data contained in the channelset file.

$$\text{channelset Channelset\_Data\_Name \{} \qquad (1)$$

The next three lines of a channelset file, define the three parameters mentioned earlier. These parameters are either specified during the setup for the motion capture session or are generated as a result of the system hardware configurations. The parameters are as follows: the number of frames stored in each sharedchannel in the set (2), the frames per second (fps) that the set was saved at during the capture (3), and the number of shared channels in the set (4). The semicolon informs the motion data parser that information follows, and is included on every line of motion data up to the last line. The motion data parser is internal to the EAI-Jack environment and interpolates the frame data and binds the specific joints contained in a channelset file to the selected digital human prior to playback.

$$\text{size = 28;} \qquad (2)$$

$$\text{fps = 3;} \qquad (3)$$

$$\text{count = 68;} \qquad (4)$$

One problem experienced with the playback of the channelset file results from the difference in the default playback of 30 fps to the rate of capture. Usually around 4 fps for a Serial configuration and baud rate around 38,400 bps. EAI-Jack has been working to solve this problem, and is looking at approaches that will provide the user with the flexibility to vary the rate of playback. Now that the parameters for the channelset file have been set, the next line in the file specifies the first sharedchannel (5). If this is an object motion channelset file, this will be the only shared channel. If this is a human motion channelset, it will be the first of 68 sharedchannels. For both cases the first sharedchannel for the human or object motion file, will be of the type "sharedfigure". The frame data for sharedchannels of this type include the root site for the figures and contain both position and orientation of these sites. Before moving on, a little discussion on the root site is

necessary. The root site for a digital human, is the site that controls the figures position and orientation within the virtual world.

$$\text{sharedchannel sharedchannel\_name \{} \qquad (5)$$

By moving the root site you move the figure. All joint rotations for the figure tree are relative to the root site, with the captured posture, for each frame, defined by combining the joint angles for each segment as you move out along the figure tree away from the root site. This provides the ability to go from a standing to a seated posture and for example hold the hands at a fixed point in space, or move the figure to a new location and maintain a fixed posture. For an object, the root site is the base site and changes in position and orientation of the object are the result of directly manipulating this site. This sharedchannel and all other sharedchannels contained in the channelset file have three parameters and one data field associated with them. The first parameter, we mentioned above, and is used to specify the "type" of data the sharedchannel contains. There two options here, either sharedfigure, as shown (6), or sharedjoint. Sharedfigure specifies that the figure location data is stored and the sharedjoint specifies that joint angle data is stored.

$$\text{type = "sharedfigure";} \qquad (6)$$

$$\text{protofiletype = "human-5.9.fig";} \qquad (7)$$

$$\text{object = "human\_5\_9";} \qquad (8)$$

When working in earlier versions of Jack, version 1.2 or older, the protofiletype (7) specified what digital human figure or object was required for playback. In effect, it specified the only file that could be bound to the channelset file during playback. Under the newer versions, 2.2 and greater, this limitation has been removed and the only constraint is that the figure be of a similar nature (i.e., digital human, same number of joints, with similar site names). The "object" parameter (8), has two uses, in the case of a "sharedfigure" channel, this is a string that holds the name of the figure used to generate the data. In the case of the "sharedjoint" channel, it is the name of the specific joint and is used to locate the joint for binding data too. The last bit of information, the data field, included in the sharedchannel is the frame data. The frame is where all of the motion data information is stored in the file. One should note here, that for a motion capture session that lasts several minutes (i.e., 120 seconds for example), at a rate of 4 fps, each shared channel stores 820 frames of data. For a digital human file, with 68 sharedchannels, this equated to at least 55,000 lines of data. It is obvious that motion data files can become quite large in a very short time period. As mentioned earlier, for a sharedfigure channel the frame contains the root site, the orientation, in degrees, and the position, in centimeters (cm). For the digital human, this is the first sharedchannel, and the only sharedchannel of

this type. For an object motion data file, the sharedfigure type is the only sharedchannel contained in the file. Due to the length of the frame data for this type, an example of the data will not be shown. The remainder of the sharedchannels for a digital human file, as mentioned earlier, is of the type "sharedjoint". The frame data for this type contain only joint angle data, and the number of angles generated depends upon the degrees of freedom for each joint. The joint angles that are written to each frame for the sharedchannel are specified in radians. A point of interest here, during one phase of the research, joint angle data for the right hand, as part of an extensive cut and paste editing session, was moved to the left hand's sharedchannel. The result was motion data for the left hand that mirrored the movement of the right hand. It is directly the result of this work that initiated the request for the development or integration of motion data editors into the EAI-Jack environment.

