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Appraising the Recital of Joints in Human Running Gait through Optical Motion

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Abstract

Recital costing of Joints in human running is biometrics evaluation technology. It has skillful series of realizations in scientific research in the last decade. In this work, we present human running joints (hip, knee and ankle) valuation recital based on the statistical computation techniques. We use the One-way ANOVA, least significant difference (LSD) test and Bartlett's test for equality of variances to determine which joint has more variation with other joints during human running gait style. These three joints rotation angle data were computed from the Biovision Hierarchical data (BVH) motion file, because these joints provide the richest information of the human lower body joints (hip, knee and ankle). The use of BVH file to estimate the participation and performance of the joints during running gait is a novel feature of our study. The experimental results indicated that, the knee joint has the decisive influence (variation) as compared to the other two joints, hip and ankle, during running gait.

Keyword: *joints importance, running concept space, size up joint*.

1. Introduction

Human motion is a very complex field of study. A broad field of applications can be found for human motion synthesis and joint performance measure in human running. The current state of knowledge is presented as it fits in the context of the history of analysis of movement. Using human motion data has been a popular approach for analyzing, animation; retarget motion and synthesizing human joints motion, particularly thanks to recent improvement of motion capture systems. In particular, there has been a lot of interest in the ways of using and re-using motion capture data [1-4].

Gait joints evaluation is a kind of biometrics and clinical science defined by Michael at et [5], which uses energy and power to evaluate individual joint performance. Gait analysis methodology and clinical gait evaluation are exp

Lained in [6], more formal definition of human gait, kinesiological recording and measurement techniques is given by [7], and three-dimensional human running is given by [8]. Davis et al. [9] proposed three dimensional marker position information to determine joint moments and powers and also Diedrich at et [10] defined methods at running gait joints.Growney et al. [11] proposed a statistical approach for gait evolutions using joints kinematic and kinetic data collected on normal subjects. The range of motion of the human body joints was described by Mackenzie [12]. Dona et.al [13] performed a principal component analysis (PCA) on the data collected from subjects to determine the dependence on the knee joint angle in human gait. The PCA has also been used for gait joints analysis [14, 31]. Steudel-Numbers et.al [15] proposed a relationship between limb length and cost for human running. There are also medical applications. 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] and [25-27, 32] for representing of motion data. In this paper, we apply statistical methods to determine which joint has utmost contribution

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(variance) with the usage of the human running motion data of the BVH file, inspired by the aforementioned research.

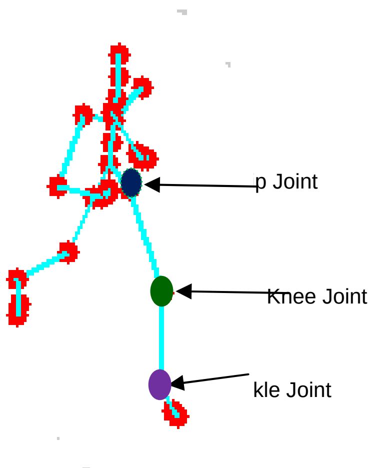

Figure 1. Skeleton Joints in Running

The motion capture data format files are explained by Meredith et al [18], it typically includes the position of the root and orientation of other joints. We have used a motion data captured from the optical motion capture system. We used BVH file format, because it is easy to extract motion data from BVH file. This file format has two parts; one is the skeleton information, can be seen in Figure 1 and other is the motion data can be seen in Table 1 and for more details [18].

By three dimension motion data, we refer to the part of the BVH file containing the data corresponding to each of the joints during movement of the skeleton. In this work, we will be concerned with three joints hip, knee and ankle. The data corresponding to these three joints in the BVH files will be called *Three Dimension Motion Data* (TDMD).

In Figure 1, showed the skeleton data structure and in Table 1 showed is an example of three joints TDMD that was computed from the BVH file. This data is running gait data of three joints that are participated to generation of the motion. The motion part is generated with the help of movement of the skeleton joints. Gait joints performance measures the participation of joints based on the style of human running gait of a subject. In this paper, an algorithm for human gait (running) joints performance evaluation is introduced. We think that it will be more helpful for motion analysis, physical animation, retarget motion, clinical field and gait recognition research. We determined, by statistical techniques, which joint has more weight during human running gait 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 human running gait. We called the *participation* of the joints during human running.The joint with the highest variance, therefore, has maximum participation and consequently is the one which has the maximum effect [20]. Based on this concept, more importance can be given to only one joint during running gait. This will greatly reduce the complexity of the problem of human gait analysis and in retarget motion and physical animation techniques in the future.

