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Running Head: Biological Motion Library

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

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Abstract

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 person properties, such as identity, gender and emotion that is available in a person's movements. The movements from a total of 30 individuals (15 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 4080 movements were obtained using techniques based on Character Studio (plug-ins for 3D Studio Max, AutoDesk Inc.), Matlab (The Mathworks) 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 behavioural analyses of movement variability, human character animation and how gender, emotion and identity are encoded and decoded from human movement.

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

The human body in motion provides a rich source of information about the intentions, and goals of an actor as well as various aspects of their internal state. For example, studies with sparse point light displays (Johansson, 1973) have revealed the competence of observers to recognize gender (Troje, 2002; Mather & Murdoch, 1994; Kozlowski & Cutting, 1978), identity (Hill & Pollick, 2000; Cutting & Kozlowski, 1977) and affect (Pollick, Paterson, Bruderlin, & Sanford, 2001; Dittrich, Troscianko, Lea, & Morgan, 1996) from human movement. Extensive reviews of the perception of biological motion, it's history and potential mechanisms can be found in several sources (Giese & Poggio, 2003; Jellema & Perrett, 2003; Verfaillie, 2000). While 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 each examination of biological motion perception has typically used a small library of movements that was devoted to the purpose of that study. Here we describe a library of motion-captured movements from 30 individuals (15 female), with each individual performing multiple repetitions of various movements (walking, knocking, lifting, throwing) with different affects (angry, sad, happy, neutral).

We envision that this library would be useful for research in the perception of biological motion studying factors such as gender, identity and affect. For example, the availability of data on different affective presentations of a movement could guide research into what movement cues are available to recognize 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 is 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 were 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 3D movement data, post-processing the movement data, converting it to appropriate formats for presentation and making it available publicly. Some of the aspects of this process are discussed by Dekeyser, Verfaillie and Vanrie (2002) as well as Vanrie and Verfaillie (in press). However, due 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 describe the processing sequence used to obtain the movement library in detail.

Methods

In describing the processing sequence used to obtain the movement library we begin with the description of the actions used, and the instructions given to the participants. Next, we describe the details of the motion capture apparatus, motion-capture sessions and the post-processing of the movements. Following this we 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 discuss the form of the files available for download.

Actors, Actions and Motion Capture

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

Actions. We captured three categories of action: walking, arm movements and a sequence of arm movements separated by walking. For walking, actors walked in a triangle for 30 seconds turning rightward (clockwise) and turning leftward (counter-clockwise) in two individual conditions. The arm movements were knocking, lifting and throwing actions that actors performed with their right hand while standing still. Finally using their right arm, actors made a sequence of the arm movements separated by walking movements. For each category of movement, we captured neutral actions as well as actions with emotion (angry, happy, sad). For the arm movements, in order to make efficient use of the motion capture session we twice captured 5 repetitions of each arm movement into a single record that was approximately 20 seconds in duration.

For each actor we obtained 40 data records. This comprised 8 records of walking (2 directions X 4 affects), 8 records of knocking (2 repetitions X 4 affects), 8 records of lifting (2 repetitions X 4 affects), 8 records of throwing (2 repetitions X 4 affects) and 8 records of the sequences (2 repetitions X 4 affects). For the walking and the sequences it is 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 is presented later in the paper. Thus, the 24 records of knocking, lifting and waving contain 120 separate movements, yielding a total of 136 movements per actor and a total of 4080 in the library.

In order to prepare actors, we met with them for about 15 minutes a day before and instructed them in 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 them to perform. This last ensured that there would be no idiosyncratic interpretations of the affects. We were careful to only give actors verbal instructions rather than to perform the actions ourselves and where necessary, adjusted their pose during practice sessions by verbal instruction. An example of this would be that for knocking movement we instructed actors to stand squarely in front of the door prop, 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 towards 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 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 retro-reflective balls that were the props for throwing actions and actors were to throw these into a bin, we did not ask them to be completely accurate and rather to aim at the bin as best they could. The position of the lifted can and thrown balls were captured.

The order of actions and emotions was randomised 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, Bruderlin 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 what ever 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 you 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 you 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.

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, USA). The system has 8 cameras that offered online monitoring of the 3-dimensional (3D) motion signals. Actors were dressed in a suit to which retro-reflective markers were attached; these retro-reflective markers are illuminated by infrared light produced by an integrated LED array in the cameras. By reflecting the light back to cameras, markers produce a number of light-spots in a two-dimensional (2D) space relative to each camera. After each capture session, 2D data from the cameras are integrated to generate 3D position data for individual markers.

