

A motion capture library for the study of identity, gender, and emotion perception from biological motion

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We present the methods that were used in capturing a library of human movements for use in computer-animated displays of human movement. The library is an attempt to systematically tap into and represent the wide range of personal properties, such as identity, gender, and emotion, that are available in a person's movements. The movements from a total of 30 nonprofessional actors (15 of them female) were captured while they performed walking, knocking, lifting, and throwing actions, as well as their combination in angry, happy, neutral, and sad affective styles. From the raw motion capture data, a library of 4,080 movements was obtained, using techniques based on Character Studio (plug-ins for 3D Studio MAX, AutoDesk, Inc.), MATLAB (The MathWorks, Inc.), or a combination of these two. For the knocking, lifting, and throwing actions, 10 repetitions of the simple action unit were obtained for each affect, and for the other actions, two longer movement recordings were obtained for each affect. We discuss the potential use of the library for computational and behavioral analyses of movement variability, of human character animation, and of how gender, emotion, and identity are encoded and decoded from human movement.

The human body in motion provides a rich source of information about the intentions and goals of an actor, as well as about various aspects of his or her internal state. For example, studies with sparse point light displays (Johansson, 1973) have revealed the competence of observers to recognize gender (Kozlowski & Cutting, 1978; Mather & Murdoch, 1994; Troje, 2002), identity (Cutting & Kozlowski, 1977; Hill & Pollick, 2000) and affect (Dittrich, Troscianko, Lea, & Morgan, 1996; Pollick, Paterson, Bruderlin, & Sanford, 2001) from human movement. Extensive reviews of the perception of biological motion, its history and potential mechanisms, can be found in several sources (Giese & Poggio, 2003; Jellema & Perrett, 2003; Verfaillie, 2000). Although these and other, related studies have proposed visual cues that might support the recognition process, the field is far from obtaining a general description of the movement properties that inform recognition. At least one reason for this is that in each examination of biological motion perception, a small library of movements that was devoted to the purpose of that study typically has been used. Here, we will describe a library of motion-captured movements from 30 individuals (15 of

them female), with each individual performing multiple repetitions of various movements (walking, knocking, lifting, or throwing) with different affects (angry, sad, happy, or neutral).

We envision that this library will be useful for research in the perception of biological motion in which such factors as gender, identity, and affect are studied. For example, the availability of data on different affective presentations of a movement could guide research into what movement cues are available for the recognition of emotion and how these cues are used by observers. Moreover, since for every affect there are multiple examples for each individual, as well as across individuals, it should be possible to find different exemplars, as well as to estimate the natural variability of movement about these exemplars. In addition, since the movement data are available in a format compatible with sophisticated animation packages, it is possible to use the motion data with a variety of physical representations of the human form and from a multitude of viewing directions and viewing conditions. The library could also prove useful in fields other than the perception of human movement, such as motor control, humanoid robotics, and computer graphics, where it would be informative to know the motion pattern and variability for performing simple tasks.

Obtaining the movement library involved many steps, including capturing the three-dimensional (3-D) movement data, postprocessing the movement data, converting it to appropriate formats for presentation, and making it available publicly. Some of the aspects of this process have been discussed by Dekeyser, Verfaillie, and Vanrie (2002), as well as by Vanrie and Verfaillie (2004). However, due

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to the nature of the movements being recorded and the larger volume of data to be collected, several differences exist with these previous works. In the following, we will describe the processing sequence used to obtain the movement library in detail.

METHOD

In describing the processing sequence used to obtain the movement library, we will begin with the description of the actions used and the instructions given to the participants. Next, we will describe the details of the motion capture apparatus, the motion capture sessions, and the postprocessing of the movements. Following this, we will describe our procedure for segmenting data records containing multiple repetitions of a movement into individual movements and the preparation of the movements for animation in a variety of formats. Finally, we will discuss the form of the files available for download.

