Comparative Study On Gait Kinematics Between Microsoft Kinect and Vicon Across Different Anthropometric Measurements

Sagida M.A. Bilal [1], Aizreena Binti Azaman [2]

[1] School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
[2] School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

Corresponding author email: aizreena@biomedical.utm.my
Received 1 July 2019; accepted 15 July, available online 1 December 2019

Abstract: The main challenge in gait analysis is to provide an accessible and affordable mean of recording a gait test. Currently, Kinect is presented as a new innovative approach in measuring gait parameters. But then, the use of Kinect camera is limited, noticing it is focused exclusively in particular groups especially adults. Therefore, a study that encompasses walking analysis in multiple anthropometry based populations can provide a comprehensive understanding of the ability of Kinect modality in capturing human motion. In this study, Kinect capability was examined in a number of ten subjects (5 adults and 5 children). Each subject was asked to walk an overall 4m distance. Vicon capturing system and Kinect camera were used to record the walking simultaneously. Kinematics data such as hip flexion angle and knee flexion angle were recorded. The results were compared using Pearson's correlation coefficient and standard deviation. The results showed that a lower correlation between the two systems was found in terms of knee and hip flexion angles with the correlation ranging from r = -0.30 to r =0.932 in the right leg. similarly, the left leg correlation ranged from r = - 0.143 to r =0.70. Likewise, in order to examine the optimum lab setting, in terms of distance and angle position of the camera. The subjects were asked to walk to 1.5 m and then 3m distance with Kinect positioned at 90° and 75°. Unexpectedly, with the correlation results indicating that placing Kinect at 3m distance and angled at 75° harbored a better correlation. These findings suggest that in general Kinect is applicable in measuring gait Kinematics with the needed modification to the analyzing software and adjustment to the camera setting.
Keywords: Gait analysis, Kinematics, Kinect, Vicon, hip flexion, knee flexion, anthropometry, Pearson's correlation

1. Introduction

Recently, the interest in Gait analysis (GA) had risen as a well-established and promising method in studying human motion. The term 'Gait Analysis' refers to the scientific investigation of animal locomotion, particularly human walking locomotion (Wood et al., 2019). The study of gait analysis aims to evaluate, record, and make any necessary corrections for a smooth gait. The focus of gait analysis centers on evaluating human movement with the aid of tools in order to quantify normal gait and document functional deficits, and patient response to therapeutic intervention.

The human motion undergoes a constant change from infancy to adulthood (Chester et al., 2006). However, human gait is deeper than that; it is a distinctive feature of a person that is determined by, among other things, an individual's height, weight, limb length, and posture combined with the characteristic motion. Hence, a person's gait can be used as a biometric measure to recognize known persons and classify unknown subjects (Lee and Grimson, 2002).

The aims of this study are first to determine the kinematic parameters from a recorded sequence of movement (walking) for a number of children and adult using Kinect and VICON. Secondly, to compare kinematic parameters gathered using Kinect and Vicon across the different subject's. Finally, to suggest the appropriate Kinect settings and noting any associated factors counting behavioral influence and instrumental adjustments.

2. Literature Review

Microsoft Kinect is an affordable motion capturing system that can detect 25 body joints and has the capability to evaluate biomechanics events. The Kinect camera detects the human motion through two methods, by either templet reconnection or algorithm recognition. The first method uses a prerecorded templet and contrasts it to the captured motion via pattern recognition. (Lun and Zhao, 2015) These attributes made the Kinect system a valuable candidate for gait analysis applications. Several studies explored the capability of the Kinect camera in the felid of gait analysis and emphasized the comparison aspect as a means of conforming such system is appropriate for clinical gait analysis. Example of these studies is the work of Kharazi (2015) where they evaluated kinematics data at three different self-selected walking speed in the sagittal plane between Kinect and four VICON MX gold motion capture system. Aiming for Kinect to measure similar to VICON. The reached outcome was throughout the trial Kinect accuracy levels varied across the joint angles. For instance, it can track the validity of the hip joint better than knee and ankle joint. (Kharazi et al., 2015).

