Analysis 3-D Joints Motion Data of Human Walk

[1,2,3,4] Sajid Ali, [1]Wu Zhongke , [2]Tauqir Ahmed Moughal, [3]Ahmad Tisman Pasha, [4]Salman Qadri

[1]Institute of Virtual Reality and Visualization Technology, Beijing Normal University, Beijing, China
[2]School of Mathematical Sciences Beijing Normal University, Beijing, China
[3]Department of Information Technology, Institute of Computing, Bahauddin Zakariya University Multan, Pakistan.
[4]Department of Computer Science & IT Islamia University Bahawalpur, Multan, Pakistan
snfa_bnu@yahoo.com

Abstract: This paper proposes statistical testing methods for gait analysis and uses three dimensional (3D) motion data to analyze the mean and variance of three types of joints: hip, knee and ankle. The extracted data is initially recorded in an ASF/AMC format by the motion capture system. Then these files are converted into the Biovision Hierarchical (BVH) files. The statistical hypothesis tests for equality of means are applied on the generated BVH data of three joints. As these joints provide the high combustible component information of human lower body Bartlett's test is also used for equality of variances movements of joints and to determine which joint has more exhibits variation among them. The usage of BVH file, to estimate the movement of joints in each x, y, and z coordinate during walk, is a novel feature in this study. The experimental results indicate that, the knee joint has the decisive influence (variation or stronger) as compared to the other two joints (hip and ankle) during human walk.
[Sajid Ali,Wu Zhongke,Tauqir Ahmed Moughal, Ahmad Tisman Pasha, Salman Qadri. **Analysis 3-D Joints Motion Data of Human Walk.** *Life Sci J* 2013;10(4):3411-3419]. (ISSN:1097-8135). http://www.lifesciencesite.com. 455

Keywords: Mocap Walk; Coordinate Walk; Joints Variance

1. Introduction

Gait joint evaluation is a kind of biometrics. Michael et al. [5] have used energy and power to evaluate individual joint performance in clinical science. Cappozzo [6] discussed about gait analysis methodology and clinical gait evaluation, more formal definition of human gait. Kinesiological recording and measurement techniques discussed by Carlsöö [7] and Hodgins [8] have used three-dimensional human running. Davis et al. [9] discussed three dimensional marker position information to determine joint movement and powers. Growney et al. [11] proposed a statistical approach for gait evaluations by using joints kinematic and kinetic data collected by normal subjects. The range of motion of human body joints was described by Mackenzie. [12], and Roaas et al. [15]. Dona et al. [13] applied a principal component analysis (PCA) on the data collected from subjects to determine the dependence on the knee joint angle in human gait. Kerrigan et al. [14] has used PCA for gait joint analysis. There is also medical application research which mainly concerned to classify the components of gait to compare pathologically abnormal patients with normal patients. Standard movement patterns of each gait component for pathologically normal people were produced by Murray et al. [10]. For example, to control active prostheses, or try to detect and understand the motion of motor impaired individual. Most researchers of motion gait analysis, synthesis, animation, retarget motion and gait recognition consider the whole motion of joints [10, 15-17]. There are many choices [1-4, 25-27] to use the motion data.

The motion capture data is widely used to animate computer graphic and video games. Using human motion data has been a popular approach for analyzing, animation; retarget motion and synthesizing human joint motion, particularly thanks to the recent improvement of motion capture systems. In particular, there have been a lot of interests in the ways of using and re-using motion capture data [1-4]. In this paper, we applied statistical testing methods to determine the performance of the joints and found that the marked joints in the following figure 2 have a utmost contribution during walk.