The basic compliment of markers was 35, this differs from the basic Character Studio marker set (Dekeyser, Verfaillie, & Vanrie, 2002) which contains 28 markers. Four of the extra markers were placed on the head to capture this motion and three extra markers were used to facilitate conversion of 2D camera data into 3D position data, the remainder of the markers were placed as Dekeseyer et al (2002).

Postprocessing the movement data

The first step of post-processing involved calculating the 3D position data from 2D 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, Canada) in order to animate bipedal characters. For additional details on this process, see Dekeyser, Verfaillie, & Vanrie (2002).

Movement segmentation: finding start and end points. In each capture record for arm movements, volunteers were asked to perform the arm movements 5 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 (3D position data) into a matrix; this part of the code has been reproduced in Appendix B. And 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 return to a relaxed pose, with their arm by their side and 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 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 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. By calculating the distances between the wrist joint and the shoulder joint over time, we were able to generate a distance curve as shown in figure 2. It was then possible to segment the whole movement by finding the local maximum distance (LMD) and calculating the velocity profile of this distance curve. However, not all actors allowed their arm to come to a complete halt between repetitions. Therefore, we defined a velocity threshold (V_{th}) at 5% of maximum velocity, as the second criteria by which to segment the data.

Insert Figure 1 around here

We formulated the start and end point of an individual movement as:

$$\begin{cases} \text{start point} \;=\; \{p_{start} \mid p \in \{LMD_{increasing}\} \quad and\; v(p) < V_{th}\} \\ \text{end point} \;=\; \{p_{end} \mid p \in \{LMD_{decreasing}\}\; and\; v(p) < V_{th}\} \end{cases}$$

where $LMD_{increasing}$ were a set of points belonging to the sub-movement where the distance between the wrist joint and the shoulder joint reached the local maximum distance and the movement velocity was increasing from the threshold. Similarly, $LMD_{decreasing}$ were the set of those points belonging to the sub-movement where the movement velocity was decreasing towards the threshold. Within each set of sub-movements, the start point was the last point satisfying these two criterions while the end point was the first point satisfying two criterions. An illustration of finding the start and end points is given in Figure 2.

Insert Figure 2 around here

This program was designed for automatic segmentation of arm movements under perfect conditions, however, the program output wrong start or end points in cases where actors produced some extra movements during the pause between actions. For instance, an actor might not have come to a complete halt between actions, or they might have "wobbled" their arm by swinging it backwards and forwards. However, the automatic procedure was robust enough to cope with the majority of arm movements and our statistics shows that less than 10% segments (360 out of 3600 segments) needed manual adjustment. The final results of start and end points were manually verified in order to correct the exceptional cases. For verification, the Matlab program used start and end points to add a few moments' worth of static frames into the CSM files so that we were able to easily observe the pause and verify the results.

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 kinds of human movements as long as the relevant moving part of the body comes into a rest position and pauses momentarily between actions.

Preparation of the movements for animation. The procedures we have outlined up to now provided us with CSM files along with start and end points that can 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, Verfaillie, & Vanrie (2002) is to use Character Studio to animate the movements. However, this might not be appropriate for all needs, particularly given the strong tradition of using point light displays as a means of presenting human movement in psychological research. In the following sections we first discuss 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, Canada). A biped is a two-legged figure containing a hierarchical system of linked bones (Figure 3). 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 Physique modifier is used to animate the solid body according to the rigid body animation from the biped model. Figure 4 (a) and b) illustrates 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 centre position of all body parts from the mesh model (solid body) were aligned to the relative parts of the biped model.

Insert Figure 3 around here

Insert Figure 4 around here

Extraction of point light data

While 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 2 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 3D 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 4(c) shows an illustration of the 15 virtual joints that we extracted. For each data record, the 3D (x, y, z) position data of virtual joints were then output as a tab delimited ASCII file with position co-ordinates 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 3D Studio MAX script and this script has been reproduced in Appendix A. 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 a on their skin. Similar approaches have been used by Troje (2002) with the use of Vicon BodyBuilder software (Vicon; Oxford Metrics, Oxford UK) and Dekeyser, Verfaillie, & Vanrie (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.

The details of technical procedures in the MAX script are divided into three steps. Firstly 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 the 3D Studio Max for switching between frames in the data file. Finally the 3D position of virtual joints was acquired from the hierarchy structure of the biped model and output to PTD files.

