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Evaluation of Calibrated Kinect Gait Kinematics Using a Vicon Motion Capture System

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KEYWORDS Gait analysis; kinect; vicon; gait kinematics

1. Introduction

Human gait analysis has been widely investigated in several applications: identification of gait impairments, therapy designing for rehabilitation, sports medicine, design of orthoses and prosthetics. Most often, gait analysis requires the use of expensive and complex devices, and as well, the experimental protocol is complicated and demands various steps. In this context, the Microsoft Kinect, a free video gaming controller, could be employed in clinical applications as a low cost and easy-to-use motion capture system.

Several studies have been conducted in evaluating the Kinect sensor using another gold standard device (Springer & Seligmann 2016)(Pfister et al. 2014). For these works, gait kinematic parameters were obtained independently from each system. In the negative, we performed a calibration procedure between the Kinect and the Vicon gold standard device. Thereby, kinematics data can be written in the same reference frame, and hence, joint centers can be defined as same for both systems. The aim of this work is to evaluate the validity of the Kinect for gait kinematics analysis in comparison to the Vicon system where a Cartesian calibration is made for both motion capture devices.

2. Materials and methods

The gait experiment was performed in PPRIME institute (RoBioSS team, University of Poitiers, France). Our experimental system consists of: i) a Kinect Xbox 360 running at 30Hz (640 × 480), ii) a Vicon system (Vicon, Oxford, UK) made out of 10 T40 cameras sampled at 90 Hz (2352 × 1728) and iii) a Treadmill (Figure 1). The Kinect was placed at a height of 0.75 m and in front of the treadmill such that the walking area is situated within a distance of 1.4 to 3 m.

A 25 years old healthy male subject having a tall of 1.75 m was recruited to perform the walking trials. A set of reflective markers was placed on the skin via double-sided tape. The participant performed 110 s of walking at two velocities: 1.4 m/s and 2.0 m/s. The calibration procedure consists on determining the coordinates of the Vicon calibration wand markers

(Figure 1) using the Kinect in order to write the transformation matrix from one system to the other. Thereby, the positions information was obtained in the same global frame.

On the one hand, markers positions were computed and exported using Vicon Nexus software. On the other, a Kinect application, based on the Kinect for Windows SDK 1.0 was developed to get and save tracked skeleton frames. Steps of post-processing are conducted using Matlab, such steps include: joint centers identification (using geometric sphere fitting method for the hip and a mean position between medial and lateral markers for the other joints), time synchronization and resampling, computing of joint Cartesian trajectories and angular kinematics, and lastly, data smoothing employing Butterworth filter. More details can be found in (Lamine et al. 2017).

In contrast to previous Kinect gait analyses, the joint Cartesian trajectories using the Kinect were shifted with mean values of the Vicon ones, thanks to the applied calibration procedure. The objective is to coincide joint centers since they are well identified using the Vicon system and their Kinect definitions are unknown.

The comparative study was carried out using 6 descriptive gait parameters: the peak angles of flexion and extension for the hip, knee and ankle joints (Figure 2): Hip F, Hip E, Knee F, Knee E, Ank F and Ank E. I.e., H5, H3, K5, K3, A3 and A5 as described in (Benedetti et al. 1998).

The statistical analysis consisted of characterizing variability via Mean (SD) values in peak angles for both right and left lower limbs. Then, the agreement between the two system is verified through paired computing of: Person's correlation coefficient (Vicon, Kinect), mean (SD) of the difference (Vicon-Kinect), and linear regression slope (Vicon vs Kinect).

3. Results and discussion

During the 110 s of walking, about 70 gait cycles were identified, leading us to obtain mean (SD) descriptive statistics of peak angular displacements (Figure 1) and agreement coefficients (Table 1).

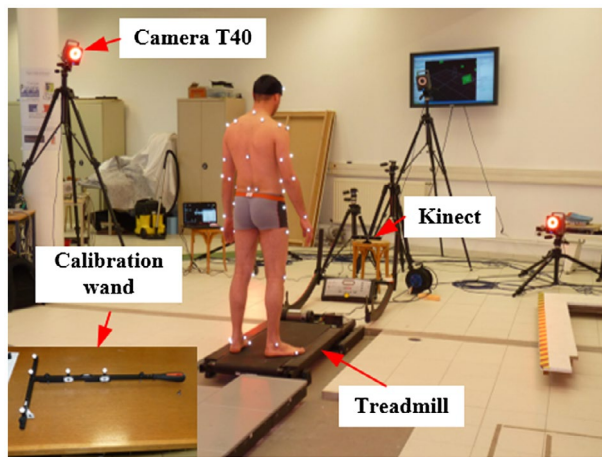


Figure 1. The experimental setup.