The motion capture data files format is explained by Meredith et al. [18]. The BVH file can be produced from a motion capture system. It contains information about the human body joints and their movement; it was originally developed by division system. This format mostly replaced an earlier file that they developed, as a way to provide skeleton hierarchy information in addition to the motion data. It is an excellent motion replaced an earlier file that they developed, as a way to provide skeleton hierarchy information in addition to the motion data. It is an excellent motion data format and consists of two parts, a header section that describes the hierarchy and initial pose of the skeleton; and the second section describes the channel data for each frame of the motion section. In this work, we will be concerned with three joints hip, knee and ankle. The motion data corresponding to these three joints in the BVH files called 3-D motion data which is shown in Table 1.

```
HIERARCHY
ROOT Hip
{
OFFSET 0.00 0.00 0.00
CHANNELS 6 Xposition Yposition Zposition
Zrotation Xrotation Yrotation
JOINT Chest
{
OFFSET 0.00 5.21 0.00
CHANNELS 3 Zrotation Xrotation Yrotation
JOINT Neck
{
OFFSET 0.00 18.65 0.00
CHANNELS 3 Zrotation Xrotation Yrotation
JOINT Head
{
OFFSET 0.00 5.45 0.00
CHANNELS 3 Zrotation Xrotation Yrotation
End Site
{
OFFSET 0.00 3.87 0.00
}
}
}
MOTION
Frames: 2
Frame Time: 0.033333
8.03 35.01 88.36 -3.41
22.78 -5.92 14.93 49.99
7.81 35.10 86.47 -3.78
15.44 -3.56 7.97 59.29
```

Figure 1.Example of motion capture BVH file format

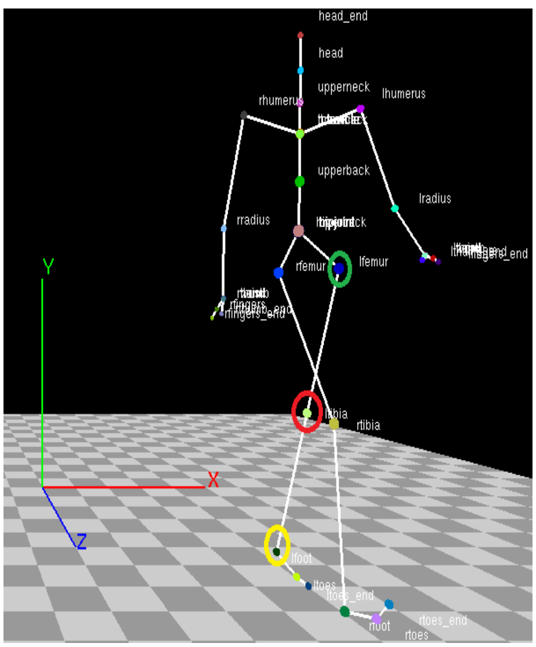

Figure 2. Walking skeleton pose of BVH file

Figure 2 illustrates the skeleton data structure and in Table 1 shows an example of 3D motion data of three joints that were extracted from the BVH file. The motion part is generated with the help of movement of the skeleton joints. Gait joint's performance measures the participation of joints based on the style of human walking. In this paper, an algorithm for human gait (walking) joints performance evaluation is introduced. We determined, by statistical techniques, which joint has more weight during human walk in natural style. Primarily, means and variances are measured for all the three coordinates of each joint i.e. X, Y and Z .These measures are then used to show how much variation occurs during walk. Then, we called the participation (contribution) of the joints during gait. The joint with the highest variability (stronger joints) of the coordinate, therefore, has maximum participation and consequently are the one which has the maximum effect [20]. Based on this concept, we will conclude that which joint has more effective influence during walk.

Our analyze approach is the performance of the joints coordinates wise by using 3D motion data, it is actually extracting motion data from the joint position of the human body and drawn conclusions by statistical techniques. Here, we introduced a novel technique under the joints of 3D motion data which will be of great use in the field of biometrics and robotic actions. The importance of the knee joint during gait has been established in various studies (such as [8], [10], [15]) and also described gait analysis observation by Saleh et al. [23]. Roach et al. [24] defined range of motion of the hip and knee joints. Sajid et al. [29] proposed a method to calculate the participation of the lower body joint in the human walk by using three dimensional motion data under statistical methods.

This paper is organized as follows. Section 2, contains an overview of materials and methods and describe the process of the construction of database and present our proposed flow chart. The section 3 is reserved for statistical calculation. Section 4 contains the results and finally ends with a conclusion in section 5 which will provide more information of the future work.