Actors, Actions, and Motion Capture

Actors. The actors were 15 male and 15 female students recruited from the University of Glasgow and the University of Edinburgh. The mean age was 22 years, ranging from 17 to 29 years. The actors were paid for their time and gave informed consent that their movements could be made available over the Internet.

We chose nonprofessional actors for two reasons. First, we wanted to avoid any systematic exaggeration of emotional expression, gender, or identity that might come about from theatrical training. Second, we hoped to introduce variability into the expressions of emotion that would lead to a range of effectiveness of the displays. All the participants were right-handed and used their right hand to perform the actions. The choice of right- versus left-handedness was arbitrary. However, we wanted to have the ability to portray the actors as solid body models and to have the arm movement fully visible for all actors while the knocking, lifting, and throwing movements were viewed from a right sagittal view. If left-handed movements were required, reflection about the midplane could be used.

Actions. We captured three categories of action: walking, arm movements, and a sequence of arm movements separated by walking. For walking, the actors walked in a triangle for 30 sec, turning rightward (clockwise) and turning leftward (counterclockwise) in two individual conditions. The arm movements were knocking, lifting, and throwing actions that the actors performed with their right hand while standing still. Finally, using their right arm, the actors made a sequence of lifting, knocking, and throwing arm movements separated by walking movements. The sequences were recorded so that in the future, we could compare the synthetic combination of multiple actions with actual events. In addition, these sequences, either as a whole or in parts, provide a more complex set of displays for behavioral studies. For each category of movement, we captured neutral actions, as well as actions with emotion (angry, happy, or sad). For the arm move-

ments, in order to make efficient use of the motion capture session, we twice captured five repetitions of each arm movement into a single record that was approximately 20 sec in duration.

For each actor, we obtained 40 data records. This consisted of 8 records of walking (2 directions \times 4 affects), 8 records of knocking (2 repetitions \times 4 affects), 8 records of lifting (2 repetitions \times 4 affects), 8 records of throwing (2 repetitions \times 4 affects), and 8 records of the sequences (2 repetitions \times 4 affects). For the walking movement and the sequences of movements, it was not essential to decompose the movement record; however, for the arm movements there were 5 repetitions per data record, and a means for segmenting the movement will be presented later in the article. Thus, the 24 records of knocking, lifting, and throwing contain 120 separate movements, yielding a total of 136 movements per actor and a total of 4,080 in the library.

In order to prepare the actors, we met with them for about 15 min the day before and instructed them as to what to expect during the motion capture sessions. This was also an opportunity for rehearsal, and each participant was presented with a series of scripts that defined the type of emotion that we expected him or her to perform. The latter ensured that there would be no idiosyncratic interpretations of the affects. We were careful to give the actors only verbal instructions, rather than performing the actions ourselves, and where necessary, adjusted their pose during practice sessions by verbal instruction. An example of this would be that for the knocking movement, we instructed the actors to stand squarely in front of the door prop and to start from the T position with their arms extended at right angles from their body and horizontal to the floor. When instructed, they were to drop their arms to a relaxed pose and pause for a moment before rising their right hand and knocking three times on the door with the back of their hand toward their face. Following this, they returned to the relaxed pose for a moment before repeating the action. After five repetitions they were asked to return to the T pose. For the lifting action, a lightweight spray can was used as a prop, and the actors were asked to pick this up, look at it for a moment, and then replace it on the same location (a cross on a table). We also made five retroreflective balls that were the props for throwing actions, and the actors were to throw these into a bin; we did not ask them to be completely accurate but, rather, to aim at the bin as best they could. The positions of the lifted can and thrown balls were captured.

The order of actions and emotions was randomized for each actor. For each emotion, a script was written that described the scenario and the affect to be produced. The emotion scripts were adapted from those of Amaya, Bruderman, and Calvert (1996) for the different actions, and the scripts for throwing actions are provided as an example.

Neutral

Imagine yourself standing by your kitchen table on a Saturday morning. You are well rested, you just had breakfast and yesterday you and your flatmates tidied the house so you are free to do whatever you want. It is a sunny day

and you are thinking about what you are going to do today. There's a bit of paper on the table and you pick it up and throw it to the bin.

