Kinect Skeleton Coordinate Calibration for Remote Physical Training

Tao Wei, Yuansong Qiao, Brian Lee
Software Research Institute, Athlone Institute of Technology
Athlone, Ireland
{twei, ysqiao}@research.ait.ie, blee@ait.ie

Abstract—**With the advent of the Microsoft Kinect sensor, skeleton coordinate systems have become an active part of interactive multimedia applications. The skeleton coordinate data captured by the Kinect sensor can be used to compare the similarity of remote users' motions in remote training systems. However, this approach is limited in that the remote users' initial positions have to be at the same position and face the sensor with the same angle. This paper proposes a Kinect Skeleton Coordinate Calibration (KSCC) algorithm to calibrate the remote user's arbitrary initial positions, thereby removing the above limitations on the initial positions and angles. It collects the remote user's initial position data, and calculates the initial centre coordinate of the user and initial angle between user and Kinect sensor. After the collection and calculation, all skeleton coordinates are transformed to a universal coordinate system according to the initial centre coordinate and rotated by a quaternion rotation. An evaluation test has been performed to assess the accuracy and limiting fields of the system. The results show that our approach is able to calibrate the Kinect skeleton coordinates with a high accuracy, with the requirements that the user's initial positions only need to be in the detection zone of the Kinect sensor.**

Keywords - Kinect skeleton coordinate; calibration; remote physical training; interactive multimedia

I. INTRODUCTION

With advances in human body recognition technologies, some 3D sensors have been able to capture and analyse the human body without marker-based systems, which require the users to wear obtrusive devices. One such device is the Microsoft Kinect [1], a marker-less motion capturing sensor, which can track a user skeleton and capture data at a rate of 30 frames per second using the Microsoft Kinect for Windows SDK [1]. Each such tracked skeleton contains twenty joints' 3D coordinates [2].

Our goal is to compare the similarity of remote users' motions. Various approaches [3][4][5] have been proposed to use the skeleton coordinates captured by Kinect sensor to do body motion comparison. In these approaches, they compare two skeletons with recorded data. These recorded data have several limitations, such as the initial positions and angles of the users are the same; the length and the content of the recorded data are constant. It is easy to control their experiments using the recorded data. However, for a practical remote body motion comparison system, the users may not act exactly according to the recorded data which are used in experimental environment. The users may stand at different positions relative to Kinect sensor, i.e., different angles facing the Kinect and/or different distances from the Kinect. Users may thus get very different coordinate data for the skeleton position, even if they do the same motion. It is difficult to compare two user-motions using these data.

This paper proposes a KSCC algorithm. The main features of this approach are to "pull" the user's skeleton to the centre of the Kinect sensor and then rotate it to face the Kinect sensor. KSCC treats this position as the initial position in a universal coordinate system. In this way all users' initial positions are normalized in the universal coordinate system, irrespective of their original standing position and angle. After reconstruction in the universal coordinate system, all movements of the skeleton are referenced in the universal coordinate system. In this approach, the user needs to stand motionless for about four seconds to enable the KSCC system to collect the data of the user's initial position. This data are then used to calculate the initial angle between user and Kinect sensor (let us call it 'initial angle') and the initial centre coordinate of the user's skeleton. Then KSCC transforms the twenty joints' coordinates of the user's skeleton according to the initial centre coordinate, and rotates them about the initial centre point's y-axis by the initial angle to a universal coordinate system. Consequently, all the skeletons are transformed to the same location with the same angle relative to the sensor. As a result, when different users do the same motions, they can get the same coordinate data for their skeletons, even if their initial positions are different.

The following experiment is designed to test the KSCC algorithm. As it is difficult for two people to do exactly the same motion at the same time, we use one person as experimenter. We setup two Kinect sensors to capture the user's skeleton separately, and then run two calibration systems to detect the person at the same time. The two skeleton images captured by the two calibration systems are drawn in the same canvas. It is intuitive to compare the calibrated results. Next, the coordinate data of left and right shoulders are recorded to find out the two calibration systems' differences of value. The experimental results show that the skeleton coordinate data are accurately calibrated by the KSCC algorithm and the differences of the value are less than 4cm, given that both initial angles of the skeleton are all less than 20°.