Meanwhile, Jebeli (2017) evaluated Kinect accuracy in providing kinematic data. By means of, equating Kinect reading with VICON in a Synchronized trial of subject walking movement, the results indicated that Kinect is highly accurate in calculating the kinematic data in the x-direction the depth direction as seen in Figure 2.6, due to the reason of the depth sensor location is in the x-direction. Moreover, they recommended the placement of the Kinect in a way that captures the movement is the in-depth direction (Jebeli et al., 2017). This outcome explains the result given by Kharazi in the way that the hip angle movement is in the X direction. Therefore, the accuracy of detecting it is higher compared to knee and ankles which are taken from the Y direction.

Further research made Kinect and VICON comparison under more precise conditions. For instants, the work of Xu in (2015) introduced subject walking on a treadmill in order to control the walking speed and two camera placements of 3.8m and 1.3m as they measured several gait parameters the interest in the knee and hip angles. The conclusion derived from Xu's work is Kinect accuracy will differ between several gait parameters (Xu et al., 2015). Specifically, rolling out the use of Kinect use for clinical gait analysis due to a joint angle difference greater than 5º is considered a clinically significant difference (McGinley et al., 2009).

Another study compiled similar testing parameters of using the treadmill and several walking speeds is research produced by Pfister. In this study, Kinect was validated by obtaining kinematic data through comparison to VICON ten camera system (Pfister et al., 2014). Noted in this study that Kinect camera was angled to 45º reasoning this selection to the Kinect-based tracking system estimates 3D position. Hence, this allows the positioning of the camera to optimize spatial distance from the subject rather than strictly keeping it normal to the plane of motion. Their results centered on angular displacement and stride timing reporting Kinect results demonstrated errors due to the selected speeds and Kinect V1 small sampling rate. A major limitation to the mentioned studies is the use of a single Kinect camera in order to capture the movement in contrast to VICON which implement a minimum of six to ten cameras per study so to fill this gap Müller tested costumed system of six Microsoft Kinect v2 cameras each connected to separate mini-computer. As for Kinect cameras arrangement, the cameras were positioned in a way that the cameras trajectories overlapped the tracking volumes. With the cameras kept at a 35º angle and 2m distance of each other (Müller et al., 2017). So as a means of evaluating the system accuracy VICON was used along with and Pearson's correlation coefficient to measure the agreement between the two systems in terms of temporal gait and spatiotemporal parameters. The outcomes were using the customized Kinect cameras system leads to excellent agreement with the VICON motion capturing system for the gait parameters step length, step width, step time, stride length and walking speed.

3. Methodology

3.1 Subjects

In order to obtain the gait data, 10 healthy subjects of 5 adults and 5 children were selected. The groups were divided into two groups the first was the adult group with an age range of 19-25 years and the second group was consisting of children aged from 7-14 years. Moreover, noting the selection condition state no limitation in terms of height nor weight. Additionally, all the subjects must be physically able to perform the test with no history of musculoskeletal disorders nor debilitating injury affecting their movements. All subject will be recruited from campus. In addition, all the participants were provided with written consent before taking part in the study and the children parents signed a parental consent form before participating.

3.2 Study Design

The experiment was carried out with VICON and Kinect operating simultaneously. In order to identify the best angle for Kinect camera, two angle setting were used which were 75 and 90 degrees to the subject. Secondly, to identify the best distance from Kinect to subject, the skeleton tracking range of 0.5m to 4.5m were tested It is important that the subject remains within the field of view of the Kinect sensor at all times, and outside of the field of view of the VICON infrared cameras to avoid possible interference during the calibration. Kinect utilized both Kinect studio SDK packet, Kinect Tool Box software and MATLAB for data collection and analysis during the trials. Meanwhile, unlike Kinect, VICON required a calibration step along with a static trial for each subject before the actual testing commenced. For the calibration, using the instruction provided by the VICON manual that includes generating new patient classification session, fixing the marker threshold and setting the capturing space, known as volume origin using the active calibration wand.