<u>Presenting the library on the web.</u> The final step to perform, after recording and post-processing 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 website (http://paco.psy.gla.ac.uk/data.php). The data are available in three packed (ZIP) 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 zip

files. The three zip files contain the data in character studio format (CSM), point light display format (PTD) and the start-end points (TXT). The zip files containing CSM and PTD data each unpack to 40 files, corresponding to the different conditions (5 action types x 4 emotions x 2 files). For each of these 40 files the filename identifies the actor, action, emotion and index.

Discussion

We described our methods for the production of a movement library containing 4080 human movements from recordings using a high-speed optical motion capture camera system. From the use of 3DS 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 female), and for each individual, data is available for walking, knocking, throwing, and lifting actions, as well as 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 behaviour analyses of how gender, emotion and identity are encoded and decoded from human movement. There are also potential uses to the synthesis of human character animation as 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 the sources of variability in movements. We can consider both identity and affect to be important contributors to the variability of movements that result 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 2D video sequences of human activity for biometric analysis (Nixon, Carter, Grant, Gordon & Hayfron-Acquah, 2003). However, the current library can be seen in contrast to other motion capture libraries that emphasise the recording of a variety of movements. For example, the libraries of Vanrie and Verfaillie (in press) and Shipley (Shipley & Brumberg, 2004) contain numerous examples of different actions in a format directly suitable for visual perceptual experiments. In addition the library available from Jessica Hodgins and colleagues at Carnegie Mellon University (Hodgins, 2004) 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 current 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, USA). 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 package Lifeforms (Credo Interactive, Vancouver, Canada) to facilitate translation from CSM to a BVH file compatible with Poser.

A methodological issue in our library of movement 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 will produce movements that do not effectively convey affect. The first criticism, while 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 in libraries of faces used to study face perception (Sim, Baker, & Bsat, 2002; Martinez & Benavente, 1998; Ekman & Friesen, 1972) that 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 where 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.

Conclusions

We have collected the movements from 30 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) has been captured. The library is freely available for research and contains movements that are presented in two major formats, as point light displays and data that can be used to drive humanoid models.

Author Notes

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APPENDIX A

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 Marco 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
```

APPENDIX B

Matlab Program to read a CSM file into a 2D 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
```

Figure Legends

Figure 1:

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

Figure 2:

Distance curve with start and end points. In (a) we show the distance curve for the five repetitions of a knocking movement and in (b) we have zoomed in on the start and end points of a single movement, where the LMD is at a maximum and the velocity of the wrist is at a minimum.

Figure 3:

The hierarchy structure of the biped model, the 15 black dots each represent the points at the centre of a joint that has been translated into position data for display as point-light animations.

Figure 4:

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 and (c) the virtual joints we used to generate position data for point-light displays.

