Evaluation of Kinect as an Analysis Tool for Kinematic Variables of Shoulder and Spine Motions

Zengwu Duan[1], Jinzhuang Xiao[2], Hongrui Wang

College of Electronic and Information Engineering, Hebei University, Baoding, China

[1]duanzengwu@163.com; [2]robot@hbu.edu.cn

***Abstract*-Specific kinematic actions of the spine and shoulder are useful for low back pain (LBP) assessment and treatment. However, the widespread application of motion capture systems in clinical settings is limited by the tedious process and expensive equipment. As a cost-effective and portable device, Kinect has the potential to be used in clinical analysis and rehabilitation for patients with LBP. Using Kinect and a motion capture system, 10healthysubjectsperformed left/right bending and extension tasks five times successively with and without simulated motion limitations. The mean range of motion (ROM)and maximum angular velocity (MAV) were then calculated. The results revealed that the Pearson's correlation coefficient was more than 0.7 with ROM. The root-mean-square error (RMSE) of the ROM difference, with and without motion limitation, was1.2°–3° (for MAV: 4.7°/s–14.6°/s). In conclusion, Kinect can be used as an analysis tool for kinematic variability of shoulder and trunk motion, which could help obtain low back information regarding movement patterns and strategies under various movement tasks.**

Keywords- Low Back Pain; Kinect; Assessment; Motion Capture; Range of Motion; Maximum Angular Velocity

I. INTRODUCTION

Low back pain (LBP) is a common and costly ailment throughout the world. The total cost of LBP is estimated to be more than $100 billion per year[1].Low back pain is one of the most common reasons for individuals to seek medical care, with chronic pain complaints estimated as high as 80%[2].New clinical methods of rehabilitation and methods that improve upon currently available therapies are constantly being proposed[3]. However, LBP is still a complicated disease that lacks accurate diagnosis procedures and effective treatments. Physical function tests and clinical treatment history are the basis of the current standard of medical treatment for patients suffering from LBP. Still, because of the uncertainty of individual differences among patients, many scales and questionnaires are still used[4]. The kinematic values of the trunk and shoulder in specific actions can provide valuable information about the movement patterns and strategies involved in various movement tasks. Moreover, evidence has shown that the three-dimensional magnitude of spinal movements is significantly reduced in subjects with LBP compared to healthy subjects. Study results show that the range of motion (ROM) and mean angular velocity are different between LBP sufferers and control groups because individuals with LBP develop trunk stiffness as a protective strategy [5,6]. The use of angular velocity and ROM as clinical parameters may improve the diagnosis of patients with LBP and could be a key indicator for treatment and long-term care[7]. Previous studies involving body postural kinematics have primarily used motion capture systems as data recording devices to track the coordinate values of markers stuck to the skin of participants [8-10].However, motion capture systems with markers are not always suitable for young children and patients who are unable to stand for long periods of time wearing complicated equipment. Because of the exorbitant price and large size, measurement and analysis can only be performed in specific places. Therefore, widespread use of these devices in clinical departments or at the patient's home is not feasible.

Kinect is a markerless motion capture system that is inexpensive, powerful, expandable, and can be used in real-time. The system includes an RGB image sensor and an infrared depth sensor for recording video. Kinect is able to recognize and extract twenty joint data simultaneously without markers attached to body, and provides an interface with which to develop the program. Kinect-based systems have been previously used as rehabilitation tools to assist people with cerebral palsy, muscleatrophy, and balance problems[11-13]. Evidence shows that these systems can accurately measure the total centre of mass and lateral trunk lean angles during postural control tests, which is a typical movement of people with cerebral palsy and upper-extremity ailments[8, 14-16].

Although previous studies have validated the use of Kinect, its accuracy has not been fully established in trunk motion. This endeavour tested a group of healthy adults performing free and limited motions to expound on previous reports on the accuracy of the Kinect system in measuring trunk and shoulder kinematics. The aim of this research was to compare the mean ROM and mean maximum angular velocity(MAV) of the shoulder and spine recorded by the markerless Kinect against a marker-based motion capture system during specific movements, including left/right lateral bending in the frontal plane and extension in the sagittal plane, to determine the validity of using Kinect as a tool for obtaining prompt kinematic information.