Next, the formation of the static trial, the subject stood for five seconds in the middle of the testing area in the anatomical position shown in Figure 1.1 The static trial defines the anatomical coordinate systems for the subject and the static (neutral) position of each marker. Subsequently within this process labeling for each marker had taken place depending on the anatomical position of the marker, noting the number of markers was constricted to fixed labeling provided by VICON only in this version. For instance, in lower gait measurement only sixteen markers ware available and corresponding to the same number of labels inside VICON Nexus. In this experiment, a basic full-body model marker set known as PlugInGait FullBody were used. In which 35 reflective markers ware placed on anatomical landmarks on each of the testing subjects as in Figure 1.1

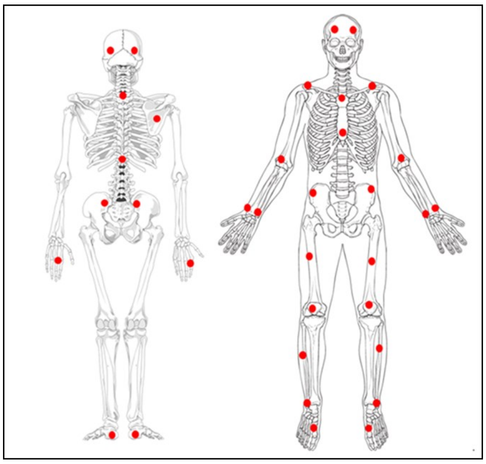

Fig. 1.1 The anatomical landmarks of the reflective marker, each group of markers representing a body segment.

3.3 Instrumentation

3.3.1 VICON Motion Capture System

VICON is a well-established marker-based motion capturing system made available through Oxford Metrics in (Oxford Metrics, Oxford, United Kingdom). For motion capture, VICON uses infrared and colored cameras that track the position of infrared reflective markers in designated space. For this experiment, the marker trajectories from several walking trials will be recorded at 100 Hz using five cameras, 3-dimensional motion capture system (MXT10 cameras, VICON Motion Systems) at the University Technology Malaysia Motion Analysis Laboratory (Johor, Malaysia). Moreover, VICON utilized two software's, VICON Nexus version 1.8.5 for collecting then processing 3D data and Polygon software version 4.3.3 for gait reporting. This system also provided additional measurement through data obtained from force plates, although this feature was only used in this research as a theoretical comparison since Kinect does not provide any base for force data measurement nor analysis.

3.3.2 Kinect

The Kinect camera made existing by Microsoft Corporation in (Redmond, Washington) Figure 3.8. Consists of an array of sensors, including a camera and a depth sensor, enabling the Kinect to track and record 3-D human motion without using controllers or markers. The system records live videos with a conventional camera and integrate these with depth information comprising a combined feed from emitted infrared light and an infrared camera. For data collection, Kinect uses The Software Development Kit (SDK) that detects the human subject within the 3-D video in real-time and extracts an artificial skeleton with joints motion over time. Then the coordinates are extracted for each joint and the software will match Vicon and Kinect sampling frequency. Additionally, after processing the outcomes will be in the form of Knee and Hip flexion angles and gait graph of both Vicon and Kinect results.