Figure 1

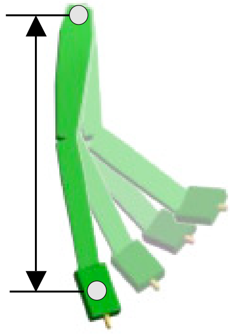


Figure 2

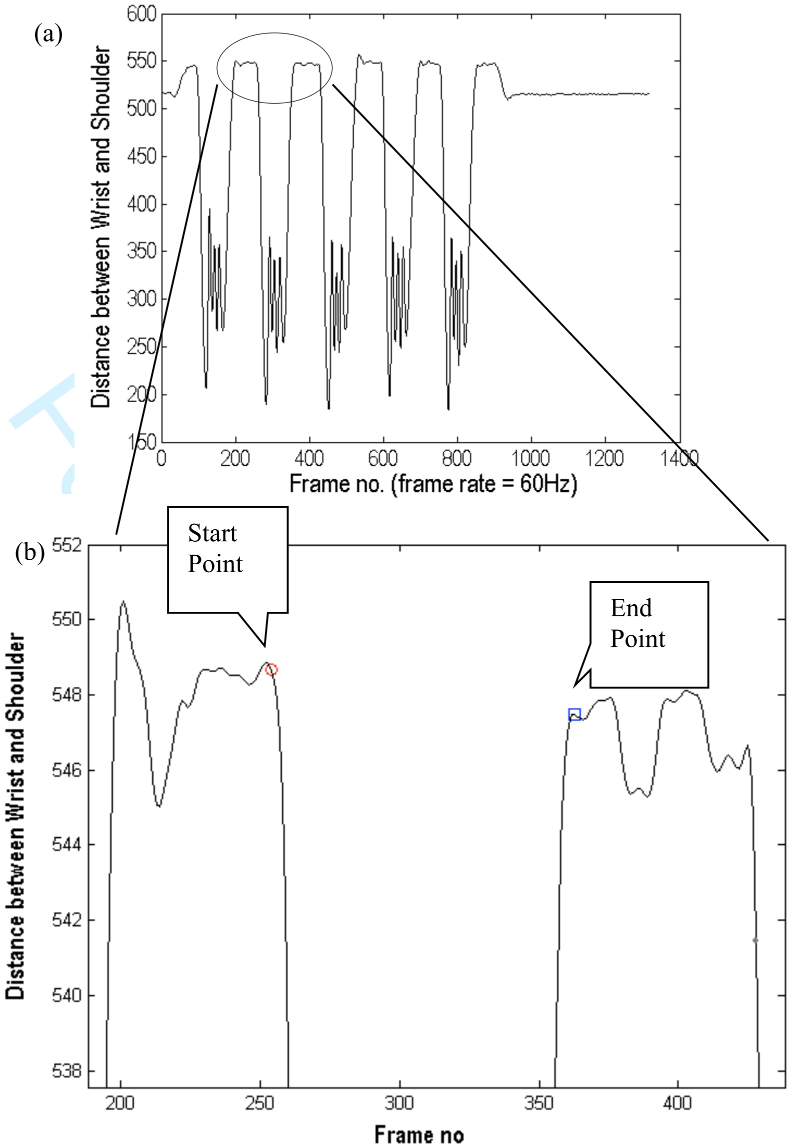

(a)
Distance between Wrist and Shoulder
Frame no. (frame rate = 60Hz)
(b)
Start Point
End Point
Distance between Wrist and Shoulder
Frame no

Figure 3

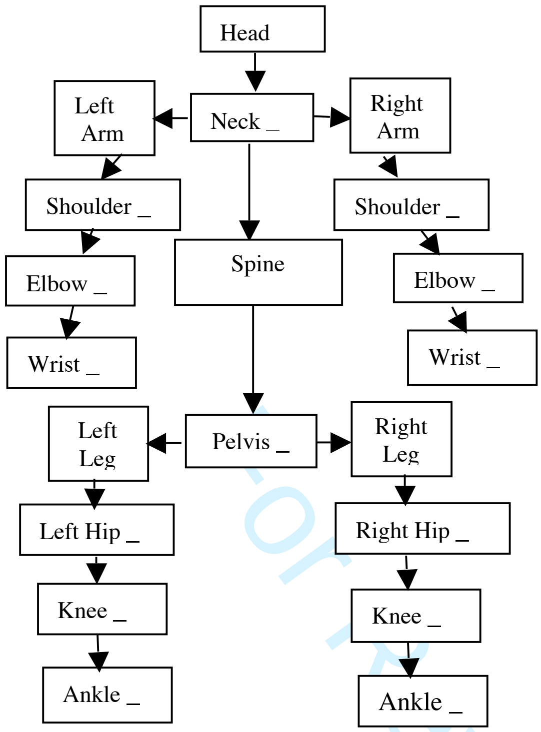
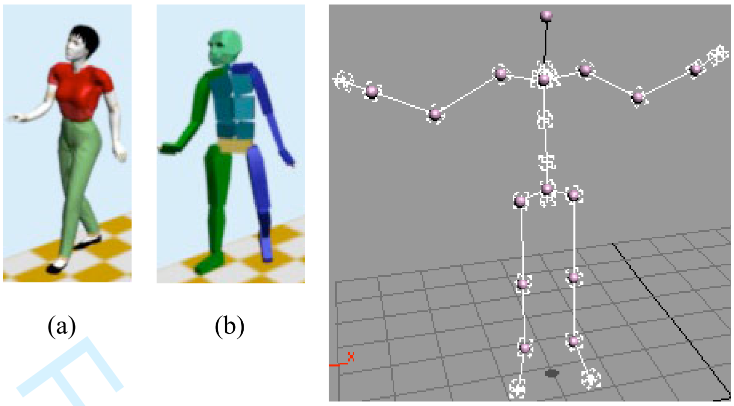

Head
Neck _
Left Arm
Right Arm
Shoulder _
Shoulder _
Spine
Elbow _
Elbow _
Wrist _
Wrist _
Left Leg
Pelvis _
Right Leg
Left Hip _
Right Hip _
Knee _
Knee _
Ankle _
Ankle _

Figure 4



(a) (b) (c)

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