2. Material and Methods

Our concept is an evaluation of the joints during walk (gait style). We have selected the three important joints: hip, knee and ankle. Then we apply statistical testing techniques to the selected joints motion data and to determine which joint has more variation in generating walking motion. Figure 1 describe BVH file format which we use in this study. The construction of database is illustrated in Figure 3; the flow chart of purpose method is shown in Figure 4.

Table 1. Example of three dimensional motion data of joints with 10 frames

Frame No	Hip joint			Knee joint			Ankle joint		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-4.546	1.4421	2.3608	4.0793	12.2651	36.6764	4.0793	12.2651	36.6764
2	-4.3387	1.7707	2.0255	4.5927	12.9098	39.0319	4.5927	12.9098	39.0319
3	-4.0652	1.9428	1.6285	4.8878	13.2563	40.3355	4.8878	13.2563	40.3355
4	-2.9478	2.0493	1.4823	5.105	13.5011	41.2744	5.105	13.5011	41.2744
5	-1.2787	2.0037	1.6024	5.2359	13.6447	41.8323	5.2359	13.6447	41.8323
6	0.1048	1.7511	2.0087	5.2778	13.69	42.0096	5.2778	13.69	42.0096
7	0.0512	1.6948	2.3671	5.2848	13.6975	42.039	5.2848	13.6975	42.039
8	-0.1114	1.8252	2.6543	5.2482	13.658	41.8842	5.2482	13.658	41.8842
9	0.0954	1.9387	2.9625	5.1059	13.5021	41.2782	5.1059	13.5021	41.2782
10	0.3216	1.9214	3.165	4.8928	13.2621	40.3575	4.8928	13.2621	40.3575

2.1. Need of the database

The CMU motion capture database [30] was built mainly to give a source of motion data for animation and other research areas [32-36]. The database contains different motion clips of full body mocap data. The actions have been performed by 144 subjects (some subjects are the same person). The database has no formal structure such that most sessions have different actions. At the same time as one set may have walk actions, other set contains both walk and run actions. Even the same action performed across different sets may not have been performed in the same way. Here we took out simple walking action motions data of one subject. Then constructed the database from the selected subject following the procedure defined in [29]. This database is called local database and it is summarized in Figure 3.

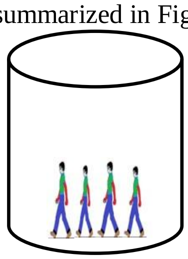

Figure 3. Local database of human walk

2.3. Algorithm Flow

The flow chart is divided into six steps as shown in Figure 4: these six the steps are called A, B, C, D, E and F respectively. Each step has individual function that performed unique calculation.

Step A

Motion data of the subject captured from the motion capture system and arranged it according to the database [29].

Step B

In this step, we retrieved the motion file (BVH file) of the subject from the local database and gave it to the step C for further processing.

Step C

Extract the three joint motion data from the BVH file and gives to step D for further calculation.

Step D

In this step, compute mean and variance of each coordinate of each joint and applied one-way ANOVA on these values and found the results about joint movement of a subject. But here, this method does not describe that how much different participations of each coordinate of each joint occurs.

Step E

In this step, we applied LSD and Bartlett test to find the characteristics equality of joints movement variability.

Step F

The last step F gives the final information related to each joint characteristic and determines that which joint has more movement during the subject walk.

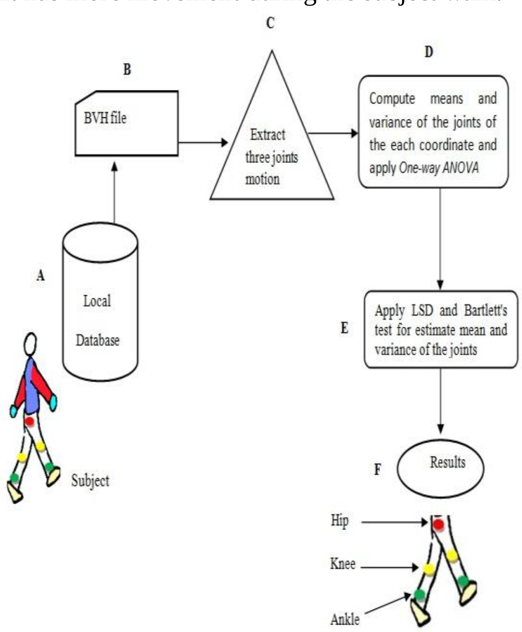

Figure 6. Data flow for our algorithm. Starting with subject motion (BVH file), extract concern joints (hip, knee and ankle) data, compute features, apply testing techniques and get as well as association information.