3.4 Data Analysis

3.4.1 Data Pre Processing

In the VICON recording, different markers trajectories were tracked according to a 3D model with labels for the 35 anatomical landmarks. After the initial labeling of the marker positions in the static trial, the 3D model was saved to recognize the correct labels when applied to the dynamic recordings in the walking trail. In many cases, the trajectories of some markers had gaps, and these gaps were filled using spiral and pattern filling. The gaps in trajectories usually were causes due to a marker occlusion to the cameras. Another reason for gaps were markers from one segment overlapping with another segment during movement. Additionally, for VICON recorded the result retrieved from polygon in the form of an excel file containing the kinematic and kinetic measurement for all tests. Out of the excel file, the angle measurements of all the body joints are available in the form of X, Y, Z coordinates and knee and hip angles were collected and plotted. Meanwhile, for Kinect, data was made available through and Kinect Tool Box software. In the form of a text file containing the X, Y, Z coordinates of all the body joints for each frame. Then all the frames data were compared and filtered using Mat-Lab through bandwidth filter to normalize the data.

3.4.2 Data Post Processing

The post-processing step entailed the usage of statistical means in order to further interpret the results. Henceforth, the walking trails results for the knee and hip flexion angles of VICON and Kinect were compared using the Pearson correlation coefficient (r). The correlation was used to assess the strength and direction of the linear relationships between pairs of variables (Mukaka et al, 2012). Pearson correlation coefficient analyzed data linear correlation based on several factors agents each other using Equation (1). In this case, the anthropometric differences represented in adult Vs children knee and hip flexion angles, camera distance, and camera angles. Subsequently, the Pearson correlation was calculated for each leg separately. Afterword's to calculate the total correlation out of the three trials, Fisher's Z transformation was used to find the mean of the correlation Equation (2). Furthermore, a backward transformation was made from Fisher's Z to Pearson correlation (Zsak, 2006). Standard deviation was calculated so to understand how the results vary among the group members.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \tag{1}$$

$$z' = .5[ln(1+r) - ln(1-r)] \tag{2}$$

4. Results

4.1 Subject's Anthropometry

The Gait analysis test was carried out on two groups of subjects (n=10) divided equally into adults and children with average age of 17.8 ± 5.2 years old and height of 156.5 ± 31.6 cm and body mass of 57.7 ± 16.6 Kg. Out of the group males represented 70% and females 30%. In addition, the anthropometry of each group was obtained and listed in Table 4.1 below. The mean and standard deviation are showed for both groups and the maximum value for each anthropometry was calculated and the adult group registered the highest readings in leg length (L. L=98.5cm), knee width and Ankle width. Meanwhile, the lowest values were registered in the children group for the upper and lower body measurements. Both these extreme values present in a small sample size population showed a significant impact on the overall results.

Table 1. Anthropometric Measurements of all Subjects.

Anthropometry	Adult1	Adult2	Adult3	Adult4	Adult5	Mean	S.D
Height-cm	176	153	151	177	182	167.8	14.6
Body Mass-Kg	80.7	45.7	43.3	72.9	86.2	65.76	19.9
Leg Length-cm	90.8	81.5	79.5	93	98.5	88.66	7.9
Knee Width-cm	7.3	9.2	7.4	8.2	8.7	8.16	0.8
Ankle Width -cm	6.8	5.6	5.7	6.2	7	6.26	0.6
Shoulder Offset-cm	9.8	5.5	3.7	7.1	6.6	6.54	2.2
Elbow Width-cm	9.1	7	6	8.7	8.5	7.86	1.3
Wrist Width -cm	4.9	4.3	3.95	4.8	5.7	4.73	0.6
Hand Thickness -cm	2.6	2	2	2.6	2.55	2.35	0.3

Anthropometry	Child 1	Child 2	Child 3	Child 4	Child 5	Mean	S.D
Height-cm	150	165	158	139	114	145.2	19.9
Body Mass -Kg	43.4	78	62.6	45.3	19.2	49.7	22.1
Leg length -cm	80	88.5	85	72	57.5	76.6	12.3
Knee Width -cm	7.6	9	7.1	7.5	7.5	7.74	0.73
Ankle Width -cm	6	6.6	7	6.4	5.05	6.21	0.74
Shoulder Offset -cm	6.5	4.5	3.4	4.5	4.05	4.59	1.15
Elbow width-cm	6.5	8.2	6	5.8	4.9	6.28	1.2

wrist width-cm	4.6	4.7	5	4.4	3.65	4.47	0.50
Hand Thickness -cm	1.9	2.3	2.9	2.2	1.7	2.2	0.45