We have used it to actually extract motion data and drawn conclusions from statistical analysis of that data. This is a new and novel technique which we think will be of great use in the field of biometrics. Importance of the knee joint in running has been established in various studies (such as [8, 10, 15]) and also described gait analysis observation by Saleh at et [23]. Roach at et [24] defined range of motion of the hip and knee joints. Sajid at et [29] proposed a method to calculate the participation of the lower body joint in the human walk by using three dimensional motion data.

Table 1. Example of 3D Motion Data of Joints Extracted from BVH File with 17 Frames

Hip Joint			Ankle Joint			Knee Joint		
X	Y	Z	X	Y	Z	X	Y	Z
-4.5460	1.4421	2.3608	-0.0334	-7.8904	-4.7895	4.0793	12.2651	36.6764
-4.3387	1.7707	2.0255	0.1684	-7.0803	-8.2387	4.5927	12.9098	39.0319
-4.0652	1.9428	1.6285	0.3107	-6.9239	-10.3465	4.8878	13.2563	40.3355
-2.9478	2.0493	1.4823	0.4275	-7.3381	-11.9686	5.1050	13.5011	41.2744
-1.2787	2.0037	1.6024	0.5776	-7.1865	-13.6925	5.2359	13.6447	41.8323
0.1048	1.7511	2.0087	0.7287	-6.7494	-15.2555	5.2778	13.6900	42.0096
0.0512	1.6948	2.3671	0.8252	-7.1454	-16.2406	5.2848	13.6975	42.0390
-0.1114	1.8252	2.6543	0.9079	-7.5548	-17.0477	5.2482	13.6580	41.8842
0.0954	1.9387	2.9625	0.9588	-7.7192	-17.5212	5.1059	13.5021	41.2782
0.3216	1.9214	3.1650	0.9509	-7.7340	-17.4514	4.8928	13.2621	40.3575
0.4809	1.9248	3.2901	0.9031	-7.8396	-17.0262	4.5814	12.8963	38.9814
0.7967	2.1492	3.4701	0.8063	-7.7740	-16.1135	4.2816	12.5260	37.6190
1.2139	2.4471	3.6886	0.6547	-7.8097	-14.6076	3.9472	12.0899	36.0506
1.6840	2.7879	3.9556	0.4708	-7.7280	-12.5683	3.6316	11.6534	34.5165
1.9763	3.3398	4.2089	0.2634	-8.2147	-10.0770	3.2982	11.1628	32.8309
2.3675	3.9177	4.4975	0.0522	-8.5184	-6.9434	2.9625	10.6341	31.0555
2.2861	4.2583	4.7371	-0.1108	-8.1714	-3.0537	2.6077	10.0312	29.0777

This paper is organized as follows. Section 2, contains an overview of materials and methods and describes the construction of the database and present our proposed flowchart. Section 3 is reserved for main results and discussion. Section 4 concludes the article along with the future work.

2. Materials and Methods

Our concept is evaluation of the joints during running gait style. We selected the three important joints: hip, knee and ankle. Then we apply statistical techniques to the selected joints motion data and determine which joint has more variation in generating running gait motion. In Figure 1 and Table 1 describe file format which we use in our work. The construction of our database is displayed in Figure 3; the flow chart for of our purpose method show in Figure 4.

2.1. Constructing the Database

The process for building the proposed motion database is summarized in Figure 3; the user provides motion files of subject running in ASF/AMC format [21] represented as a pair of skeleton and motion information (joints angle). The skeleton part contains of the human skeleton, and the motion part is related to joints angle movement of the human, typically obtained by a human motion capture system. However, joint angle representation strictly depends on the skeleton model of the human. After that, these pairs of files are converted into single file as a BVH file format by using BVH Converter script techniques.