The rest of the paper is organized as following. In Section 2, the related work is presented and compared. The Kinect system environment and details of the KSCC algorithm are described in Section 3. Section 4 presents the experiments that have been made to evaluate the KSCC algorithm. Section 5 is dedicated to the conclusion and the future work.

II. Related Work

Multimedia devices have been widely applied in remote physical training. Huang et al. [6] present a Multiple-video-based E-learning Platform for Physical Education. Their system records videos and voices in three different angles synchronously. Then, the user reviews the records to teach or learn the sports actions. Li et al. [7] propose a tennis e-learning system. In that system, a Nintendo Wii Remote is used as the input device to capture the motion of a tennis swing. The system is aimed at differentiating different types of swings. Muller et al. [8] propose a pre-processing method substantially accelerating the cost-intensive classical dynamic time warping techniques for the time alignment of logically similar motion data streams.

With the advent of the Microsoft Kinect sensor, a lot of attention has been focused on skeleton coordinate system. Tamura et al. [9] propose a three-dimensional motion capture and feedback system for flying disc throwing action learners. Their system captures learners' body movement, checks their skeleton positions in pre-motion/motion/post-motion in several ways, and displays feedback messages to refine their actions. However, they set presupposed motion in the system. It only supports throwing motion comparison. Essid et al. [3][4] propose a virtual dance performance evaluator based on 17 skeletal joints positions. It can be used to evaluate a student's performance and provide him/her with meaningful feedback to aid improvement. In their system, Kinect sensors are used to acquire a "choreography" dance rating. Three choreography scores are calculated by considering the modulus of the Quaternion Correlation Coefficient for each pair of joint position signals. The 3D coordinates of each joint are used to be input data directly. The angular skeleton representation of Raptis et al. [5] is a good method to remove dependence on Kinect position. They treat the torso as a vertically elongated rigid body. Their approach is to fit the full torso with a single frame of reference, and to use this frame to parameterize the orientation estimates of both the first-degree and second-degree limb joints. However, these approaches compare experimenter's skeleton coordinates with recorded data, not with the real people.

Due to different users' skeleton coordinates belonging to different Kinect skeleton coordinate systems, finding the relationship between the two coordinate systems is useful. A closed-form solution [10][11] is to calibrate a number of points' coordinates in two different Cartesian coordinate systems. Their approach transforms the points from one coordinate system to another using a 4 × 4 transformation matrix. However, their solution is used to solve local multiple cameras fusion problems, i.e., the multiple cameras must shoot the same object, and the system needs to know the points' coordinates data from all cameras system before calibration.

In this paper, a novel calibration algorithm KSCC that calibrates all remote users' skeleton coordinates into a universal coordinate system is presented. Unlike [3][4][5][9] the KSCC algorithm is used for a practical remote body motion comparison system rather than recorded data or presupposed motions. It reduces the limitation of the users' initial positions and angles which are constant in recorded data. Moreover, unlike the closed-form solution [10][11], the KSCC algorithm does not transform the skeleton coordinate from one skeleton to another. The remote calibration systems of both users do not need to know each other's skeleton coordinates data before calibration. As a result, the remote calibrated skeletons can be compared in a universal coordinate system for the practical remote body motion comparison system.

III. Skeleton Calibration

A. *Kinect Skeleton Coordinate System*

As shown in Fig. 1, the Kinect sensor has a practical ranging limit of 82cm~400cm [2]. The Kinect sensor also can maintain tracking through an extended range of approximately 70cm~600cm in the context of ignoring some accuracy. The field of view of the sensor is pyramid shaped. It has an angular field of view of 57° horizontally and 43° vertically, while the motorized pivot is capable of tilting the sensor up to 27° either up or down [12].