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II. METHODOLOGY

A. Participants

Ten healthy young adult subjects(5 females and 5 males, age 25.9±1.7 years, height 171.5±7.3cm, weight 65±6.1kg) from Hebei University volunteered to participate in the experiment. The participants reported no injuries, illnesses, or LBP. All subjects gave informed consent.

B. Instrumentation

First, the subjects were asked to stand barefoot on the floor in front of a motion capture system consisting of 12 V100R2 cameras and Motive software (NaturePoint Ltd, USA), which was operated at a sampling frequency of 100 Hz.V100R2cameras were used as measurement standards with a resolution of 640x480, 20s–1ms shutter speed, submillimeter accuracy, and the ability to save the coordinates of the data in a*fbx* format[17]. Five reflective markers were attached to tights outfitted in the motion capture system, which included two markers on the acromium process, one on the seventh cervical vertebra, and two on the posterior superior iliac spine (Fig. 1). Kinect was set with a skeleton image frequencyof30 Hz, placed 2.5m from the subjects. The smoothing parameters were set at default, correction factor0.5, smoothing factor 0.5, jitter radius 0.05 m, maximum deviation radius 0.04 m. Kinect was programmed with software development kit version 1.8 (Microsoft Ltd, USA) and Visual Studio 2010.

Prior studies determined that a 45% reduction in lateral bending and a 54% reduction in extension were found in LBP patients compared to healthy subjects [7]. In order to imitate the performance of patients suffering from LBP, all healthy subjects wore tie-down straps in tights to limit their movement, as shown in Fig. 1, and the same subjects without the limitations were considered as the healthy group.

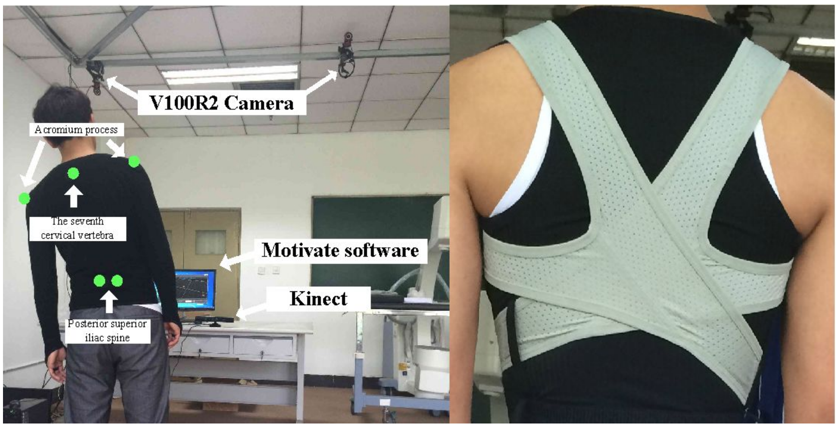

Fig. 1 System composition, marker positions, and tie-down straps

C. Procedure

For the initial position, the subjects were asked to stand upright in their natural posture and look straight ahead with both hands down at their sides. In order to obtain ROM and MAV in each cycle, all subjects were asked to perform three specific movements of their trunk in succession five times. The movements were as follow: extension in the sagittal plane and left/right lateral bending in the frontal plane. Each subject performed the same action in both limited and free motions. During tasks, kinematic data were recorded by the motion capture system and Kinect.

In the process of these tasks, the subjects were asked to reach their maximal ROM as quickly as possible, keeping their knees and neck as straight as possible and avoiding hip movement. The participants were also instructed not to change their feet or hip positions, and keep both hands down at their sides during the execution of the movements.

D. Data analysis

The values of the spine and shoulder angle were defined by the difference between the current motion position and the initial position of the subjects (Fig. 2). The ROM and MAV of the spines and shoulders were calculated in every cycle of five successive bending or extension movements, with a total of three specific tasks. In order to facilitate data analysis, the data recorded at the moment when testing began (initial position) was set at 0 degree as the origin of motion. The coordinatesystem was oriented positively to the right on the lateral vector of the subjects, which was the X-axis, upward on the vertical vector (Y-axis), and backward on the sagittal vector (Z-axis). This procedure was conducted to determine the mean MAV and mean ROM of the spine and shoulder after each specific task was finished. Kinematic data obtained by Kinect were computed, and then the movement angles and velocity were added to an Excel file simultaneously using NPOI, which is an open source library that can read and write *xls* files. Relative to these data, the computer calculated the ROM and mean MAV of the

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movement immediately following the completion of each task. Otherwise, the skeleton data obtained by the motion capture system shoulder were calculated offline.