The BVH file format is populated in Biovision with the hierarchical data structure representing the bones of the skeleton. The BVH file consists of two parts: the first section details the hierarchy and initial pose of the skeleton and the second section has channeled data for each frame. These channel data are stored in different orders of xyz such as yzx, zxy and zyx. Here we have used the zyx order for generating of channel data of subject joints and arranged into xyz order. This is done to ensure there is no statistical bias towards any particular data set. We have constructed the database from the BVH files by taking an equal number of frames of the subject each running data and then stored into the database. This is called *precise database of the human motion.*

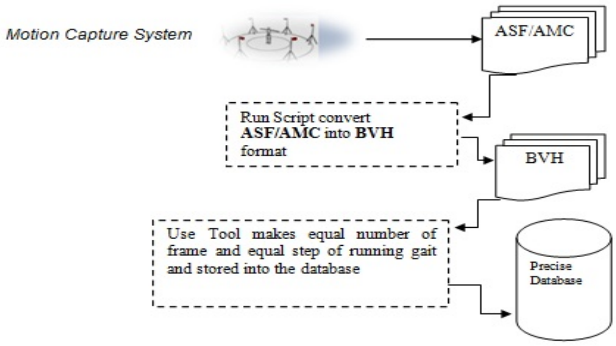

Figure 3. Architecture of the Precise Database

2.3. Our Proposed Flow Chart

The flowchart is divided into two units as shown in Figure 4: one unit is called the preprocessing unit and the second is called the calculation unit.

2.3.1. Preprocessing Unit

The preprocessing unit has three steps. The first step is taking the ASF/AMC file captured from the motion capture system. The second step is converting the ASF/AMC file into a BVH file format. Last step of the preprocessing unit is to store the BVH files, having an equal number of frames and steps on the subject for each time of running gait.

2.3.2. Calculation Unit

The calculation unit also has two steps. The first step is to extract the motion data of the concerned joints (hip, knee, ankle) from the precise motion database. The second step is to apply statistical techniques to the selected motion data of the joints and to obtain the results to measure the participation of the joints during running gait.

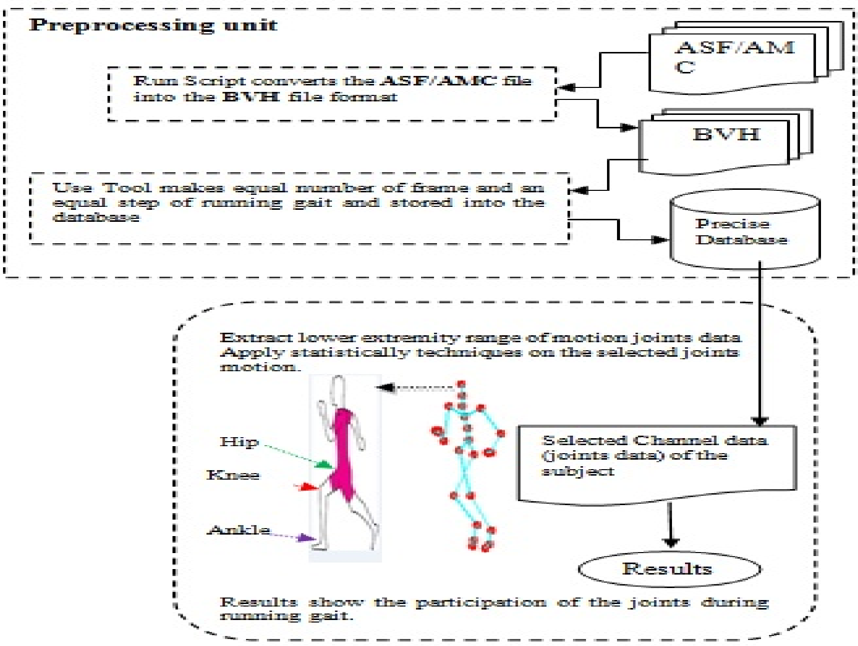

Figure 4. Flow Chart

3. Statistical Methods for Joints Calculation

As mentioned above, we are interested in determining the performance of the three joints during the human running gait. For calculating this, we used statical moments and testing techniques for joint estimation variation during running gait. The important quantities are used to measure the participation of the joints movement during running gait under 3-D motion. The calculation was carried out as described below.