Skeleton data contain 3D position data for human skeletons. Each joint position in the skeleton space is represented as (x, y, z). The skeleton space coordinates are expressed in meters. As illustrated in Fig. 2, it is a right-hand coordinate system that places a Kinect sensor at the origin. More specifically, the positive x-axis extends to the left of the Kinect, and the positive y-axis extends upward. The positive z-axis is extending in the direction in which the Kinect is looking at.

It assumes that the distance between the Kinect sensor and floor is 100cm. And the surface on which the Kinect sensor is placed parallels the floor. Also, the Kinect sensor is not tilted, i.e., the z-axis of the skeleton coordinate system also parallels the floor.

In the context of detecting the whole body of the user, the available active area is an isosceles trapezoid area. The minimum distance D_{min} between Kinect sensor and the user can be calculated by

$$D_{min} = h / \tan (\theta_v / 2). \tag{1}$$

where h is the distance between Kinect sensor and floor. h equals 100cm. θ_v is the vertical angular field of view. θ_v equals 43°.

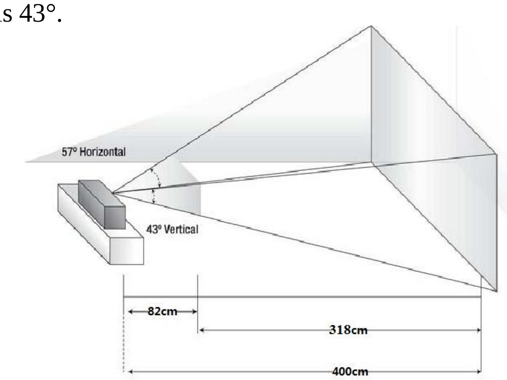


Figure 1. Detecting range of Kinect [2]

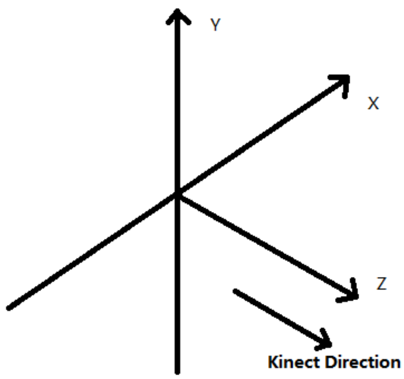


Figure 2. Kinect skeleton space

The minimum distance D_{min} equals 254cm, and the maximum D_{max} equals 400cm which is limited by the Kinect sensor.

The two bases of the isosceles trapezoid area can be calculated by

$$B = D \times \tan(\theta_h / 2). \tag{2}$$

where θ_h is the horizontal angular field of view, θ_h equals 57°. The short base is calculated when D equals D_{min}; the long base is calculated when D equals D_{max}.

Finally, the available active area is a isosceles trapezoid whose height is 146cm (D_{max} – D_{min}), and two bases are 138cm and 217cm respectively.

B. Initial Data Collection and Calculation

In order to calibrate the initial position of the user, the system collects the first 120 frames as initial data. These initial data are used to calculate the initial angle and the initial centre coordinate of the user. Since the Kinect products about 30 frames data per second [2], it suggests that the user remains standing still around four seconds.

1) Initial Angle between User and Kinect Sensor

KSCC assumes that all joints of the user are in the same plane when the user stands straight. Also, the line between left shoulder and right shoulder is treated as the horizontal line in the user's body plane. According to the initial data, it obtains the average coordinate values of left and right shoulders as:

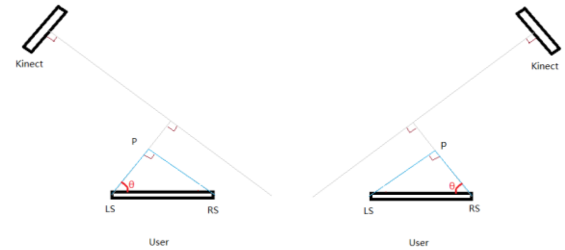
$$LS = (X_l, Y_l, Z_l) \tag{3}$$
$$RS = (X_r, Y_r, Z_r) \tag{4}$$

