EXAMINATION OF AN APPLICABLE RANGE FOR A MARKERLESS MOTION CAPTURE SYSTEM IN GAIT ANALYSIS

T. Sakurai[1], and H. Okada[1]

[1]The University of Electro-Communications, Tokyo, Japan

This study aimed to verify the measurement accuracy of a markerless motion capture system using OpenPose in comparison with the conventional motion capture system using infrared cameras and to discuss an applicable range for the markerless motion capture system. We verified the accuracy of the system by calculating errors in the fundamental parameters of gait analysis. Those errors were 4.42 ± 2.02° in hip angle, 4.26 ± 2.54° in knee angle and 5.93 ± 4.31° in ankle angle. The verification test revealed that this markerless motion capture system could be readily available, at least in the case of collecting 2D kinematics in the sagittal plane for gait motion.

KEYWORDS: OpenPose, Accuracy verification, Kinematics

INTRODUCTION: Recently, there has been a great deal of interest in markerless motion capture systems for gait measurement, and various methods have been developed. However, the measurement accuracy of these methods is lower than that of optical motion capture systems such as OptiTrack and Vicon, and the applicable range is unclear.
We previously reported the accuracy verification of a markerless motion capture system using Kinect v2 and Motion Mobile Visualizer-AKIRA (SYSTEM FRIEND, Inc., Hiroshima, Japan) (Sakurai and Okada, 2020). This system could measure 3D gait motion by a single time-of-flight camera. Conversely, it demonstrated low accuracy in ankle joint kinematics and was difficult to use for gait motion analysis that required ankle joint angle or foot segment angle.
Therefore, we focused on a system using a video camera and OpenPose (Cao et al., 2017) as the method, which could only acquire 2D data by a single camera but is expected to have better accuracy.

METHODS: Seven healthy males participated in this study (age: $22.6 \pm 1.8\ yrs$, height: $1.68 \pm 0.05\ \mathrm{m}$, weight: $61.7 \pm 9.4\ \mathrm{kg}$). The subjects walked freely with their shoes on a walkway 8 m in length. Gait motions were measured concurrently using infrared cameras (OptiTrack Prime13, NaturalPoint, Inc., Oregon, United States) at 200 fps. In the markerless system, the coordinates of the anatomical landmarks were calculated using the estimated skeleton model from the video data (640×512 pixels) using OpenPose (v1.6.0) after adjusting image intensity values. Figure 1 shows an example of skeletal recognition. In the motion capture system (Mocap), the coordinates of the anatomical landmarks were obtained from 49 reflective markers. To clarify the differences according to the systems, we analyzed the left lower extremity (the whole leg on the near side of the camera in all subjects) during one gait cycle. We calculated the lower extremity joint angles in the sagittal plane during walking using the coordinate data obtained from each system. The cutoff frequency of the Butterworth low-pass filter was set to 6 Hz for smoothing. In this comparative verification, the value from the Mocap was regarded as a true value, and the errors were calculated. We calculated the time series data of the hip, knee, and ankle angles in the sagittal plane as a displacement from the standing posture. Time was normalized so that one gait cycle from the foot contact to the next contact was 100%.