3. Applied Statistical methods

As mentioned above, we are interested to determine the performance of joints during the human gait. For calculating this, statistical moments and testing techniques for joints estimation variation during walk. The important quantities are used to measure the contribution of the joint movement through the walk under 3-D motion data. The calculation was carried out as described below.

3.1. Feature extraction of joints

First, we compute the features of hip, knee and ankle joints, for each of coordinates X,Y, and Z, as follows (more details about this computation is discussed in [19]).

$$\bar{X}_{hip} = \frac{1}{n}\sum_{i=1}^{n} x_{hip_i} \qquad (1)$$

$$\bar{Y}_{hip} = \frac{1}{n}\sum_{i=1}^{n} y_{hip_i} \qquad (2)$$

$$\bar{Z}_{hip} = \frac{1}{n}\sum_{i=1}^{n} z_{hip_i} \qquad (3)$$

i= 1, 2, 3 …, n

Here n is the total number of frames during a subject walk. Following the Esq. (1), (2) and (3), the features for knee and ankle can be computed in a same way as computed for hip. The calculated values of these equations can be used for one way ANOVA that will decide about equality or inequality of joints movements.

3.1.1. Compare joints feature (mean) values

Considering 7 repetitions and one-way ANOVA, the means of coordinates for different joints are compared. We compared the means of X-coordinate for hip, knee and ankle joints and a similar comparison is repeated for Y- and Z-coordinates and observed those joints which have different participation during gait. It can be seen in Table1 in experiment section.

3.1.2. Means of mean of joints X-Y-Z-coordinates

Replication is a statistical technique which is used to minimize the extraneous variation in an experiment. Generally, when an experiment performed then tried to have it several replicates (subject walk couple of times) in order to increase precision of estimates. One way to represent motion data of several replicates (couple of times walk) by a single quantity is a Grand Mean (GM). The grand mean is the mean of the means of a couple of times subject walk. In this case on each axis, we have means of each joint with seven replicates. Then further calculated its GM by averaging these sub means for each joint on each axis of the subject and it minimizes the error rate between joints rotation. The calculation were carried out as described below

$$\bar{X}_{ghip} = \frac{1}{N}\sum_{j=1}^{N} \bar{X}_{hip_j} \qquad (4)$$

$$\bar{Y}_{ghip} = \frac{1}{N}\sum_{j=1}^{N} \bar{Y}_{hip_j} \qquad (5)$$

$$\bar{Z}_{ghip} = \frac{1}{N}\sum_{J=1}^{N} \bar{Z}_{hip_j} \qquad (6)$$

j= 1, 2, 3 ………, N

Here, $\bar{Y}_{ghip}$ and $\bar{Z}_{ghip}$ are the GM of the each coordinate of the hip joint and N is the total number of times of a subject walk. In a similar way, GM can be computed for the other two joints (knee, ankle) and these values are shown in the experiment section in Table 2.

3.1.3. Least significant difference (LSD)

The least significant difference (LSD) method is used for testing the equality of two means. Here it is used to test the equality of features characteristics of each joint when one-way ANOVA rejects the hypothesis of equality of several means. We reject the equality of two means if;

$$\left|\bar{X}_I - \bar{X}_J\right| \geq LSD \qquad (7)$$

Where

$$LSD = t_{\alpha/2}(dfw)\sqrt{MSW\left(\frac{1}{n_I}+\frac{1}{n_J}\right)}$$

with dwf = d.f (within), MSW= Mean Squares Within, n_I and n_J are the respective sample sizes for what $\bar{X}_I$ and $\bar{X}_J$ have been computed. See Montgomery [22] for more details. The calculated values can be seen in Table 4 in the experimental section.