Angry

Today you slept in, so you had to rush to get ready. Then on the way to work, a policeman flags you down and gives you a speeding ticket, although you were just keeping up with traffic. You finally get to work where a note is waiting for you denying your request for having Friday off; now you are furious. Standing by your desk, you reach for a bit of rubbish and slam it into the bin as your temper flares.

Happy

It's Friday evening and you feel great, because earlier you handed in your final year project. Your supervisor was very pleased, he complimented you on it and hinted that you're going to get excellent marks for it. You just talked to your best friend who suggested you go out to celebrate and now you are just waiting for her to arrive. As your excitement mounts you joyously pick up a bit of rubbish on the table in front of you and throw it at the bin.

Sad

You are in your flat after just trying to finish dinner. You didn't feel like eating, your stomach is heavy and seems to be bearing all of your body's inner activity and weight. Half an hour ago, you received a telephone call that your best friend had died in a car accident. Deeply grieving, you don't know what to do. Needing to do something you reach for a bit of rubbish and throw it in the bin.

Sad, angry, and happy affects were chosen because they represent emotional states or moods that may last for an extended period of time. They are also emotions that our past experience (Pollick, Lestou, Ryu, & Cho, 2002; Pollick et al., 2001) suggests actors find easy to map onto a wide variety of actions and that observers can recognize. In comparison, affects such as surprise and disgust are reactive emotions and, hence, are associated with specific movements that are not easily mapped onto the actions that we have chosen. We did, however, attempt to capture some examples of the affect afraid from 6 actors (3 of them female) but found that the actors preferred that this emotion be directed at an object, rather than using it as an extended emotional state or mood. Recently, Atkinson, Dittrich, Gemmell, and Young (2004) have recorded point light video displays of a variety of emotions in which the actions were specific to each emotion, choreographed in consultation with a professional actor and performed by experienced drama students.

Motion capture. Motion capture took place at the Edinburgh Virtual Environment Centre (EdVEC) with the Falcon Analog optical motion capture system (Motion Analysis Corporation, Santa Rosa, CA). The system has eight cameras that offer online monitoring of 3-D motion signals. The actors were dressed in a suit to which retro-reflective markers were attached; these retroreflective markers are illuminated by infrared light produced by an integrated LED array in the cameras. By reflecting the light back to the cameras, the markers produce a number of light spots in a two-dimensional (2-D) space, relative to each camera. After each capture session, 2-D data from

the cameras are integrated to generate 3-D position data for individual markers.

The basic complement of markers was 35; this differs from the basic Character Studio marker set (Dekeyser et al., 2002), which contains 30 markers. Some of the extra markers were placed on the head to capture this motion so that the orientation of the head could be extracted, and three markers were used to facilitate conversion of 2-D camera data into 3-D position data; the remainder of the markers were placed as in Dekeyser et al.

Postprocessing the Movement Data

The first step of postprocessing involved calculating the 3-D position data from 2-D camera data and interpolating the missing data. The final file produced during the process was in Character Studio motion capture (CSM) format. The CSM format is an ASCII file that is used to import positional marker data from various motion capture systems into Character Studio (Discreet, Montreal) in order to animate bipedal characters. For additional details on this process, see Dekeyser et al. (2002).

Movement segmentation: Finding start and end points. In each capture record for arm movements, volunteers were asked to perform the arm movements five times, with a brief pause between each example. It was therefore necessary to provide start and end points of individual repetitions, in order to segment these movement sequences into individual actions. We developed a MATLAB program to automatically search the start and end points of each repetition for a knocking, lifting, or throwing record. The program read a CSM file into MATLAB and converted all marker data (3-D position data) into a matrix; this part of the code has been reproduced in Appendix A. From this matrix, we identified the data associated with the right arm of each actor and, specifically, the right wrist and shoulder of the actor. Because the volunteers were asked to return to a relaxed pose, with their arm by their side, and to pause the hand for a moment at the beginning and end of the movement, as well as between two repetitions, there were two characteristics that we were able to use in order to detect the start and end of each repetition. For the start of each repetition, we assumed that the distance between the wrist joint and the shoulder joint reached a local maximum distance (Figure 1) and that the velocity of the wrist joint increased from the local minimum. On the other hand, for the end of each repetition, the distance between those two joints should again have reached the local maximum distance; however, the velocity of the wrist joint should have decreased toward a local minimum.