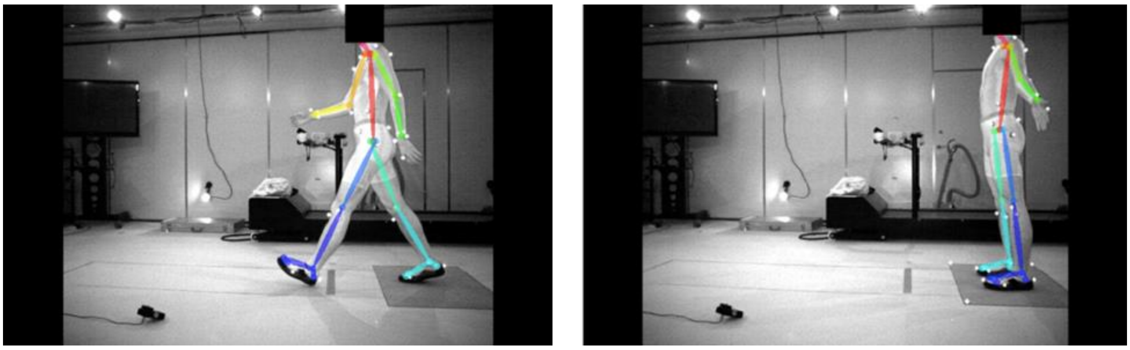

Figure 1: The skeleton model estimated by OpenPose (left: gait, right: standing posture). A number of pixels per real length was approximately 240 pixel/m.

RESULTS: The joint angle errors measured by OpenPose systems are shown in Table 1. These errors are the average values during one gait cycle. The correlation coefficients (r) show that all the joint angles are strongly related to the true value. The variations in the correlation coefficient (r) were very small, indicating that the measurement was applicable, regardless of the subjects. However, the angles from OpenPose were measured to be smaller than they should be as an overall tendency.

Table 1: Errors and correlation coefficients between the systems in lower joint angles.

Joint	Error (deg)	RMSE (deg)	r
Hip	-1.13 ± 2.02	4.42 ± 2.02	0.992 ± 0.003
Knee	-1.67 ± 2.54	4.26 ± 2.54	0.994 ± 0.004
Ankle	-3.22 ± 4.31	5.93 ± 4.31	0.917 ± 0.032

A comparison of the means and standard deviations for the time series data of each angle is shown in Figure 2. From this figure, there seems to be a tendency of high similarity in almost all phases, except for a part of the ankle joint.

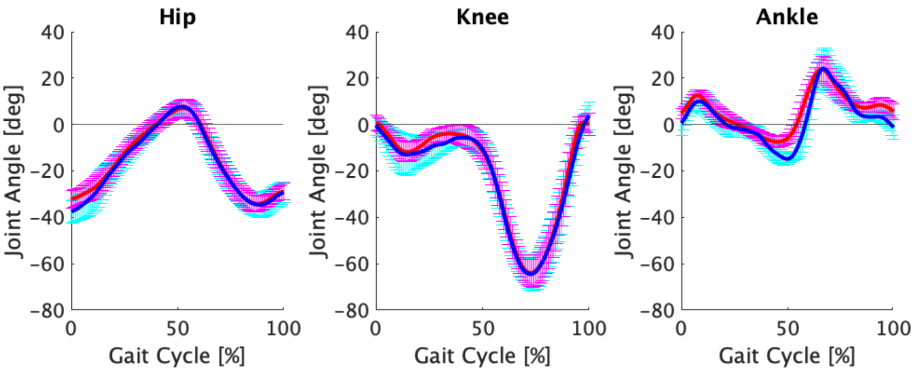

Figure 2: Left lower extremity joint angles (red line: Mocap; blue line: OpenPose).

DISCUSSION: As a result of the comparison, errors of approximately 5° between the systems were observed in lower extremity joint angles. These errors, which were particularly notable in the ankle joint angle, could be attributed to the perspective error in the 2D measurement. The problem could be improved by the improvement of the measurement method, such as a measurement in 3D using a multiple camera and an increase in the camera distance. On the other hand, those angles were found to have a strong correlation with the true value in all subjects. This suggests that skeleton tracking using OpenPose can be acquired with high similarity to the real skeleton. However, it is necessary to perform measurements under various conditions to apply this method in practice. Further studies are needed to clarify the effects of the measurement environment and the subject's clothes. In addition, we intend to collect and analyze extensive gait data using this method.

CONCLUSION: We compared the fundamental parameters of gait analysis acquired by the markerless measuring system using a video camera with those of a conventional system using infrared cameras and examined the applicable range of the markerless system. To some extent, the present study has demonstrated the availability of OpenPose as a markerless motion capture system for use in the automatic analysis and construction of a database of walking motion.

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