3.2. Variability of the X-, Y-Z- coordinates of the joint and Bartlett's statistic

For this, at first, we computed the variances of the means of all the coordinates of the hip joint: see more detail of variance [19].

$$S^2_{X_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\bar{x}_{hip_j} - \bar{\bar{x}}_{hip})^2 \qquad (8)$$

$$S^2_{Y_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\bar{y}_{hip_j} - \bar{\bar{y}}_{hip})^2 \qquad (9)$$

$$S^2_{Z_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\bar{z}_{hip_j} - \bar{\bar{z}}_{hip})^2 \qquad (10)$$

Here $S^2_{X_{hip}}$, $S^2_{Y_{hip}}$ and $S^2_{Z_{hip}}$ are the variances of the hip joint coordinates.

where

$\overline{\overline{x}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{x}_{hip_j}$, $\overline{\overline{y}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{y}_{hip_j}$ and $\overline{\overline{z}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{z}_{hip_j}$

are the means of the GM of the hip joint coordinates and ***r*** is the number of repetitions (i.e. 7 in our case). Similar approach used to calculate all the variation between the other two joints that is knee and ankle by following the Eq (8), (9) and (10). In order to compare the characteristic of variability between different coordinates of the joints, Bartlett's test [28] is used for equality of variances considering all coordinates of the three joints (hip, knee, and ankle).

Now, we compared the variability of the X-coordinate of the hip, knee and ankle joints by using Eq (11).

Here $s_i^2 \in \left\{ S^2_{x_{hip}}, S^2_{x_{knee}}, S^2_{x_{ankle}} \right\}$ these variances are denoted the X-coordinate of the hip, knee and ankle joints.

$$T = \frac{(N-k)\ln s_p^2 - \sum_{i=1}^{k}(N_i-1)\ln s_i^2}{1+\left(1/\left(3(k-1)\right)\right)\left(\left(\sum_{i=1}^{k}1/(N_i-1)\right)-1/(N-k)\right)} \qquad (11)$$

In the above Eq (11), s_i^2 is the variability of the youth group N_i is the total sample size, Ni is the sample size of the ith group, k is the number of groups, and sp^2 is the pooled variance. The pooled variance is a weighted average of the group variance that is defined as:

$$s_p^2 = \sum_{i=1}^{k}(N_i-1)s_i^2/(N-k)$$

Here above value of T is the critical region value and evaluate the variance value between the joints coordinate. Similarly, the following procedure of section 3.2, the variability can be compared with the other two Y, Z coordinates of the three joints (hip, knee, and ankle) and found combine performance of coordinates of the three joints and to determine joint which has more stronger (variations) during the walk. The calculated value of T can be seen in Table 5 and Figures 5, 6 and 7 also depict the variation of the joints in case of coordinates wise.

4. Results and Discussion

This section based on the above theory, we are interested to determine the performance of the three joints during the human gait. To calculate this, we used motion data available at [30] of a subject that was walking a couple of times within 280 frames and each time walks several steps. Table 3 illustrates the grand means of each coordinate of each joint and it is computed to the subject walk during several times (7 times). Table 4 shows the difference between performances (mean) of each joint of the coordinate's wise by using Eq (7). Table 5 describes the joints variance between each other's by using Eq (11) (see Table 5 and Figure 5, 6, 7 for more details.

Table 2 shows the computation of one-way ANOVA for X coordinate of each joint that there is a significant difference among the X-coordinate of hip, knee and ankle joints. A similar conclusion can be drawn for another two coordinates i.e. Y and Z. This method just gives the result about comparison of performance of the joints to each other; it does not give the results about the correct performance among of them.