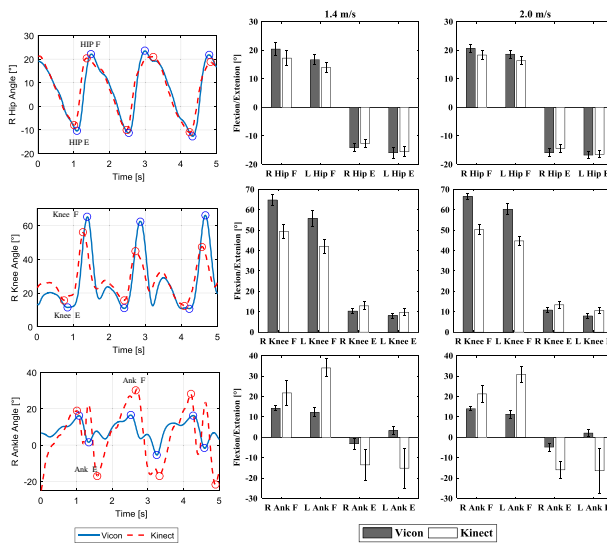


Figure 2. Angular displacement curves and Mean (SD) statistics of peak flexion and extension angles for the hip, knee and ankle joints (R: right, L: left, F: Flexion, E: Extension and Ank: Ankle).

Figure 2 depicts gait displacement curves for a 1.4 m/s velocity, a first observation can be stated: peak flexions are very close for the hip joint, underestimated for the knee joint and overestimated for the ankle joint.

Examining the right hip joint, mean R Hip F for 1.4 m/s velocity is 20.41° for Vicon and 17.27° for Kinect, a difference of 3.17° is consistent, and in addition, variabilities (i.e., SD) of each system are close: 2.21° vs 2.72°. The increase in velocity to 2.0 m/s doesn't induce remarkable changes. The correlation coefficient r is 0.86 and the linear relationship m is 1.06, thus a good concordance can be noted. Considering the left limb or the peak in extension, similar results are reported.

For the knee joint, the error rises to 15.43±2.65° for R Knee F but still consistent leading to a slope of 0.91. Surprisingly, when velocity increases to 2.0 m/s the correlation and the slope drop to 0.24 and 0.38 respectively, however, the error is still consistent: 16.21±2.54°.

Moving to the ankle articulation, a maximum non-consistent error of -21.81±4.38° for L Ank F and 18.49±9.46° for L Ank E are calculated. In addition, weak correlation and

Table 1. Correlation, error and slope of the Vicon vs Kinect.

	1.4 m/s			2.0 m/s		
	r	Error	m	r	Error	m
R Hip F	0.86	3.17±1.40	1.06	0.82	2.29±0.96	0.92
L Hip F	0.84	2.69±1.04	0.89	0.85	2.25±0.77	0.93
R Hip E	0.80	-1.44±0.92	1.06	0.86	-1.50±0.7	0.92
L Hip E	0.92	-0.38±0.78	0.89	0.77	-0.27±0.85	0.93
R Knee F	0.69	15.43±2.65	0.91	0.24	16.21±2.54	0.38
L Knee F	0.73	13.68±2.64	0.68	0.61	15.53±2.16	0.51
R Knee E	0.56	-2.57±1.68	0.91	0.29	-2.55±1.89	0.38
L Knee E	0.25	-1.73±1.92	0.68	0.19	-2.62±1.83	0.51
R Ank F	0.34	-7.52±5.75	1.66	0.09	-7.28±4.21	0.37
L Ank F	0.25	-21.81±4.38	0.51	0.30	-19.58±3.92	0.64
R Ank E	0.18	10.37±7.54	1.66	0.05	11.15±4.48	0.37
L Ank E	0.27	18.49±9.46	0.51	0.18	18.46±10.08	0.64

slope are found for L Ank F: 0.25 and 0.51 respectively. For 2.0 m/s velocity, almost results still not changing.

So far, high correlation $r > 0.70$ and linear regression slopes $m > 0.89$ were found for the hip joint. Further, the maximum error 3.17±1.4° is weak and regular. The knee joint comes in second place with fairly acceptable values, indeed, a mean flexion error of about 15° is steady.

Lastly, the ankle joint was overestimated in flexion and in extension with a mean error varying approximately from 4° to 20°. Nevertheless, the error SD was more or less weak. Further, correlations and slopes are most often below 0.5.

4. Conclusions

In this study, we have found that the Kinect, with a Cartesian calibrated joint centers in relation to the Vicon system, follows accurately the hip joint. Besides, changes in angular displacement of the knee joint were tracked acceptably. Lastly, the ankle angle, which is omitted in several studies (Springer & Seligmann, 2016), was the most difficult to track, however, representative traces can be assessed. Therefore, only for the hip joint, the Kinect can be used in clinical applications. Nevertheless, more intensive validations are substantial.

One shall notice that first visual remarks were confirmed using the statistical analysis. In summary, the Kinect was able to track changes in gait kinematics, and further, unity slopes were found (E.g. 1.06 for R Hip F and R Hip E and 0.91 for R Knee F and R Knee E), thus, we believe that by the use of appropriate preliminary calibrations and with further algorithms improvement, the gait kinematics could be precisely assessed.

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