In-Home Measurement System of User's Motion and Center of Pressure

Tomoya Tamei*, Yasuyuki Orito*, Tomohiro Shibata† and Kazushi Ikeda*
* Nara Institute of Science and Technology, Japan
E-mail: {tomo-tam, orito.yasuyuki.oq6, kazushi}@is.naist.jp Tel/Fax: +81-743-72-5985/5989
† Kyushu Institute of Technology, Japan
E-mail: tom@brain.kyutech.ac.jp Tel/Fax: +81-93-695-6088

***Abstract*—Aiming at in-home rehabilitation and continuous monitoring of elderly people and patients in balance disorders, we developed a low-cost and compact system monitoring motion and center of pressure (COP) using Microsoft Kinect and Wii Balance Board. The motion tracking accuracy of the developed system was evaluated in COP tracking tasks proposed for assessing balancing ability. The results showed the existence of biases (discrepancies) between the actual motion and measured by the developed system, but the standard deviations were very small, indicating that, the system has small tracking error if the motion is appropriately calibrated.**

I. Introduction

As the age of people increases, the risk of falls gets higher and its consequence becomes more serious, such as the decrease of the QOL (Quality of Life) [1]. In fact, more than 30% of elderly people fall once or more a year and 4% of them sustain a fracture [2]. Fracture is one of the major reasons for leading to bedridden state and injury death of elderly people. Hence, evaluating the fall-risk and predicting the fall probability are useful to avoid the fall and to train their balance control. It is suggested that spacial relationship between COP (center of pressure) and COM (center of mass) is related to dynamic balance control [3], [4]. The user's posture and balance are accurately measured using a motion capture system and a force plate in the studies. However, such equipments are expensive and bulky for in-home use.

It is suggested that the fall-risk is closely related to (both of static and dynamic) balance control, and can be evaluated by a quantitative evaluation index of the balance control, Berg Balance Scale (BBS) [5], [6] [7], [8]. However, it is not so practical to measure BBS because it takes time about 15 minutes and requires large space and a parson in charge of measurement.

In this study, we developed a system to measure the user's posture and COP using Kinect (Microsoft Corp.) and Wii Balance Board (WBB) (Nintendo Corp.) for in-home use. We also proposed COP tracking task for assessing balance control ability. The motion tracking accuracy of the developed system was evaluated in the tasks comparing with the motion measured by an optical motion capture system as a ground truth. The results showed that the system can acquire user's joint positions and angles with enough accuracy calibrating biases (discrepancies) between the ground truth and measured by the developed system.

II. Methods

A. Measurement system

The measurement system consists of a PC, Kinect, and WBB. Kinect is a new and inexpensive RGB-D camera that acquires motion data in via Kinect SDK with a sampling frequency of 30 [Hz]. The WBB is a piece of equipment that measures the COP.

Kinect located 0.9 [m] height from the floor and 2 [m] in front of the subject standing on WBB. On a screen (0.92 [m] $\times$ 1.22 [m]) located 3.5 [m] in front of the subject, target COP (the blue circle in Fig. 1) and actual COP (the red circle) are displayed in real-time.