The sampling frequency of the motion capture system was set at 100 Hz, while Kinect was set at 30Hz due to hardware limitations. In order to facilitate analysis, all data from Kinect were interpolated to 100Hz using the Matlab cubic spline interpolation function, which was cross-compiled in the customised software for Kinect, and recorded in the Excel file at the same time.

Then mean values, standard deviations of ROM and MAV with the root-mean-square error(RMSE) by different devices, were calculated. Meanwhile, the Pearson correlation coefficient(PCC) was applied to the data. The priori p value was 0.05.

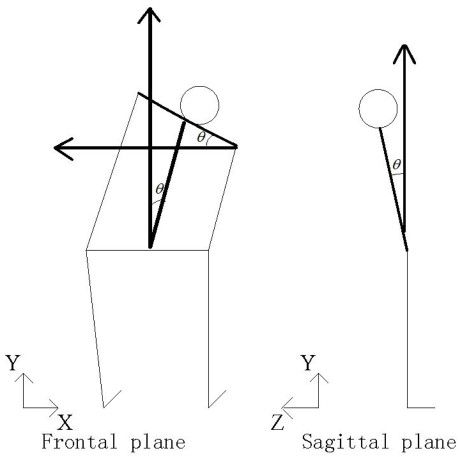

Fig. 2 The angle motion (θ) was defined in two anatomical planes: The kinetic values of the shoulder and spine were calculated in the lateral bending motion, and the kinetic values of the spine were calculated in extension

III. RESULTS

By subtracting the initial angle data and angle data during the task acquired by the motion capture system and Kinect, Fig.3 shows samples of spine angle trajectories of one subject with and without limitation, performing the left lateral bending task compared to the data from Kinect. The ROM without limitation was larger than the ROM with limitation, both with the motion capture system and Kinect, as shown in Fig. 3.

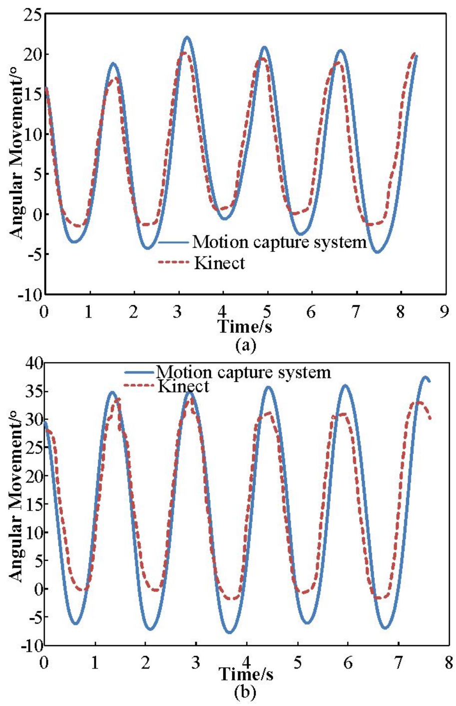

Fig. 3 Samples of spine angle trajectories of one subject: (a)Limitation; (b)Free

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The mean values and standard deviations of ROM and MAV calculated and compared between the motion capture system and Kinect for every task are shown in Fig. 4. In the same task, the left legend symbol represents data from the motion capture system with variations between the motion with limitation and the motion without limitation(the larger value in the same legend symbol). The right is from the Kinect system. The values of the shoulder in left/ right bending (LS, RS), the spine in left/right bending (LE, RE), and the spine in extension (EE) are represented in Fig. 4.