This technique was robust enough to cope with the majority of arm movements, and fewer than 10% of the segments needed manual adjustment. The final results of start and end points were manually verified in order to correct the exceptional cases.

A final note is that the two characteristic properties of velocity and distance worked for the segmentation of arm movements, but they could be adapted to segment any kind of human movement, as long as the relevant mov-

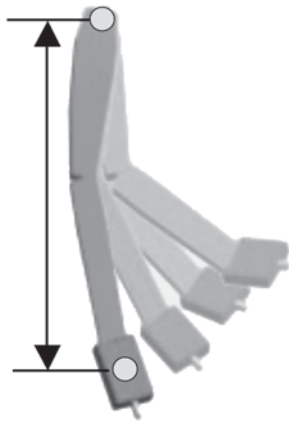


Figure 1. The local maximum distance (LMD), defined as the maximum distance between shoulder and wrist and representing the stage in the movements at which an actor is at rest at the start or end of a movement. The LMD, along with a velocity threshold, was used in an automatic procedure for finding the start and end points.

ing part of the body comes into a rest position and pauses momentarily between actions.

Preparation of the Movements for Animation

The procedures that we have outlined up to now provided us with CSM files, along with start and end points that could be used to segment the arm movement files into the component actions. The final step that was needed was to create animations of the movements. A straightforward step, discussed by Dekeyser et al. (2002), is to use Character Studio to animate the movements and generate point light displays of human movement. In the following sections, we will discuss first how the program 3D Studio MAX can be used to produce animations and then how point light data were extracted from the CSM files.

3D Studio MAX. The solid-body animations were created by using a *biped* model and a *physique* modifier, which are two plug-ins for 3D Studio MAX (Discreet; Montreal). A biped is a two-legged figure containing a hierarchical system of linked bones (Figure 2). Physique is a mesh object modifier that enables animators to deform a solid-body model by using a biped or other 3D Studio MAX bone system. The biped model uses motion capture data to create rigid body animations, and the physique modifier is used to animate the solid body according to the rigid body animation from the biped model. Figures 3A and 3B illustrate the solid-body and default biped models that we animated with our captured motion. In order to create an accurate representation of the movement, the dimension, orientation, and center position of all the body parts from the mesh model (solid body) were aligned to the relative parts of the biped model.

Extraction of point light data. Although the CSM file contains all the necessary information to animate a biped model in Character Studio, it does not contain the data necessary to generate point light displays. For instance, in

the marker set, each hip was represented by two markers, one on the front of the waist at the hip bone prominence and the other on the left back waist, on the side of the back dimples. However, since the 3-D structure of each actor was retained, we were able to obtain the virtual joint position data by searching for the hierarchical structure of joints in the biped model's skeleton, on a frame-by-frame basis. Figure 3C shows an illustration of the 15 virtual joints that we extracted. For each data record, the 3-D (*x, y, z*) position data of the virtual joints were then output as a tab-delimited ASCII file, with position coordinates in columns and rows containing the information for each frame of the data record; we have named these point light display files *PTD files*. The procedure was automated with a 3-D Studio MAX script, and this script has been reproduced in Appendix B. An important aspect of these point light files are that unlike those produced by Johansson (1973) and others, each marker represents a virtual joint located within the skeleton of the person, rather than on their skin. Similar approaches have been used by Troje (2002) with the use of Vicon BodyBuilder software (Vicon; Oxford Metrics, Oxford) and Dekeyser et al. (2002), using the more time-consuming procedure of manually attaching spheres to the joint centers and extracting the location of the center of these spheres.