The initial angle has three situations:

1. The user's body plane is perpendicular to the z-axis direction of the skeleton coordinate system.

2. The user's body plane faces right direction (Fig. 3-(a)).

3. The user's body plane faces left direction (Fig. 3-(b)).



(a) (b)

Figure 3. (a) The left shoulder is closer to the Kinect; (b) the right shoulder is closer to the Kinect.

In the first situation, as the initial angle θ is 0, i.e., the user parallels the Kinect, it is not necessary to consider the angle problem. The other two situations are shown in Fig. 3. First, when the body plane faces right, the z-axis value of left shoulder (LS) is less than the right shoulder (RS). Second, when the body plane faces left direction, the z-axis value of LS is larger than the RS.

The lengths of (LS, P) and (RS, P) in the right triangles can be calculated by

$$D = Z_r - Z_l \tag{5}$$

where D is (RS, P) in Fig. 3-(a); D is (LS, P) in Fig. 3-(b).

$$W = X_r - X_l \tag{6}$$

where W is (LS, P) in Fig. 3-(a); W is (RS, P) in Fig. 3-(b).

Then, the initial angle θ is:

$$\theta = \mathrm{Atan}(D / W) \tag{7}$$

where θ is positive in the situation 2, is negative in the situation 3, and equals 0 in the situation 1.

2) Initial Centre of User's Skeleton

In order to get the initial centre coordinate of user's skeleton, the sum of all joints coordinates in one frame is calculated by

$$\vec{S}(X, Y, Z) = \textstyle\sum_j \vec{J}(X, Y, Z), \quad j = 0, \ldots, 19 \tag{8}$$

where, j is the index of joints in a skeleton.

Then, the average of the twenty joints' coordinates is treated as the centre of the skeleton in one frame:

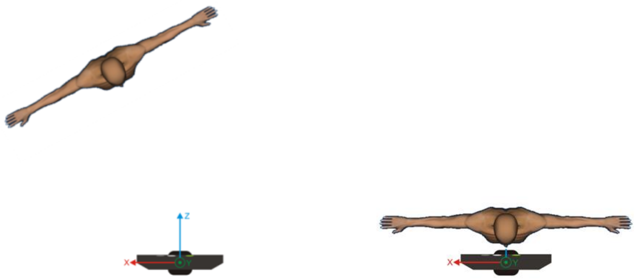
$$\vec{A}(X, Y, Z) = \vec{S}(X, Y, Z) / 20 \tag{9}$$

Finally, the initial centre coordinate of the user's skeleton in the period time can be calculated by the average of the 120 centre coordinates:

$$\vec{C}(X_C, Y_C, Z_C) = \{\textstyle\sum_t \vec{A}(X, Y, Z)\} / T, \quad t = 1, \ldots, T \tag{10}$$

where T is the total frames in the period, here T equals 120.

 ISBN: 978-1-61208-320-9



(a) (b)

Figure 4. (a) User's skeleton position before calibration; (b) user's skeleton position after calibration.

C. Transform and Rotation

After the collection and calculation of the initial position data, the initial angle θ and the initial centre coordinate vector $C(X_C, Y_C, Z_C)$ are obtained. These two results are the foundation of the calibration, and will be utilized all the time, unless the Kinect sensor is moved or the system is restarted. Then, any joint coordinates can be transformed and rotated to a universal coordinate system that places the initial centre at the origin.

As illustrated in Fig. 4, the calibration process can be regarded as pulling the original skeleton to the centre of the Kinect sensor, and rotating it to face the Kinect sensor. This is the initial position in a universal coordinate system. Thus, all users' initial positions are the same in the universal coordinate system, wherever they stand at. After reconstruction in the universal coordinate system, all movements of the skeleton are in the universal coordinate system.