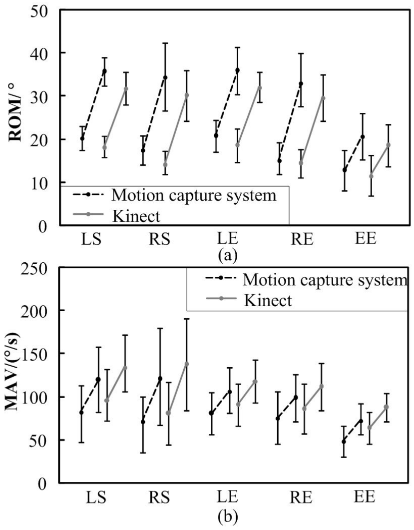

Fig. 4Mean values and standard deviations of mean ROM and mean MAV as measured using Kinect and the motion capture system(In the same task, the left legend symbol represents the motion capture system, and the right is from the Kinect system): (a)ROM; (b)MAV

The figures show that both the ROM and the MAV with limitations were smaller compared to the non-limited motions in both devices. Considering the ROM value, it was noted that the motion capture system showed a larger ROM and MAV than Kinect in the corresponding task. However, with the velocity value, Kinect was larger. During the left lateral bending task, the mean ROM obtained by the motion capture system varied from 20.7° with the limitation (mean MAV was 82.1°/s) to 30.9°without the limitation(mean MAV was 119.1°/s), compared to 17.9° with the limitation(mean MAV was 95.9°/s) and 31.8° without the limitation(mean MAV was134.1°/s) from Kinect. In addition, the differences of the mean ROM and MAV between the limited and non-limited variables with the same device were computed accordingly. Then the RMSE in the same task for each device was calculated, as shown in Fig. 5.

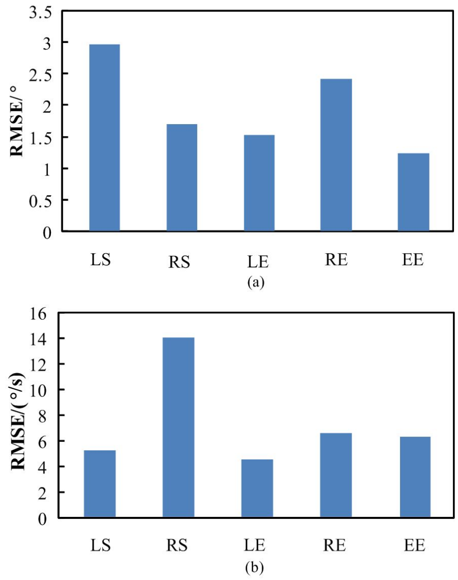

Fig. 5 RMSE of the differences between two states using different devices: (a)ROM; (b)MAV

The results revealed that the RMSE of the mean ROM between the different devices when conducting the same task ranged from 1.2° to 3°.For the value of the difference for the mean MAV, the RMSE ranged from 4.7°/s to 14.6°/s. Fig.6 illustrates the PCC values of ROM and MAV for the two devices in each task with limitation and without limitation. Except for ROM of LS with limitation and MAV of RS without limitation, there were high PCC values(more than 0.7) and significant correlations(p<0.05)[18]. Even some significant values are less than 0.01.

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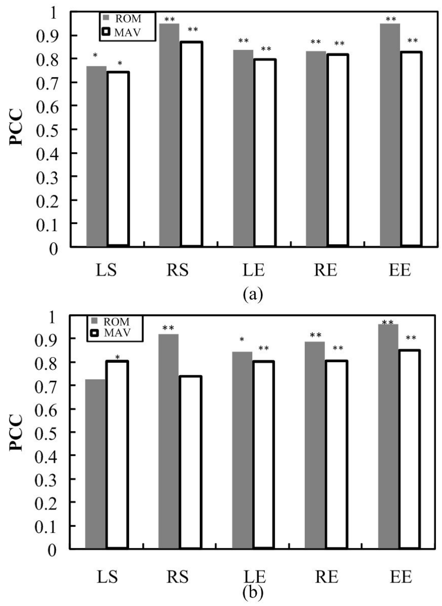

Fig. 6 PCC values of ROM and MAV: (a) Limited; (b)Non-limited (*p< 0.05; **p< 0.01)

IV. DISCUSSION

This study examined participants performing three different tasks to evaluate whether Kinect is an effective tool for providing kinematic parameters(mean ROM and MAV) of the shoulder and trunk. Movements performed in previous studies that were found to be affected by the presence of LBP were simulated to confirm that Kinect could distinguish ROM and velocity features during these tasks. Except for the ROM of LS and MAV of RS without limitation, Kinect's performance was sufficient for the tasks[19,20]. The PCC values of ROM of RS and EE in both states were larger than 0.9 with significant correlations, showing that Kinect was able to obtain accurate measurements in data acquisition of the human skeleton.