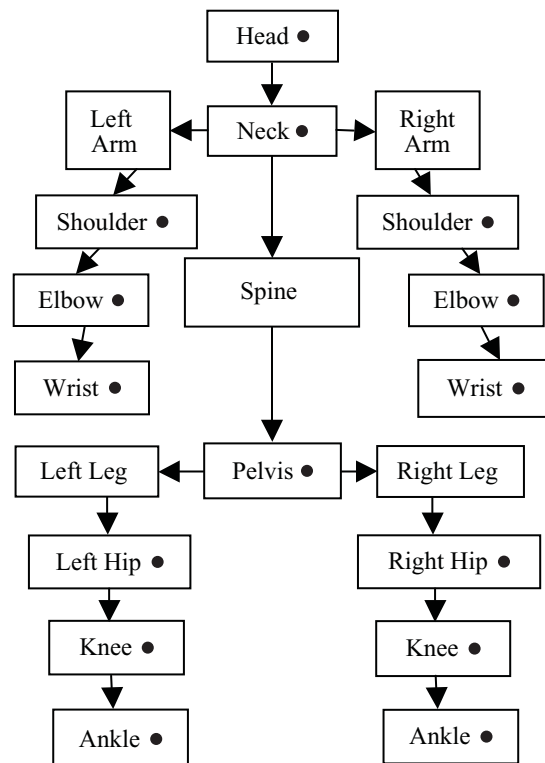


Figure 2. The hierarchy structure of the biped model. Each of the 15 black dots represents a point at the center of a joint that has been translated into position data for display in point light animations.

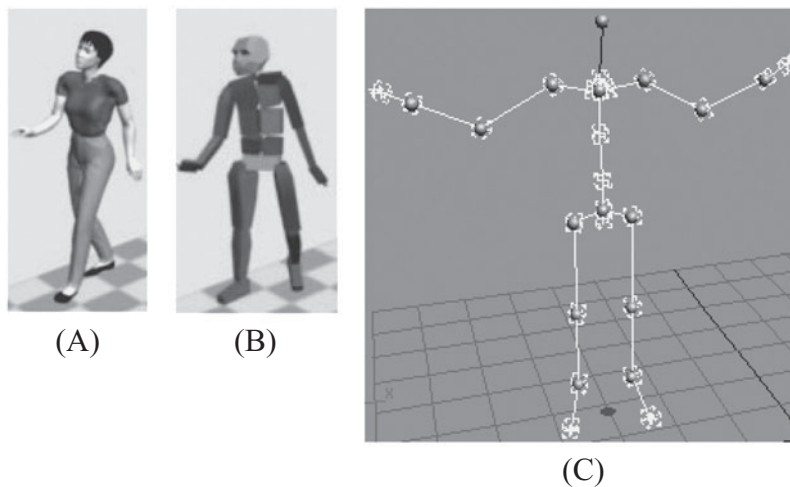


Figure 3. Three types of models in 3D Studio MAX. (A) A solid model generated in Poser and imported to 3D Studio MAX. (B) The default 3D Studio MAX biped model. (C) The virtual joints we used to generate position data for point light displays.

The details of the technical procedures in the MAX script are divided into three steps. First, a biped model was created, and a motion capture data file was loaded. Following this, in order to speed up the script's operation, we triggered an internal time change within 3D Studio MAX for switching between frames in the data file. Finally, the 3-D position of virtual joints was acquired from the hierarchy structure of the biped model and was output to PTD files.

Presenting the Library on the Web

The final step to perform, after recording and postprocessing of all movements, was to make them available publicly. To achieve this, the movements were organized into a library and made available on our group Web site (paco.psy.gla.ac.uk/data.php). The data are available in three zipped files for each actor. These files are arranged in an HTML table, with a row for each actor that provides the actor's name, a brief description, and separate links for each of the three zipped files. The three zipped files contain the data in CSM and PTD format and the start–end points (TXT). Each of the zipped files containing CSM and PTD data unpacks to 40 files, corresponding to the different conditions (5 action types \times 4 emotions \times 2 files). For each of these 40 files, the filename identifies the actor, action, emotion, and index. Also on the Web site, the age and gender of each actor has been recorded, and specific instructions for downloading the files have been included.