BENEFITS OF HUMAN MOTION CAPTURE – Human motion capture that is used to provide human motion data to virtual simulations containing digital human models is quickly becoming a valuable tool for both the U.S. Army TACOM and Delphi Automotive Systems. The uses of human motion capture will increase as the technology, accuracy, and supporting software improves. The present uses, however, of human motion capture for use in virtual simulations are still significant. These human motion capture and analysis applications are detailed in the following sections.

Product Engineering And Design – Human motion capture for use within virtual simulations can be an invaluable tool for digital product mock-ups used during the product design process. The products may vary between the two users, automotive interiors for Delphi, and military vehicle crew stations for TACOM, but the human motion capture applications remain consistent. When a human motion capture session is conducted within a virtual design mock-up or physical design representation, the instrumented person interacts with the product to validate the design criteria. These criteria include ergonomic reach, human body to product interference, maneuverability within vehicle, sight lines to instruments or vehicle exterior, ergonomic comfort, ingress/egress, and ergonomic space requirements. The virtual product design is validated using a digital human model that can apply the captured human motion data. The digital human interacts with the virtual product mock-up while the ergonomic analysis software analyzes the ergonomic criteria for a full range of humans (typically 5th to 95th percentile). The product design is modified to optimize ergonomic interaction in this time and cost saving manner. Using virtual product mock-ups and virtual ergonomic simulation and analysis rather than manually analyzing ergonomic criteria using physical product mock-ups saves time and money. Time is also saved when creating the ergonomic simulations. For example, human motion capture data can be produced in the same amount of time needed by a person to perform

the operation. The length of time to create the same motions using the ergonomic software tools is significantly longer. For example, the time required to manually script a simple lifting exercise, where a one-foot square block was raised from one shelf to a higher one, took three hours of programming to accomplish. The same exercise using motion capture, including the time to instrument a person and perform several motion capture iterations, took 20 minutes.

Manufacturing Engineering – The applications of human motion capture for manufacturing engineering is similar to the previous product engineering design discussion. The difference is the objects that the human interacts with. In this case, an instrumented human interface with a manufacturing work area, machine, table, station, or any other manufacturing related equipment. The manufacturing process is analyzed using the captured human motion data applied to a digital human contained in a virtual manufacturing work environment. Through ergonomic analysis software, the processes and captured human motions are analyzed using digital human models, 5th to 95th percentile, to determine if ergonomic design criteria are met. The ergonomic criteria ensures the safety of the workers by checking reach issues, fatigue, energy expenditure, posture analysis, repetitive motion, strength analysis, lifting analysis, etc. In this application, analyzing manufacturing equipment and process designs before building costly models and equipment saves time and money. Improvements can be made if the process is analyzed using digital human models that are manipulated using captured human motion data. For example, a videotape of a process believed to be stressful on the knees was used to choreograph a motion capture session. The resulting simulation and the subsequent analysis flagged the suspect posture and provided valuable insight.

Maintenance Process Design – In this scenario, maintenance operations can be evaluated by capturing human motion data while a person interacts with a digital product mock-up. By evaluating the product accessibility using an instrumented human operating on a virtual product mock-up, design changes can be made before the design is finalized and physically built. Ergonomic issues with maintenance operations can be evaluated with a full range of digital humans (typically 5th to 95th percentile) within a virtual environment. As a result, product design changes can be made earlier in the design process, thus avoiding costly and time consuming design changes later in the design process.

Process Training – Human motion capture can also be applied as a training tool. Rather than produce a written procedure documenting an operation, a video clip can be produced using an ergonomic software package. An instrumented person would perform an operation while the motions are captured and stored. The human motion data would then be applied to a digital human model

placed within a virtual simulation environment. The entire simulation could then be output into a movie clip format that could be shipped to various sites to visually convey the detailed operation, thus, reducing the interpretation errors that could result from a written operation description. Another potential approach is to take the digital simulation, export it to either the Virtual Reality Modeling Language (VRML) or a Java3D as a web based animation. This would provide the ability to share the simulation over a local Intranet or via the Internet and provide a remote viewer the ability to zoom in/out or change the viewing angle as the simulation progresses. This would provide the remote viewer the capability to focus on critical areas of the animation sequence.

CONCLUSION

The intent in writing this paper, was the development of a document that could be used as a reference by those organizations just getting started in the field of motion capture and digital human simulation. The basis for this document are the lessons learned during the cooperative research between TACOM and Delphi. This paper potentially provides alternative approaches to those organizations doing similar work, but focusing on different corporate goals or objectives.