Analysis of the data illustrated that the mean ROM and MAV were significantly reduced with simulated limited motion compared to the non-limited state both with Kinect and with the motion capture system, which were consistent with previous studies[21]. The ROM of the spine and shoulder in the lateral bending task was larger than the spine value in extension, indicating that the subjects were more flexible in the frontal plane than in the sagittal plane. With the same task, the mean ROM from the motion capture system was less than with Kinect, although the mean MAV was larger with Kinect. Both devices directly acquired the angle of motion. However, data from Kinect were interpolated from 30Hz up to 100Hz because of hardware limitations, resulting in a ROM that was less while the MAV was larger. Fig. 5 shows that the RMSE of the ROM and MAV difference between free and limited motion using two systems did not show causality. Moreover, the difference of the RMSE of the ROM ranged from 1° to 3°, which showed that the value of LS was the largest and the value of EE was the smallest, and for the mean MAV, the largest value was 13°/s with RS, and the smallest was4°/s with LE.

This study found that Kinect demonstrated concurrent validity with a motion capture system for spatiotemporal values of trunk motion; however, there were limitations in the research. Firstly, in order to imitate the restricted behaviours of LBP, tie-down straps were used to restrict the subjects, who were healthy and young. Although the results were consistent with the reality, the ability of Kinect to assess abnormal patterns of those suffering from LBP was not evaluated. Moreover, various body types, contours, and ages may also impact the accuracy of the systems. Further study will involve different figures and ages other than young, thin individuals. Secondly, the participants stood in front of Kinect at a distance of2.5m; however, the data error analysis was not complete because the random error of depth measurement varied along with distance. A previous study showed that the random error of depth measurement ranges from a few millimetres up to 4cm, increasing with the distance to the Kinect sensor[22].Varying errors could influence the accuracy of the Kinect system when used in the clinic or patients'homes. This will need to be standardized to obtain more meaningful data. Thirdly, all data from Kinect were sent through cubic spline interpolation because of the limited sample frequency of Kinect. Higher degree polynomial interpolation would acquire more realistic data, which require higher real-time computing performance. In addition, enhanced hardware or software could improve precision and upgrade Kinect to the level of a high performance assistive device[23].

This research intended to verify the validity of Kinect being used as an assessment tool. The systematic error of Kinect, which shows an additional 3° in ROM, was acceptable for obtaining valuable information regarding the movement patterns and strategies involved in various movement tasks, which may be useful for research of LBP[7].Though the mean values and standarddeviations of the ROM and MAV for the Kinetic system were not completely consistent, relative to the complex motion detective system, it could be used as a rapid detection tool to quickly obtain motion information. It could be a candidate for clinical motion assessment. Instead of computing ROM and MAV offline, Kinect performed motion values in real-time,

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leading to faster and more convenient results. Quite differently, angle motion data acquisition using markers attached to the skin using motion capture systems is tedious and complicated for patients with LBP. Moreover, Kinect is cheap, easy to setup, and portable. It does not require time-consuming calibration and provides information involving movement patterns and strategies in various low back movement tasks. This could prove useful for those with LBP both in clinical settings and at home. Therefore, Kinect can be considered as a potential tool for clinical evaluation of trunk motion and obtaining kinematic information regarding trunk and shoulder motion in clinical settings in place of traditional motion capture systems.

V. CONCLUSIONS

In this research article, three tasks were performed by participants to compare Kinect to a commercial motion capture system for verifying Kinect's validity as a kinematic assessment tool. PCC values, which were more than 0.7, revealed that Kinect correlated well with motion capture systems during gross trunk motion measurements. The RMSE of the ROM difference was 1.2–3°, and for the MAV the difference was 4.7–14.6°/s.

The performance of Kinect depends on the direction of the motion task and the selection of the skeleton parameters with the software. Trunk motion capture can potentially become more precise if the thoracic region joints are included in the acquisition. Kinect performs better in extension tasks that measure spine characteristics. In order to improve the accuracy of the measurements, there is potential to apply an appropriate filtering method in software to improve the accuracy of the hardware. In conclusion, the Kinect system can be used in clinical institutions to measure gross trunk motions and is probably financially feasible for providing information regarding movement patterns and strategies useful for LBP studies as an alternative to traditional motion capture systems.

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