DISCUSSION

We have described our methods for the production of a movement library containing 4,080 human movements from recordings, using a high-speed optical motion capture camera system. From the use of 3D Studio MAX scripts and MATLAB routines, we were able to process

and convert motion capture data into formats useful for animation as solid-body and point light displays. The library contains data from 30 individuals (15 of them female), and for each individual, data are available for walking, knocking, throwing, and lifting actions, as well as for sequences of these different actions. For all these actions, movements were captured in an angry, happy, neutral, and sad style; and for the knocking, lifting, and throwing actions, 10 repetitions of each movement in each style were obtained. The potential uses of the library include computational and behavior analyses of how gender, emotion, and identity are encoded and decoded from human movement. There are also potential uses in the synthesis of human character animation, since our library provides the collection of single-action movements, as well as the sequences of movements.

Our library, with its emphasis on multiple recordings of the same action by the same individual, is well suited to the study of the sources of variability in movements. We can consider both identity and affect to be important contributors to the variability of movements that results in different styles of movement being appreciated. By obtaining the same action with different affects and actors, we can obtain useful estimates of the boundaries of the available movement space. This information can be used to constrain models of how movements are interpreted. A similar approach to the design of movement libraries exists in the area of 2-D video sequences of human activity for biometric analysis (Nixon, Carter, Grant, Gordon, & Hayfron-Acquah, 2003). However, the present library can be seen in contrast to other motion capture libraries that emphasize the recording of a variety of movements. For example, the libraries of Vanrie and Verfaillie (2004) and Shipley (Shipley & Brumberg, 2005) contain numerous examples of different actions in a format directly suitable for visual perception experiments. In addition, the library available from Jessica Hodgins and colleagues at Carnegie

Mellon University (Hodgins, 2005) is a source of a large variety of actions represented in different data formats suitable for computer animation. Thus, our library, with its emphasis on multiple recordings for a single actor, action, and affect, makes a unique contribution to the growing field of available motion capture libraries.

There are some possible technical, as well as methodological, limitations of the library that deserve mention. For example, the present library includes data to create point light displays, as well as animations, using Character Studio. However, it does not include movement data in other formats, such as the BVH format, for use in the popular software package Poser (Curious Labs Inc., Santa Cruz, CA). Under the current version of 3D Studio MAX (5.0), there is no facility for converting CSM files into poser BVH files, and there does not appear to be any third-party software that can directly accomplish this conversion. One possible solution to this issue is to use the joint editor within the Lifeforms package (Credo Interactive, Vancouver) to facilitate translation from CSM to a BVH file compatible with Poser.

A methodological issue for our library of movements involves our choice of inexperienced actors to portray the different affects. This can be criticized on two levels: first, that we used actors at all, and second, that the inexperience of the actors produced movements that did not effectively convey affect. The first criticism, although important to keep in mind, is impossible to get around, since at present it is impossible to get both control of measurement and naturally occurring expressions. A similar dilemma exists for libraries of faces used to study face perception (Ekman & Friesen, 1972; Martinez & Benavente, 1998; Sim, Baker, & Bsat, 2002), which have been used to good effect. The second criticism about the use of inexperienced actors was the result of our decision to avoid any systematic exaggeration or distortion of movement that might result from specific training in acting. However, the possible variability of expression quality resulting from using inexperienced actors has the potential to be used to advantage in experiments in which a range of expressivity is required. A useful next step in the development of the library for use in affective research would be to perform extensive and systematic evaluation of the library. We have begun this validation with the examination of affect from walking movements. Preliminary results show that affect was recognized at levels well above chance and that there was a broad range in the ratings of emotional intensity.