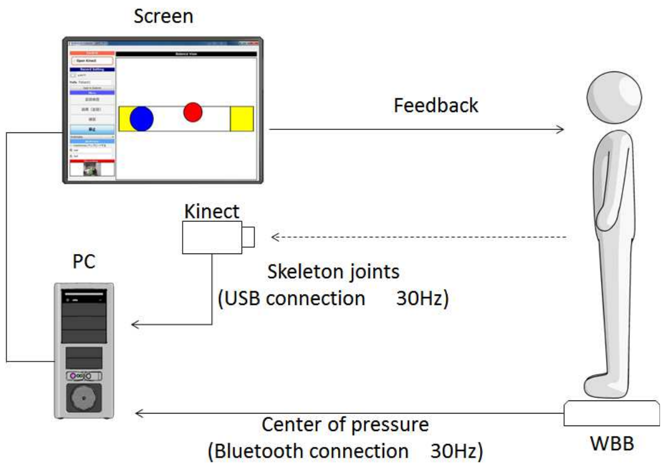


Fig. 1. System overview

B. COP tracking tasks

Lizama et al. proposed a COP tracking task to track a target COP signal that moves in ML (medio-lateral) direction by moving subject's COP. In this study, we expanded the task to AP (anterior-posterior) direction and ellipsoidal trajectory (EL) to evaluate the tracking ability in each direction and in composed trajectory of ML and AP. The target signal was sine wave that increases the frequency by 0.1 [Hz] every 5 [sec] (ref Fig. 3). The frequency was 0.1-2.0 [Hz] (in total 100 [sec]) in ML and AP tasks and was 0.1-1.5 [Hz] (75 [sec]) in EL task. The standing position on WBB and the amplitude of the target signals were as shown in Fig 2. Since COM in AP direction is located in approximately 40% point of feet length from the end of the feet during static standing, the 40% point was defined as the center of the target signals in AP direction. The amplitude of the target signal in AP direction was determined as 50% of the feet length, because range of COM in backward direction is 25% of the feet length from the center. The amplitude in ML direction was determined as [8% of body heigt + width of the ankle joint] following the study of Lizma et al.. In ML and AP tasks, beep sound was given at the peaks of the target signal (Fig. 3) [9]. In EL task, the target was moved in the clockwise direction on the ellipsoidal trajectory which has two axes equal to amplitudes of AP and ML task.

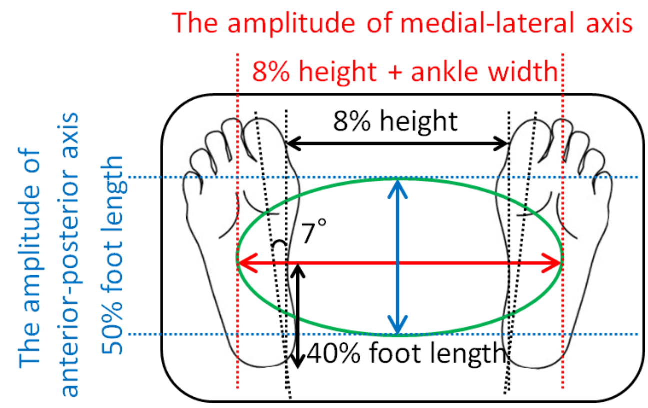


Fig. 2. Amplitude of target signal and subject's stance.

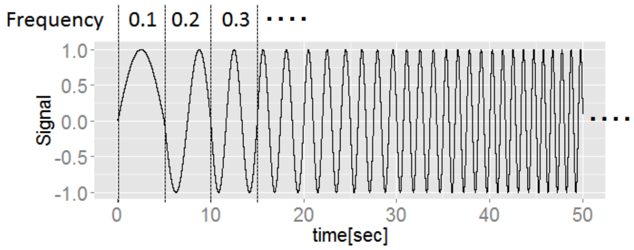


Fig. 3. Target signal of COP.

III. Evaluation of the Proposed System

A. Method

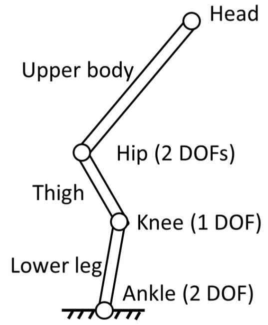
To evaluate the accuracy of the motion measured by the proposed system during the COP tracking tasks, we compared the joint positions and joint angles with the values acquired from an optical motion capture system.

The calculation of the values were based on a model of 3-link and 5-DOFs (degree of freedoms) presented in Fig. 4(a). The points measured by the motion capture system and Kinect are as in Fig. 4(b) and Fig. 4(c). The joint positions and angles were calculated according to the correspondence between the link model and the measured points (Table I).