Firstly, all joints are transformed to the origin of the universal coordinate system according to the initial centre coordinate:

$$\vec{P}_j(X_P, Y_P, Z_P) = (X_j - X_C, Y_j - Y_C, Z_j - Z_C,), j = 0,\ldots,19 \quad (11)$$

where X_j, Y_j, Z_j are coordinates of joint j; X_C, Y_C, Z_C are coordinates of the initial centre.

Secondly, a quaternion rotation [13] is used to rotate the coordinate vector $P_j(X_P, Y_P, Z_P)$ about the y-axis of the initial centre by the initial angle θ. The quaternion rotation is a right handed rotation. The thumb points the direction of unit rotation axis vector R which is the y-axis of the initial centre.

$$\vec{R} = (X_R, Y_R, Z_R) \quad (12)$$

where $\|\vec{R}\| = 1$. Thus, $X_R = 0$, $Y_R = 1$ and $Z_R = 0$.

The rotation quaternion [13] is defined to be:

$$Q = \cos(\frac{\theta}{2}) + X_R \sin(\frac{\theta}{2})i + Y_R \sin(\frac{\theta}{2})j + Z_R \sin(\frac{\theta}{2})k \quad (13)$$

The point $\vec{P}_j(X_P, Y_P, Z_P)$ is viewed as a quaternion without scalar part [14]:

$$Q_P = 0 + X_P\, i + Y_P\, j + Z_P\, k \quad (14)$$

Then, to rotate Q_P about the axis $\vec{R}$ by the angle θ, the quaternion rotation function [13] is defined to be:

$$Q_{PR} = Q \times Q_P \times Q^{-1} \quad (15)$$

$$Q^{-1} = \frac{Q^*}{Q \cdot Q} \quad (16)$$

where Q^{-1} is the reciprocal [14] of the rotation quaternion Q, Q* is the conjugation [14] of the rotation quaternion Q.

The result of Q_{PR} is a quaternion without scalar part:

$$Q_{PR} = 0 + (X_P \cos\theta + Z_P \sin\theta)\, i + Y_P\, j + (Z_P \cos\theta - X_P \sin\theta)\, k \quad (17)$$

Finally, the vector part of the quaternion Q_{PR} is the coordinate of the new point:

$$N_{PR} = (X_P \cos\theta + Z_P \sin\theta, Y_P, Z_P \cos\theta - X_P \sin\theta) \quad (18)$$

The system can utilize the calculated initial angle and initial centre coordinate as long as the Kinect remains in the same position.

IV. EXPERIMENTAL RESULT

In order to evaluate the accuracy of this system, a skeleton calibration experimental system (Fig. 5) is used to show and compare calibrated results from two Kinect calibration systems. The reason for using two Kinect to test one person is that it is difficult for two people to do the completely same motion at the same time. In our experimental system, for the two Kinect calibration systems, the person does the same motion all the time. Consequently, comparing the calibrated results of both systems is an effective method to test the KSCC algorithm.

Firstly, when the two systems finish the initial data collection, one system starts to send the skeleton calibrated results to another system via TCP. According to the calibrated skeleton coordinates, two skeletons which come from two systems respectively are displayed in one canvas.

Shown in Fig. 6 is an example of the image results after calibration. The left skeleton (Fig. 6-(a)) captured by the left Kinect is facing right. While the middle skeleton (Fig. 6-(b)) captured by the right Kinect is facing left. Fig. 6-(c) shows the result after calibrating the two skeletons. Both skeletons are calibrated to face the same direction, and the coordinates of corresponding joints are very close to each other. The result indicates that the KSCC algorithm is able to calibrate the Kinect skeleton coordinate system.

