Estimation of Mediolateral Gait Postural Stability using Time-Series Pelvis Angular Velocities

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***Abstract*—Gait stability indices play an important role in both clinical and commercial applications and are effective for estimating an individual's fall risk. In general, the computation of gait stability indices requires motion-capture systems to measure the positions and angles of multiple body segments. If the stability indices can be estimated from the time-series data of a single body segment, they can be easier to access. We used principal motion analysis to estimate the margin of stability, which is a popular gait stability index, based on the time series of the angular velocities of the pelvis during walking. The linear combination of three principal motions could estimate the minimum margin of stability along the mediolateral direction with a correlation coefficient of 0.58. The angular velocities of the pelvis can be used to estimate gait stability independently or in conjunction with other kinematic information.**

***Index Terms*—Gait stability, pelvis, margin of stability, angular velocity**

I. Introduction

Gait stability indices are used to estimate the risk of falling during normal or perturbed walking [1]. Several researchers are trying to establish such indices to screen people with high fall risk or evaluate the effect of clinical intervention for people with walking disabilities. In this study, we focused on the gait stability index called mediolateral margin of stability (MoS), which evaluates postural stability using kinematic information [2].

The computation of the mediolateral MoS requires the time-series positions of the center of the human body mass (CoM) and two feet, that is, the measurements of at least three points are required. The motivation of the present study is to estimate the mediolateral MoS by using kinematic information of only one point on the body such that a single inertial measurement unit replaces motion capture systems for measuring multiple body points or segments.

One challenging approach was performed by Iwasaki et al. [3], who estimated the minimum mediolateral MoS values using the time-series of the triaxial velocity of the CoM with a correlation coefficient of 0.68 between the observed and estimated mediolateral MoS values. They used principal motion analysis [4]–[6] to link the mediolateral MoS and the velocities of the CoM.

In this study, we estimated the minimum mediolateral MoS values using principal motion analysis and the angular velocities of the pelvis, which is close to the CoM. Although Iwasaki et al. [3] used CoM velocities to estimate MoS values, the angular velocities of the pelvis can be easily measured using an inertial measurement unit. Hence, for practical applications, it is important to investigate the effectiveness of pelvis angular velocities in the estimation of MoS values.

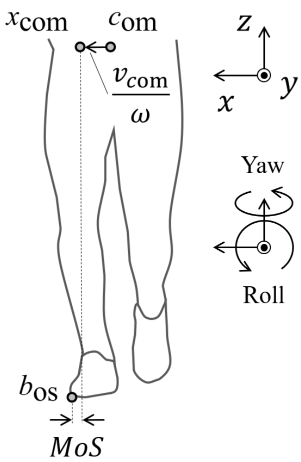

Fig. 1. Mediolateral margin of stability from the frontal viewpoint. Postural stability along the mediolateral direction during walking.

II. Mediolateral Margin of Stability (MoS)

As shown in Fig. 1, mediolateral MoS is defined as the distance between the extrapolated position of the CoM and the boundary of the base of support (i.e., supporting feet) in the mediolateral direction at any given instant t. This value indicates the margin against falling in mediolateral direction. The extrapolated CoM position $x_{\mathrm{com}}(t)$ is its prospective position in the near future and is defined as

$$x_{\mathrm{com}}(t) = c_{\mathrm{com}}(t) + \frac{v_{\mathrm{com}}(t)}{\omega}, \tag{1}$$

where $c_{\mathrm{com}}(t)$ and $v_{\mathrm{com}}(t)$ are the position and velocity of the CoM in mediolateral direction, respectively, and ω is computed as

$$\omega = \sqrt{\frac{g}{l}}, \tag{2}$$

where g is the gravitational acceleration, and l is the height of the CoM from the floor in an upright body posture. The mediolateral MoS is defined as

$$m_{\mathrm{os}} = b_{\mathrm{os}} - x_{\mathrm{com}}. \quad (3)$$

We used the minimum value of the mediolateral MoS during the gait cycle. During normal gait, the mediolateral MoS has a positive value, and its minimum values appear at approximately 10% and 60% of the gait cycles, which occur at the early phases of the double stance periods [2]. The MoS values can be computed for mediolateral and anterior directions. In this study, we used only the mediolateral MoS. Kuroda et al. explored the relationship between the mediolateral and anterior MoSs [7].