3.1. Means of the X-, Y-, Z- Coordinates of the Joints

First, we computed the means of the X-, Y-, Z- coordinates for hip, knee and ankle joints as follows (for more details about the mean value we refer to [19]).

$$\overline{X}_{hip} = \frac{1}{n}\sum_{i=1}^{n} X_{hip_i} \quad (1)$$

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

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

i= 1, 2, 3 ………………..***n***

Here ***n*** is the number of frames during running. Following (1), (2) and (3) mean for the other two joints, i.e. knee and ankle, are computed. The calculation values of these equastions can be seen in the experiment section under Table 2.

3.1.1. Compare Joints Mean Values by One-way ANOVA

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 found that the joints have different participation during running gait. It can be seen in Table 3 which presents the findings of one-way ANOVA.

Table 3**.** Comparison of Means of X-, Y- and Z- Coordinates for Hip, Knee and Ankle Joints

	Joints	Sum of Squares	df	Mean Square	F	p-value
X	Between Groups	388.239	2	194.119	116.650	0.000
	Within Groups	29.954	18	1.664		
	Total	418.193	20			
Y	Between Groups	740.104	2	370.052	175.756	0.000
	Within Groups	37.899	18	2.105		
	Total	778.003	20			
Z	Between Groups	8389.309	2	4194.654	207.476	0.000
	Within Groups	363.916	18	20.218		
	Total	8753.225	20			

Table 3 shows that there is a significant difference between the means of X-coordinate of hip, knee and ankle joint. A similar conclusion can be drawn for the other two coordinates i.e. Y and Z. The one-way ANOVA just gave the result about camparison of means of considering joints but not gave the result of how much different values of each coordinate for each joint. This has followed the least significance difference method that gave result about these values.

3.1.2. Least Significance Difference (LSD)

The least significance difference (LSD) method is used for testing the equality of two means when one-way ANOVA rejects the hypothesis of equality of several means. We reject the equality of two means if;

$$\left|\overline{X}_I - \overline{X}_J\right| \geq LSD \cdot \quad (4)$$

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 $\overline{X}_I$ and $\overline{X}_J$ have been computed. See Montgomery [22] for more details. The calculatioin values can be seen in Table 4 in the experiment section.

3.2. Variances of the X-, Y-, Z- Coordinate of the Joints and Bartlett's Statistic

For this, first of all, we computed the variances of the means of all the coordinates of the hip joint, given in Table 2 as under: see more detail of variance [19].

$$s^2_{X_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\overline{x}_{hip_j} - \overline{\overline{x}}_{hip})^2 \quad (5)$$

$$s^2_{Y_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\overline{y}_{hip_j} - \overline{\overline{y}}_{hip})^2 \quad (6)$$

$$s^2_{Z_{hip}} = \frac{1}{(r-1)}\sum_{j=1}^{r}(\overline{z}_{hip_j} - \overline{\overline{z}}_{hip})^2 \quad (7)$$

Here $s^2_{X_{hip}}$, $s^2_{Y_{hip}}$ and $s^2_{Z_{hip}}$ are the variances of the hip joint coordinates and $\overline{\overline{x}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{x}_{hip_j}$, $\overline{\overline{y}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{y}_{hip_j}$ and $\overline{\overline{z}}_{hip} = \frac{1}{r}\sum_{j=1}^{r}\overline{z}_{hip_j}$ are the mean of means of the hip joint coordinates and ***r*** is the number of repetitions (i.e. 7 in our case). Following similar approach, we calculated all the variances of the other two joints coordinates as knee and ankle byfollowng Equation (5) (6) and (7). In order to compare the variances of different coordinates of the joints, we used Bartlett's test [28] for equality of variances considering of the coordinate wise of the three joints as (hip, knee, ankle).

First, we campared the variances of the X-coordinate of the hip, knee and ankle joint by using Equation (8). 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-coordindate of the hip, knee and ankle joints.

$$T = \frac{(N-k)\ln s_p^2 - \sum_{i=1}^{k}(N_i - 1)\ln s_i^2}{1 + \left(1/\left(3(k-1)\right)\right)\left(\left(\sum_{i=1}^{k} 1/(N_i - 1)\right) - 1/(N-k)\right)} \quad (8)$$

In the above, s_i^2 is the variance of the ith group, ***N*** is the total sample size, N_i is the sample size of the *i*th group, ***k*** is the number of groups, and s_p^2 is the pooled variance.The pooled variance is a weighted average of the group variance and is defined as:

$$s_p^2 = \sum_{i=1}^{k}(N_i - 1)s_i^2 / (N-k) \quad (9)$$

Here above value of **T** denoted the critical region values and evaluator the variances values.Similarly, following the procedure of section 3.2, we campared variances of the other two Y, Z coordinates of the joints (knee, ankle) and found which joint has more variation during running gait style.the calculation values of **T** can be seen in Table 5 and Figures 5,6and 7 also depicted the variation of the joints.