CONCLUSIONS

We have collected movements from 30 nonprofessional actors in an attempt to make a library of movements in which as many as possible of the diverse range of person properties (identity, variability, emotion, and gender) have been captured. The library is freely available for research and contains movements that are presented in two major

formats, as point light displays and as data that can be used to drive humanoid models.

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APPENDIX A
MATLAB Program to Read a CSM File Into a 2-D Matrix

```
[FileError, WristIndex, ShoulderIndex, PosData] = ReadCSM(filename)
%FileError is the boolean variable for the result of reading file.
% -1 for succeed, 1 for failure.
%WristIndex is the index of wrist joint for 2D position matrix
%ShoulderIndex is the index of shoulder joint for 2D position matrix

NumMarkers = -1; FileError = -1; wristIndex = -1; shoulderIndex=-1;

fp = fopen(filename,'r');
if (fp == -1)
    disp('ERROR: no such file');    FileError = 1;    return;
end

%Read the header information
while (1)
    HeaderString = fscanf(fp,'%s',1);
    if(strcmp(HeaderString,'$NumMarkers')==1)    NumMarkers=fscanf(fp,'%d',1);
    end
    if(strcmp(HeaderString,'$Order')==1)    break;
    end
end

%Read Markers
for i=1:NumMarkers
    MarkerName = fscanf(fp,'%s',1);
    if(strcmp(MarkerName,'RSHO')==1)    %Shoulder joint marker
        ShoulderIndex=i;
    end
    if(strcmp(MarkerName,'RWRE')==1)    %Wrist Joint marker
        WristIndex=i;
    end
end

% Read the XYZ position data
% Attention!! The first one is index, NOT Position data
Total = NumMarkers*3+1; PosData = zeros(Total,NumFrames); count = 1;

while(1)
    tline = fgetl(fp);
    if ~ischar(tline), break, end    % Read whole line into variable tline
    Value = sscanf(tline,'%g');    VecLength = length(Value);
    if(VecLength==0)
        continue;
    elseif (VecLength~=Total)
        PosData(1:VecLength,count)=Value(1:VecLength);
        PosData(VecLength+1:Total,count)=0.0;
        count=count+1;
    else
        PosData(:,count)=Value(:);
        count=count+1;
    end
end
end
```

APPENDIX B
Program to Extract Point Light Display Data From the Coordinates of a Set of Markers
to an ASCII File (Script Written in the 3D Studio MAX Macro Language)

```

macroScript PtOut
(
  max file new
  bipObj = biped.createNew 100 100 [0,0,0] -- create a biped
  bip = bipObj.transform.controller -- select bipObj
  max motion mode

  animationRange=interval 0 10
  biped.loadMocapFile bip ("CSM file")
  output_name = ("output file")
  output_file = createfile output_name
  format "%\n" animationrange.end to:output_file

  for t = animationrange.start to animationrange.end do
  (
    --get Head data, 11-----
    anode = biped.getNode bipObj 11
    at time t current_pos=anode.center
    format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    --get Neck data, 17-----
    anode = biped.getNode bipObj 17
    at time t current_pos=anode.transform.pos
    format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    --get Left arm data-----
    for i = 2 to 4 do
    (
      alink =biped.getNode bipObj 1 link:i
      at time t current_pos=alink.transform.pos
      format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    )
    --get Right arm data-----
    for i = 2 to 4 do
    (
      alink =biped.getNode bipObj 2 link:i
      at time t current_pos=alink.transform.pos
      format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    )
    --get Pelvis data, 12-----
    anode = biped.getNode bipObj 12
    at time t current_pos=anode.transform.pos
    format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    --get Left Leg data-----
    for i = 1 to 3 do
    (
      alink =biped.getNode bipObj 5 link:i
      at time t current_pos=alink.transform.pos
      format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    )
    --get Right Leg data-----
    for i = 1 to 3 do
    (
      alink =biped.getNode bipObj 6 link:i
      at time t current_pos=alink.transform.pos
      format "% % % " current_pos.x current_pos.y current_pos.z to:output_file
    )
    format "\n" to:output_file
  )--for(t)
  close output_file
)--end macroScript

```