III. Methods

A. Gait database

We used the dataset from the AIST Gait database [8], among which the walking samples of 60 elderly people (30 healthy women and men with a mean age $\pm$ standard deviation of 67.6 ± 3.4) were used for this study. Participants walked on a 10-meter straight line at their own comfortable speeds. A camera-based motion capture system was used to localize the reflective markers attached to the participants at 200 Hz.

B. Principal motion analysis

Principal motion analysis is a supervised multivariate time-series analysis [3]. It determines the base functions called principal motions such that their linear combination approximates multivariate time-series samples. Typically, normal human gait motions can be represented using two to three time-series bases [3], [9]. The score of a principal motion indicates the extent to which a sample includes that principal motion, and the scores are determined such that the variance between the scores and objective values is maximized for each principal motion.

In this study, the objective value was the minimum value of the mediolateral MoS in a stride sample, which consisted of two successive steps. The multivariate time-series are the angular velocities of the pelvis, as described in Section III-C.

C. Yaw and roll velocities of pelvis

MoS is computed based on the translational motion of the CoM, which is located beneath the navel and above the pelvis. Considering the use of an inertial measurement unit, the pelvis is a potentially good segment to attach the measurement unit to because its bone features can be easily palpated. Furthermore, the measurement unit can be firmly attached to the body part because the area near the pelvis contains few muscle and fat tissues. Hence, we used the yaw and roll angular velocities of the pelvis as the time-series postural data for the principal motion analysis.

In this study, we did not use the inertial measurement unit. Instead, the angular velocities of the pelvis were computed using the coordinates of the two bone features of the pelvis: the left and right anterior superior iliac spines (ASISs). We

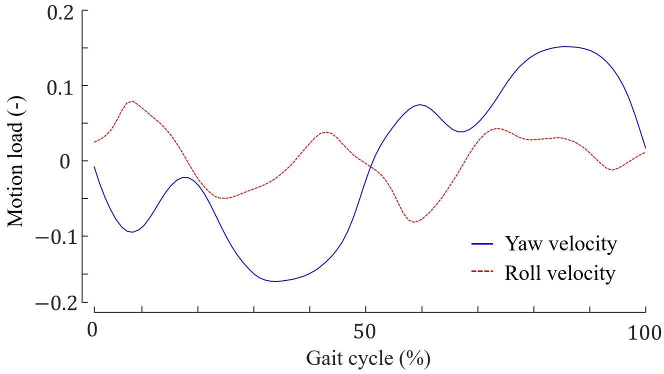

Fig. 2. First principal motion of pelvis angular velocity. Positive (negative) load indicates that the angular velocity is larger (smaller) than the mean angular velocity at the moment. Left heel contact is the 0% gait cycle.

computed the roll and yaw velocities of the line connecting the left and right ASISs around the y-axis (forward direction) and the z-axis (gravitational direction), respectively. We did not use the pitch velocity because it is not considered important in determining the mediolateral MoS.

IV. Results

We computed three principal motions, following [3]. As an example, Fig. 2 shows the motion loads of yaw and roll velocities of the first principal motion. The motion loads indicate the yaw and roll velocities of the sample in comparison with the mean velocities. For example, the profiles of Fig. 2 are nearly the opposite to those of the mean angular velocities. A sample with a positive first principal score includes relatively smaller yaw and roll velocities during the gait cycle. That sample may involve small gait motion.

We estimated the minimum mediolateral MoS values using regression analysis, with the scores of the three principal motions as explanatory variables. The correlation coefficient between the observed and estimated minimum mediolateral MoS was 0.58. This correlation is slightly smaller than 0.68 reported in the study by Iwasaki et al. [3], where the MoS values were estimated using triaxial CoM velocities.

V. Conclusion

The MoS is a popular gait stability index for indicating fall risk. We estimated the minimum mediolateral MoS values using the temporal variations of the two-axial angular velocities of the pelvis, considering the potential use of an inertial measurement unit to record human motion data. No previous research has attempted to estimate the MoS based on the angular velocities of single-body segments. On performing principal motion analysis, the estimated minimum MoS values exhibited a moderate correlation of 0.58 with the observed values. The conjunctive use of the velocities along the x, y, and z-directions and the roll, pitch, and yaw angular velocities will increase the estimation accuracy of MoS values. The combination of the translational and angular velocities of the pelvis may achieve a more accurate estimation than either of the two types of velocities. Further, this study used motion data recorded by an optical motion capture to calculate pelvis motions; however, the quality of motion information are different between inertial measurement units and optical motion captures. Hence, our method needs to be tested by using inertial measurement units in the future.

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