 ISBN: 978-1-61208-320-9

TABLE I. AVERAGE DIFFERENCES OF TWO KINECT SKELETON CALIBRATION SYSTEMS

Test Index	Left Angle	Right Angle	Angle Gap	Average Difference before Movement			Average Difference after Movement		
				X	Y	Z	X	Y	Z
Test1	-3.4648°	0.7889°	4.2537°	0.00cm	1.00cm	2.00cm	2.00cm	1.28cm	3.78cm
Test2	16.3570°	0.5013°	15.7557°	0.50cm	0.00cm	3.00cm	1.71cm	1.57cm	2.92cm
Test3	21.2544°	0.1923°	21.0621°	0.50cm	1.00cm	3.00cm	1.21cm	1.50cm	2.14cm
Test4	26.4897°	0.9105°	25.5792°	0.50cm	1.50cm	1.00cm	1.85cm	1.92cm	3.87cm
Test5	14.9705°	-12.1837°	27.1542°	0.50cm	1.00cm	1.00cm	2.14cm	1.50cm	1.64cm
Test6	30.6423°	2.0577°	28.5846°	0.50cm	0.50cm	2.50cm	4.50cm	1.50cm	5.57cm
Test7	21.0891°	-17.7214°	38.8105°	0.00cm	0.50cm	2.50cm	2.00cm	1.78cm	3.21cm
Test8	24.5130°	-19.8589°	44.3719°	1.00cm	1.00cm	1.50cm	4.28cm	1.64cm	5.28cm
Test9	24.5566°	-25.8503°	50.4069°	1.50cm	0.50cm	2.50cm	6.35cm	2.21cm	6.00cm
Test10	29.3320°	-26.0919°	55.4239°	0.00cm	1.00cm	2.00cm	4.50cm	3.21cm	5.71cm

Note: 1° = 1 degree of arc, 1cm = 1 centimetre.

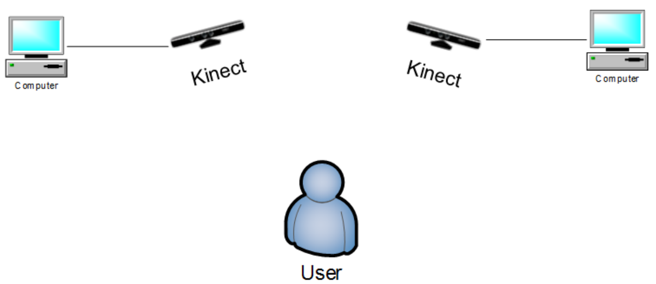
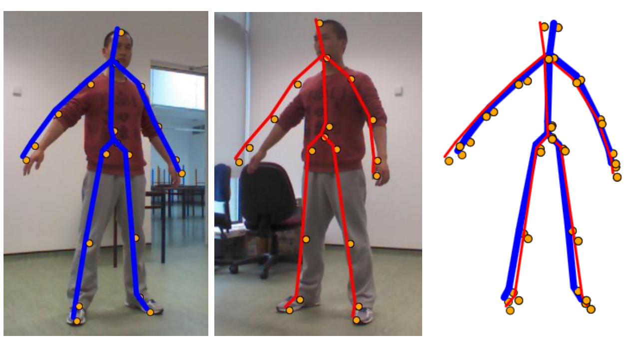


Figure 5. Skeleton calibration testing system



(a) (b) (c)

Figure 6. Original skeletons and calibrated skeletons:
(a) skeleton captured by left Kinect; (b) skeleton captured by right Kinect;
(c) calibrated skeletons result