As stated in the introduction, the focus was on the electromagnetic motion capture hardware configuration for the two organizations. Discussion topics covered Ascension's different systems, hardware placement, field integrity, field orientation (i.e., hemisphere), and the effects of the different operating modes on field strength. The focus then shifted to the different options for viewing the virtual world (i.e., CAVE vs. HMD). The problems encountered with each configuration, and the unique system traits, discovered as a result of this research, were also addressed. The discussion then introduced the interaction and setup of the EAI-Jack digital human with the motion capture hardware. Topics touched on included: transmitter location, site position and orientation, the number of sensors required, and an alternative approach to controlling the digital human's head. Moving on, the discussion focused on the channelset motion data file, breaking it down to the individual syntax for the data contained in the file. Finally, the discussion focused on the potential benefits resulting from the combined use of motion capture and digital humans, from the perspective of the two different organizations.

So what's next? Last year the optical motion capture industry demonstrated real time motion capture and playback. The significance here is the benefit that the commercial entertainment industry has recognized from the start. This benefit is that no tethers are needed to connect the motion sensors to the human body during motion capture. Up until this point all optical motion capture data had to be post processed prior to playback, which was a very time consuming task, requiring extensive user interaction during editing to eliminate data spikes. One potential benefit is the ability to generate motion data within a large space, with no tethers to worry about, and by integrating an HMD, you only have to worry about its tether when immersed in a virtual world. Optical systems have the added benefit of saving motion data files in the standard formats used by the entertainment industry for playback in commonly used commercial simulation packages, where motion data editors already exist. The current drawback is that software drivers have yet to be developed that integrate optical motion capture system with ergonomic simulation and analysis environments like EAI-Jack. The other area touched upon slightly in the paper and alluded to here, is the complete lack of motion data editors for the channelset file format. One potential resource is the development of a motion capture data library, where, instead of capturing data, existing data for similar processes can be modified to fit the task being analyzed. Consequently, new motion capture data is developed only when the human motion required to accomplish a process or task is new or unique. In closing, the authors hope that this discussion will act as food for thought, initiating new programs and continued research in these areas.

REFERENCES

1. The Effects of Metals and Interfering Fields on Electromagnetic Trackers, Mark A. Nixon, Bruce C. McCallum, W. Richard Fright, and N. Brent Price, the Massachusetts Institute of Technology, 1998.

2. Jack/TTES: A System for Production and Real-time Playback of Human Figure Motion in a DIS Environment, John P. Granieri, Center for Human Modeling and Simulation, University of Pennsylvania.

3. DC-based magnetic tracking information, http://www.ascension-tech.com/graphic.htm

4. AC-based magnetic tracking information, http://www.polhemus.com

5. EAI-Jack, http://www.eai.com/products/jack

6. Air Force Research Lab, Design Evaluation for Personnel, Training and Human Factors (DEPTH), http://www.he.afrl.af.mil/hes/hess/programs/depth/depth%201.htm

7. Alias/wavefront Maya web site: http://www.aw.sgi.com/pages/home/index.html

CONTACT

Kyle Nebel is a Senior Mechanical Engineer with the U.S. Army TACOM/TARDEC. He has worked extensively over the last 14 years with CAD modeling, virtual manufacturing, and CNC, He has also done research work in the areas of Digital Humans and Motion Capture over the last four years, including collaborative work through the Cooperative Research and Development Agreement (CRADA) with Delphi. Kyle can be reached by phone at 810-574-8809, fax at 810-574-5015 or by E-mail: nebelk@tardec.tacom.army.mil.

Andrew Yee has been with General Motors, and Delphi Automotive Systems (after the spin-off from General Motors) since 1983. His most recent assignments within the Advanced Development Group, Advanced Manufacturing Engineering, have allowed him to explore various technologies that might change current processes to bring better products to market faster, more efficiently, and at lower costs while incorporating human safety considerations. By using technologies such as Virtual Environment Visualization, Virtual Simulation, and Ergonomic Simulation, many of Delphi's goals can be achieved. Andrew can be reached by phone at 248-696-5270, fax at 248-696-5150, or by E-Mail: andrew.yee@delphiauto.com.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AC: Alternating Current
bps: bits per second
CAVE: CAVE Automatic Virtual Environment
cm: centimeters
CPU: Central Processing Unit
DC: Direct Current
EAI: Engineering Animation Incorporated
ERT: Extended Range Transmitter
FOB: Flock of Birds
fps: frames per second
GUI: Graphic User Interface
HMD: Head Mounted Display
IPT: Integrated Process/Product Team
MCO: Multi Channel Option
SGI: Silicon Graphics
TACOM: Tank Automotive & Armaments Command
TARDEC: TACOM, Research, Development, and Engineering Center
VRML: Virtual Reality Modeling Language