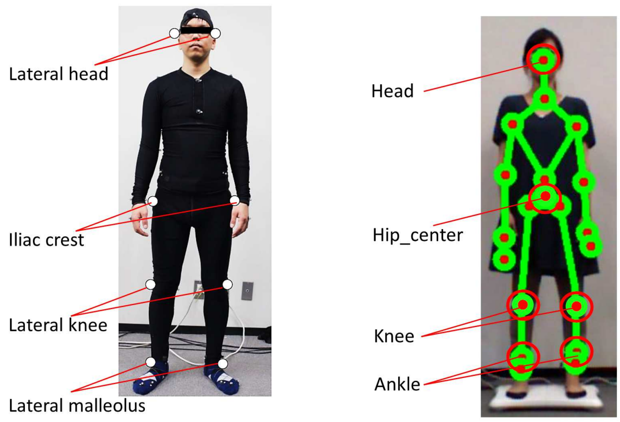
MAC3D system (Motion Analysis Corp.) was used as the optical motion capture system. The transformation between the coordinates system from Kinect to the motion capture system was calibrated in advance of the experiment resulting with the error of 0.24 [mm] in average and 0.15 [mm] in SD (standard deviation). One healthy male participated to the experiment and performed 3 COP tracking tasks (ML, AP and EL) 2 times for each.

TABLE I
Correspondence between the link model and the measured points

Link model	Motion capture	Kinect
Ankle	Lateral malleolus (average of left-right)	Ankle (average of left-right)
Knee	Lateral knees (average of left-right)	Knee (average of left-right)
Hip	Iliac crests (average of left-right)	Hip_center
Head	Lateral head (average of left-right)	Head



(a) Link model



(b) Marker locations of the motion capture (c) Measurement point of Kinect SDK

Fig. 4. Link model and the the measurement points of subject's motion

B. Result

Error in joint positions was 4–13 [cm] (SD > 1 [cm]) as shown in Fig. 5. Error in joint angles was 1.7–5.7 [deg] (SD > 1.5 [deg]) as shown in Fig. 6.

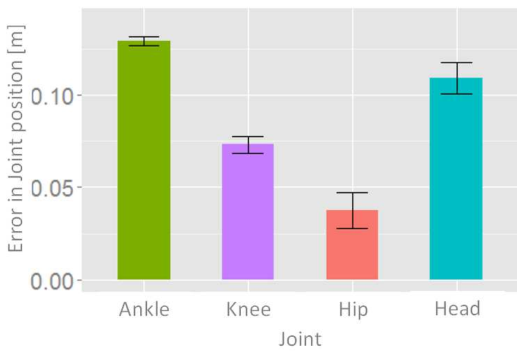


Fig. 5. Error in joint positions

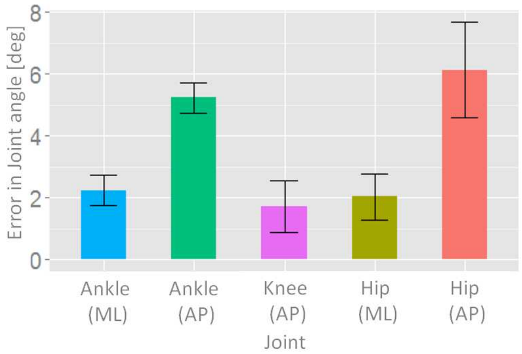


Fig. 6. Error in joint angles

IV. Discussion

The averaged error of joint positions and joint angles were 13 [cm] and 5.7 [deg] at maximum. This fact would be due to the difference of the measured points by the motion capture and Kinect (ref Fig. 4), so the biases exist. Since Kinect estimates the joint positions from the distance between the sensor and the subject using infrared [10], it is suggested that the error in AP direction tends to be larger [11]. In contrast to the average, the maximum SDs were 1 [cm] and 1.5 [deg]. Therefore, by modeling the relationship between Kinect data and the motion capture data [12], these values must be accurately estimated by our system.

V. Conclusion

In this study, we proposed a low-cost in-home monitoring system of motion and COP using Kinect and WBB, and COP tracking tasks for assessing balance control ability. The system was evaluated in estimating the joint positions the angles using the motion capture system for the ground truth. By modeling the relationship between the estimations with the ground truth, the system can achieve practical accuracy.

We plan to confirm the relevance of the COP tracking tasks comparing the performance of the tasks and a quantitative evaluation index of balance control such as Berg Balance Scale (BBS).

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