4. Results and Discussion

As mentioned above, we are interested in determining the performance of the three joints during the human running gait. For calculating this, we used motion data [30] of one subject that was run a couple of times with in 130 frames and each time run several steps.Table 2 showed the simple means of each coordinate for each joint in every time subject run.Table 4 showed the difference between means of each joint of the coordinates wise using eq(4)(more details are given below in Table 4).Table 5 showed the joints variance between each others usng eq(8) (see Table 5 and Figure 5,6,7 for more details)

Table 2. Means of X-, Y- and Z- coordinates for hip, knee and ankle joints

Repetition	Hip Joint			Knee Joint			Ankle Joint		
	X	Y	Z	X	Y	Z	X	Y	Z
1	-0.2655	-0.7740	3.8266	7.7897	11.9008	45.3789	1.3002	0.0103	12.8014
2	-2.0831	-2.0334	4.9725	8.2035	12.5768	47.5329	1.1039	1.9458	9.4558
3	-0.2820	-2.4342	3.7750	8.8860	11.9749	48.1651	1.5821	4.4217	16.3857
4	0.0460	-1.1708	4.3509	7.3427	12.1615	44.5491	0.5989	-1.9582	5.5401
5	-0.2522	-1.3485	4.7345	12.2890	13.4182	60.4401	0.6384	-0.1766	10.3119
6	-1.3712	-2.0227	4.5449	11.8483	12.7250	58.3214	1.3669	3.2688	15.8283
7	-1.0797	0.6972	4.7361	7.6337	11.5997	44.4397	0.9297	0.4799	8.6608

Table 5. Bartlett's test for equality of variances

Coordinates	Joints	Variances	Bartlett's Statistic	p-value
X	Hip	0.60		
	Knee	4.25	14.33	0.0008
	Ankle	0.14		
Y	Hip	1.11		
	Knee	0.38	8.54	0.0140
	Ankle	4.83		
Z	Hip	0.22		
	Knee	44.91	22.39	0.0000
	Ankle	15.52		

From Table 4, we seen that $\bar{X}_{Hip} - \bar{X}_{Knee} = -9.90.$ it showed that both the means are significantly different and Knee-joint has more contribution in running as the hip-joint for X-coordinate. Similarly, we can interpret the other results of the Y, Z coordinates. It can easily be concluded that for all the three coordinates (X, Y and Z), knee joint has largest mean as compared to the other two joints (hip, ankle).

Table 5 presents the variances, Bartlett's statistic and p-values. It is clear from Table 5 that the variances for all the joints are significantly different. Moreover, the knee joint has larger variances for X- and Z-coordinates. For Y-coordinate, the ankle joint has the larger variance to the other tow jints.Figure 6 show that the ankle joint has more contribution in comparision with other joints.Overall we have found from the calculation that knee join has more contribution when human run In this table also showed that knee joint has more contribution as compared to other two joints during human running gait

Table 4. Multiple means comparisons using LSD

Dependent Variable	(I) Joint	(J) Joint	Mean Difference (I-J)	p-value
X	Hip	Knee	-9.90	0.000
		Ankle	-1.83	0.016
	Knee	Hip	9.90	0.000
		Ankle	8.07	0.000
	Ankle	Hip	1.83	0.016
		Knee	-8.07	0.000
Y	Hip	Knee	-13.63	0.000
		Ankle	-2.44	0.006
	Knee	Hip	13.63	0.000
		Ankle	11.20	0.000
	Ankle	Hip	2.44	0.006
		Knee	-11.20	0.000
Z	Hip	Knee	-45.41	0.000
		Ankle	-6.86	0.011
	Knee	Hip	45.41	0.000
		Ankle	38.55	0.000
	Ankle	Hip	6.86	0.011
		Knee	-38.55	0.000