4.2 Gait Kinematics

Knee and hip flexion angles were obtained from both recording means (Kinect and Vicon), Kinect results differ from Vicon in a number of important ways. For instance, the evidence derived from the correlation result showed a weak connection between the two devices. This outcome is consistent in both groups were the correlation score ranged between (r = -0.777) to (r =0.775) in the adult group. While in children's group the correlation score ranged from s (r = -0.720) to (r =0.766). Another difference between Kinect and Vicon is the presence of a high standard deviation of (SD= 9.81) and (SD= 7.54) measured in the left and right knee and hip flexion angles. This outcome indicts that the data points are widely spreading from their mean. In addition, the subject's size influenced the outcome dramatically particularly in knee flexion were the correlation value improved with the increment of age-related body size. Meanwhile, this outcome was not consistent at hip flexion angles, reinforcing the fact that hip flexion was difficult to obtain from the presented data. Table 2 and Table 3 shows the correlation results and Fisher's z transformation listed for Adult and children group across two kinematics; knee and hip flexion. These findings were unexpected and suggested that Kinect recording is affected by the diversity in the anthropometric data as evident by the lower correlation is linked to increased limb length. Similar findings were observed across the literature specifically the work of Andersson (2015) in a sample of 140 volunteers, the subject's anthropometry influenced the accuracy of gait measurement in 63% of the subjects (Andersson et al., 2015).

Table 1. Fisher's z transformation and correlation coefficients for lift and right Hip Flexion.

Gait Kinematics: Hip Flexion					
Subject	**Age**	**ZL**	**ZR**	**rL**	**rR**
Child 1	7 years	-0.768	0.667	-0.646	0.583
Child 2	9 years	-0.153	-0.298	-0.151	-0.290
Child 3	9years	0.073	0.315	0.073	0.305
Child 4	13years	-0.909	0.625	-0.720	0.554
Child 5	15 years	0.516	1.011	0.474	0.766
Adult 1	20 years	-0.257	0.054	-0.252	0.054
Adult 2	20 years	-0.294	0.486	-0.286	0.451
Adult 3	25 years	-0.307	0.608	-0.298	0.543
Adult 4	25 years	-0.003	-0.172	-0.004	-0.171
Adult 5	25 years	-1.038	0.743	-0.777	0.631

Gait Kinematics: Knee Flexion					
Subject	**Age**	**ZL**	**ZR**	**rL**	**rR**
Child 1	7 years	-0.033	0.082	-0.033	0.082
Child 2	9 years	0.282	-0.299	0.275	-0.290
Child 3	9years	0.272	0.318	0.265	0.308
Child 4	13years	-0.178	0.657	-0.177	0.576
Child 5	15 years	0.562	0.297	0.509	0.288
Adult 1	20 years	0.861	0.406	0.697	0.385
Adult 2	20 years	0.433	0.097	0.407	0.097
Adult 3	25 years	0.559	0.601	0.507	0.538
Adult 4	25 years	1.032	0.553	0.775	0.503
Adult 5	25 years	0.287	0.258	0.279	0.253

4.3 Discussion

Examining the final results, the most important clinically relevant finding was the correlation presents between Kinect and Vicon. Even though the correlation as weak, and thus addressing the reasoning behind such an outcome. We found out that the absence of anthropometry consideration in the Kinect analyzing software and lack of calibration for Kinect lead to inconsistencies in the recording process. These findings coincide with similar studies. Andersson and Wang considered this absence as a primary reason for the error in Kinect recording (Andersson et al., 2015; Wang et al., 2015). Moreover, the kinematic data recorded with Kinect favored Knee flexion correlation better than hip flexion (Pfister et al., 2014). In addition to that, the inspected laboratory setting indicated in term of distance 3m was the best for recording because it allowed for full skeleton pipeline detection and gait cycle generation (Mentiplay and Clark, 2018). Consequently, after analyzing the behavioral influence on Kinect recording process, it becomes evident the relationship between walking speed and the correlation. The relationship is clearer while the camera is positioned at a 75° angle. Indicating a positive regression in knee flexion angles and on the opposite side in the hip flexion, a negative regression was noticed when the walking speed increased.