Table 2. Comparison of the performance of the joints (X-, Y- and Z- coordinates for hip, knee and ankle joints)

Joint coordinates	Sum of squares	df	Mean square	F	P-values
X	Between Groups 71.543 2 Within Groups 2.7365 18 Total 74.2802 20	35.7719 0.152 235.3 0 .000			
Y	Between Groups 409.161 2 Within Groups 12.498 18 Total 421.658 20	204.58 0.694 294.65 .000			
Z	Between Groups 6055.71 2 Within Groups 49.71 18 Total 6105.43 20	3027.86 2.76 1096.35 .00			

Table 3. Grand mean of X-, Y- and Z- coordinates for hip, knee and ankle joints

Joint Name	Joint Coordinates		
	X	Y	Z
Hip	-0.3811458	-1.1208601	7.533813
Knee	3.845269	9.56590743	30.103465
Ankle	0.3414282	2.80055414	-11.440428

First, according to Table 4, it describes X coordinate all of the three joints. The hip joint compared with other two joints (knee and ankle) such as $\bar{X}_{Hip} - \bar{X}_{Knee} = -4.22641464$ and $\bar{X}_{Hip} - \bar{X}_{Ankle} = -.72257413$, knee joint compared with hip and ankle joints like as $\bar{X}_{Knee} - \bar{X}_{Hip} = 4.22641464$ and $\bar{X}_{Knee} - \bar{X}_{Ankle} = 3.50384051$. The ankle joint also compared to hip and knee like us $\bar{X}_{Ankle} - \bar{X}_{Hip} = 1.82967472$ and $\bar{X}_{Ankle} - \bar{X}_{Knee} = .72257413$, and found that at X coordinate, the knee joint has stronger performance among the three joints. Similarly, we compare the joints at Y, Z coordinate. It can easily be concluded that for all the three coordinates (X, Y and Z), knee joint is more stronger as compared to the other two joints (hip, ankle) and also found that the knee joint has more participation, when the subject walks.

Table 4. Comparison of joint's performance by using the LSD method

Joint of coordinates	Joint (i)	Joint (j)	Mean, Difference (i)-(j)	Sig
X_Axis	Hip	Knee	-4.22641464	.000
		Ankle	-.72257413	.003
	Knee	Hip	4.22641464	.000
		Ankle	3.50384051	.000
	Ankle	Hip	.72257413	.003
		Knee	-3.50384051	.000
Y_Axis	Hip	Knee	-10.68676796	.000
		Ankle	-3.92141418	.000
	Knee	Hip	10.68676796	.000
		Ankle	6.76535377	.000
	Ankle	Hip	3.92141418	.000
		Knee	-6.76535377	.000
Z_Axis	Hip	Knee	-22.56965286	.000
		Ankle	18.97424102	.000
	Knee	Hip	22.56965286	.000
		Ankle	41.54389388	.000
	Ankle	Hip	-18.97424102	.000
		Knee	-41.54389388	.000

Table 5. Bartlett's test for equality of variances

Joint coordi	Joint Name	Joint variance	Bartlett statistic	P-val
X	Hip	0.277962		
	Knee	0.158656	7.87	0.020
	Ankle	0.019463		
Y	Hip	0.48234		
	Knee	0.40586	2.00	0.367
	Ankle	1.19477		
Z	Hip	1.87058		
	Knee	4.62810	1.73	0.422
	Ankle	1.78663		

Table 5 presents the variability of the joints characteristics in case of joint movements (variances), by a Bartlett's statistic and p-values. It is also clear from Table 5 that the variances of all joints are significantly different at X- , Y- and Z-coordinates. For X-coordinate, the three joints use different participation such as: hip joint 61%, knee joint 35% and ankle joint 4%, these computed from Table 5 and shown in Figure 5. Similarly, Figure 6, 7 depict the participation of joints at Y- and Z-coordinate respectively. Figure 8 shows the overall participation of XYZ coordinate of each joint. It is concluded that knee joint has more contribution among other two joints (hip and ankle) during walk.

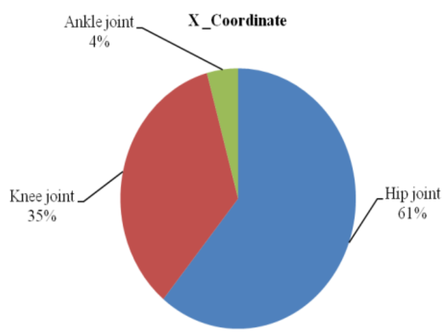

Figure 5. Participation of X coordinate of each joint during walk of a subject.