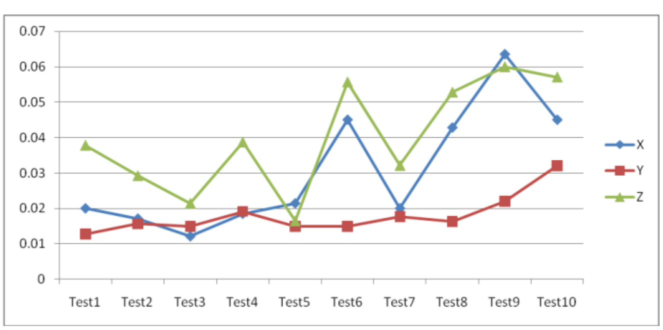


Figure 7. Average differences of 10 Tests

In order to evaluate out the accuracy of the KSCC algorithm, the relative differences for the two calibrated skeletons are also evaluated by using the coordinate recorded for the left and right shoulders as estimation of the measurement. Ten different Kinect angle classes with a total of 420 pairs of recording are evaluated. Each Kinect angle class represents different pairs of initial angles. In each test, seven different locations of experimenter (initial location, move a step forward, move a step to the left, move a step to the right, move a step backward, move a step backward and a step to the left, and move a step backward and a step to the right. All movements start from the initial location) are used to record the coordinates.

Table I shows ten tests' average differences of two Kinect skeleton calibration systems. The second column (Left Angle) is the initial angle between experimenter and the left Kinect; the third column (Right Angle) is the initial angle between experimenter and the right Kinect; the fourth column (Angle Gap) is the gap of the Left Angle and Right Angle; the following three columns are the average differences of coordinates (X, Y, Z) before movement, i.e., after calibration the experimenter still stand at the initial location; the last three columns are the average differences of coordinates (X, Y, Z) after movement, each value is calculated by fourteen pairs of recording (two shoulders and seven locations). We test the initial angle in a range from 0.1923° to 30.6423°. Since the experimenter is human, it is difficult to find absolute 0 degree. We also test the maximum workable initial angle, when the Kinect can detect all twenty joints of the experimenter. The maximum angle is up to 50°. The variation of the maximum angle depends on different standing location of the experimenter. Standing at the middle of the Kinect detection zone has smaller maximum angle than standing at the edges. And the accuracy of the Kinect will be decreased when the angle is increased. Moreover, it will increase the probability of self-occluded other body parts [15][17].

The initial angle gap is a range from 4.2537° to 55.4239°. The average differences in Table 1 show that the differences are very small (1cm~3cm). After movement, the difference increases with the increasing of the initial angle gap. The

ISBN: 978-1-61208-320-9

average differences of Y are much smaller than X and Z, and more stable. The maximum average difference is 6.35cm (Test9-X).

Test1 is intended to get the least differences, but due to the two Kinect sensors being very close in Test1, the interference with each other will result in a larger error [11]. The average differences of Test6 become large abruptly. It illustrates that the average differences not only depends on the initial angle gap, but also depends on the value of the Left Angle or Right Angle.

A random error of depth measurement increases with increasing distance to a Kinect sensor, and ranges from a few millimetres up to about 4cm at the maximum range (82cm~400cm) of the sensor [15][16]. If setting 4cm as boundary in Fig. 7, there are two kinds of solutions. Solution 1: the initial angle of one Kinect sensor is set to be around 0 degree and the initial angle of another Kinect sensor must be less than around 26.4897° (Test4). Solution 2: the two initial angles (Left Angle and Right Angle) are all less than approximately 21.2544° (Test3). Consequently, in order to control the average differences to less than 4cm, the solution of satisfying the two situations is that the two initial angles must be all less than approximately 20°.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a KSCC algorithm to calibrate the Kinect skeleton coordinate for remote physical training applications. The calibration approach is based on the user's initial position data detected by the Kinect sensor. The user's initial centre coordinate and initial angle can be calculated by the initial position data. Twenty joints' coordinates of the user are transformed according to this initial centre coordinate, and rotated by quaternion rotation to a universal coordinate system. An experiment is designed to assess the accuracy and limitation of the system. The experiment results show that the proposed method removes the common constraint in traditional motion comparison systems that the users' initial positions have to be at the same position and facing the sensor with the same angle. Instead, users are allowed to stand at any position in the detection zone of the Kinect sensor, and the initial angle is extended to 20° for a high accuracy result. This improves the consumer experience and gives users more freedom.