Acknowledgment

We thank our colleagues from Universiti Teknologi Malaysia who provided insight and expertise that greatly assisted the research. Our acknowledgment extends to all the participants and their families for aiding in the recording and data gathering process.

5. References

[1] Wood, Tyler A, et al. "Balance and Gait Alternations Observed More Than 2 Weeks after Concussion: A Systematic Review and Meta-Analysis." *American journal of physical medicine & rehabilitation* (2019). Print.

[2] Chester, Victoria L, Maureen Tingley, and Edmund N Biden. "A Comparison of Kinetic Gait Parameters for 3–13 Year Olds." *Clinical Biomechanics* 21.7 (2006): 726-32. Print.

[3] *Gait Analysis for Recognition and Classification*. Proceedings of Fifth IEEE International Conference on Automatic Face Gesture Recognition. 2002. IEEE. Print.

[4] Lun, Roanna, and Wenbing Zhao. "A Survey of Applications and Human Motion Recognition with Microsoft Kinect." *International Journal of Pattern Recognition and Artificial Intelligence* 29.05 (2015): 1555008. Print.

[5] *The validity of Microsoft Kinecttm for Measuring Gait Parameters*. 2015 22nd Iranian Conference on Biomedical Engineering (ICBME). 2015. IEEE. Print.

[6] Jebeli, Mahvash, Alireza Bilesan, and Ahmadreza Arshi. "A Study on Validating Kinectv2 in Comparison of Vicon System as a Motion Capture System for Using in Health Engineering in Industry." *Nonlinear Engineering* 6.2 (2017): 95-99. Print.

[7] Xu, Xu, et al. "Accuracy of the Microsoft Kinect™ for Measuring Gait Parameters During Treadmill Walking." *Gait & posture* 42.2 (2015): 145-51. Print.

[8] McGinley, Jennifer L, et al. "The Reliability of Three-Dimensional Kinematic Gait Measurements: A Systematic Review." *Gait & posture* 29.3 (2009): 360-69. Print.

[9] Pfister, Alexandra, et al. "Comparative Abilities of Microsoft Kinect and Vicon 3d Motion Capture for Gait Analysis." *Journal of medical engineering & technology* 38.5 (2014): 274-80. Print.

[10] Müller, Björn, et al. "Validation of Enhanced Kinect Sensor Based Motion Capturing for Gait Assessment." *PloS one* 12.4 (2017): e0175813. Print.

[11] Mukaka, Mavuto M. "A Guide to Appropriate Use of Correlation Coefficient in Medical Research." *Malawi Medical Journal* 24.3 (2012): 69-71. Print.

[12] Zsak, MI. "Decision Support for Energy Technology Investments in Built Environment." Master Thesis Norwegian University of Science and Technology. http://www …, 2006. Print.

[13] *Person Identification Using Anthropometric and Gait Data from Kinect Sensor*. Twenty-Ninth AAAI Conference on Artificial Intelligence. 2015. Print.

[14] *Evaluation of Pose Tracking Accuracy in the First and Second Generations of Microsoft Kinect*. 2015 international conference on healthcare informatics. 2015. IEEE. Print.

[15] Mentiplay, Benjamin F, et al. "Gait Assessment Using the Microsoft Xbox One Kinect: Concurrent Validity and Inter-Day Reliability of Spatiotemporal and Kinematic Variables." *Journal of biomechanics* 48.10 (2015): 2166-70. Print.