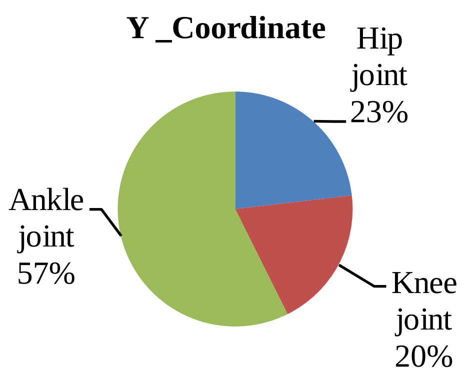

Figure 6. Participation of Y coordinate of each joint during walk of a subject.

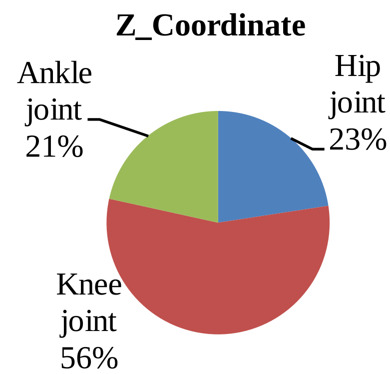

Figure 7. Participation of Z coordinate of each joint during walk of a subject.

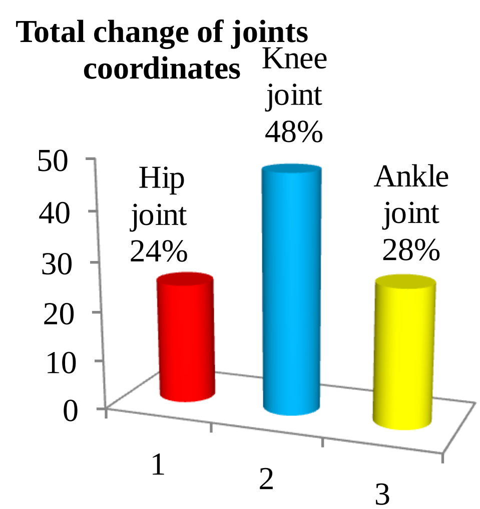

Figure 8. Contribution of XYZ coordinates in each joint during walk.

5. Conclusion and Future work

In this paper, the joint's performance is estimated through 3D joints motion data of human walking that can identify which joint has the decisive influence (more stronger) among the three joints(hip,knee and ankle). It is found that the overall movement of the knee joint has maximum influence (stronger) in human walking through statistical testing techniques (One-way ANOVA, Least Significant difference and Bartlett's test). The experimental results of this study indicated that, X-coordinate has the different movement between the three joints such as hip joint

61%, knee joint 35%, ankle joint 4%, Y-coordinate has the different movement between three joints such as hip joint 23%, knee joint 5%, ankle joint 57% and in Z-coordinate also has the different movement such as hip joint 23%, knee joint 56%, ankle joint 21%. The combine movements of three coordinates in each joint such as: hip joint 24%, knee joint 48% and ankle joint 28% show the contribution during walk. It is concluded that the knee joint has maximum influence (stronger) than the other two joints (hip and ankle). It is the first time, that BVH file is used for joint performance evaluation during walk.

In previous research, researchers had used it for animation, retarget motion and analysis and motion synthesis but not for joints participation performance by using the statistical techniques to analyze the means and variances of the joints. The research approach and results might be useful for sports technology, human motion analysis, human identification, computer animation, clinical studies and especially for physical animator. In future we would like to further strengthen the results by studying a much larger database. The used method would be extended to investigate which joint is most significant in other human action as jumping or different style of walking.

Acknowledgement

The data used in this paper were obtained from [30]. We thank them for sharing with us. This work is supported by the National Natural Science Foundation of China under Grant No.61170203, 61170170, The National Key Technology Research and Development Program of China under Grant No.2012BAH33F04, Beijing Key Laboratory Program of China under Grant No.Z111101055311056.

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12/11/2013