As a foundation work for body motion comparison for remote physical training, the KSCC algorithm still needs improvement to reduce the constraints of user's position and motion. As mentioned previously, the accuracy of the Kinect will be decreased when the initial angle is increased. And some body parts often self-occluded due to the limitation of single Kinect sensor. In future work, multiple sensors can be utilized in a 360° environment to reduce the limitation of the single Kinect sensor and extend the available active area of the users.

The Kinect based body motion comparison for remote physical training is not discussed in this paper. In the future, it will be shown that this can be done simply and easily with the KSCC algorithm. Finally, the system will be tested with real physical training motions under remote environment.

REFERENCES

[1] Microsoft Kinect, [Online] Available: http://www.microsoft.com/en-us/kinectforwindows/, December 2013.

[2] J. Webb and J. Ashley, "Beginning Kinect Programming with the Microsoft Kinect SDK," , 2012, pp. 52, pp. 67-100.

[3] S. Essid, et al., "An advanced virtual dance performance evaluator," IEEE Conference on Acoustics, Speech and Signal Processing (ICASSP), 2012, pp. 2269 - 2272.

[4] D. Alexiadis, P. Daras, P. Kelly, N. E. O'Connor, T. Boubekeur and M. B. Moussa, "Evaluating a dancer's performance using Kinect-based skeleton tracking," in ACM Multimedia, 2011, pp. 659-662.

[5] M. Raptis, D. Kirovski and H. Hoppe, "Real-Time classification of dance gesture from skeleton animation," Eurographics ACM SIGGRAPH Symposium on Computer Animation, 2011, pp. 147-156.

[6] C. H. Huang, T. L. Won, C. Y. Liu, Y. D. Chen and Y. H. Chen, "Multiple-video-based E-learning platform for physical education," Pervasive Computing (JCPC), 3-5 Dec. 2009, pp. 21-26.

[7] K. F. Li, T. Kosuke and G. J. Mark, "Motion tracking and processing for multimedia sport E-Learning," International Conference on Broadband and Wireless Computing, Communication and Applications, 2011, pp. 75-82.

[8] M. Muller, T. Roder, and M. Clausen, "Efficient content-based retrieval of motion capture data," in ACM Siggraph, 2005, pp. 677-685.

[9] Y. Tamura, K. Yamaoka, M. Uehara, and T. Shima, "Capture and feedback in flying disc throw with use of Kinect," Word Academy of Science, engineering and Technology, Feb. 2013, pp. 313-317.

[10] B. K. P. Horn, "Closed-form solution of absolute orientation using unit quaternions," Journal of the Optical Society of America, April 1987, Vol. 4, Issue 4, pp. 629-642.

[11] M. Caon, Y. Yue, J. Tscherrig, E. Mugellini, and O. A. Khaled, "Context-Aware 3D gesture interaction based on multiple Kinects," The first International conference on Ambient Computing, Applications, Services and Technologies, October 2011, pp. 7-12.

[12] Kinect Wikipedia, [Online] Available: http://en.wikipedia.org/wiki/Kinect, December 2013

[13] C. H. John, K. F. George and H. K. Louis, "Visualizing quaternion rotation", ACM Transactions on Graphics, July 1994, Vol. 13, No. 3.

[14] Quaternion Wikipedia, [Online] Available: http://en.wikipedia.org/wiki/Quaternion, December 2013

[15] J. Shotton, et al, "Real-time human pose recognition in parts from single depth images," in CVPR, 2011, pp. 1297-1304.

[16] K. Khoshelham and S. O. Elberink, "Accuracy and resolution of Kinect depth data for indoor mapping applications," Sensors (Basel) 2012, 12(2): 1437-1454.

[17] S. Obdrzalek, et al, "Accuracy and robustness of Kinect pose estimation in the context of coaching of elderly population," Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE, Aug. 28, 2012-Sept. 1, 2012, pp. 1188 - 1193.

 ISBN: 978-1-61208-320-9