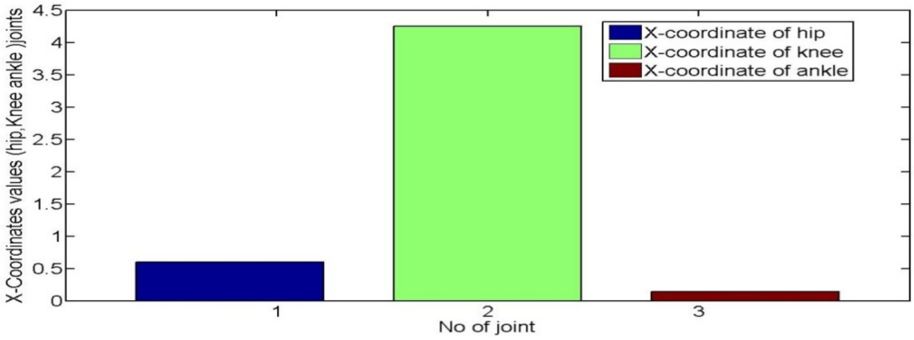

Figure 5.X-coordinate variation of the three joints (hip, knee, and ankle)

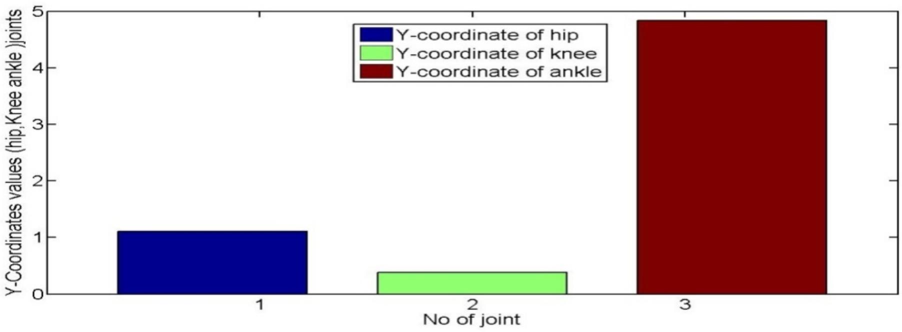

Figure 6.Y-coordinate variation of the three joints (hip, knee, and ankle)

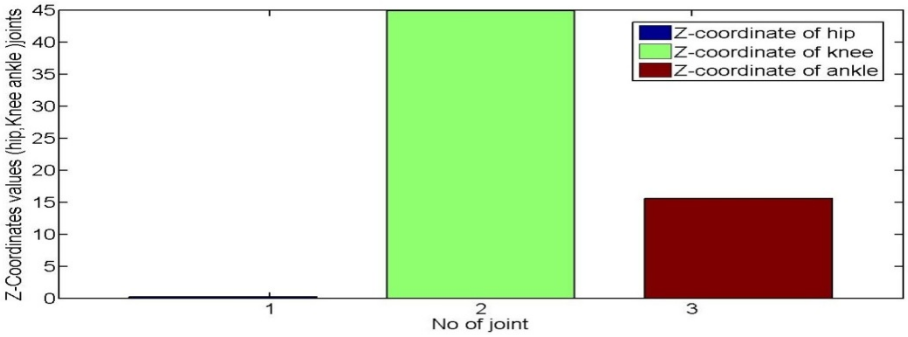

Figure 7. Z-coordinate variation of the three joints (hip, knee, and ankle)

5. Conclusion and Future work

In this paper we proposed a statistical method to estimate joint performance (contribution) approached through human running under 3-D moiton data that can identify which joint has the decisive influence among the joints in human running gait.Novelity ofour work is that we are the first, to use the BVH file for human joints to estimate the performance during running gait. Before our work, the researcher used it for animation, retarget motion [3-4] but not for evaluating the performance of the joints. The experimental results indicated that the knee joint has the decisive influence (variation) among the three joints (hip, knee and ankle) and has the largest contribution during human running gait. The research approach and results might be useful for sports, gait recognition technology, robotic, retarget motion, clinical studies and special for physical animator. In future work, we would like to further strengthen our result by studying a much larger database and result use in gait reconaiton and physical base animation.

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