Development of balance assessment system via estimation method of center of mass based on a human mechanical model

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Background:

Modeling an individual's standing balance system, including time delay, will contribute to the development of diagnostic and rehabilitation methods. It is also important that the model be derived from practical measurements rather than the laboratory environment. However, no study has identified a reliable individual model. In previous studies, we have shown that individual balance characteristics related to center-of-mass (COM) control can be identified using a dynamic model with rigid-body link models, assumptions of balance control measures in response to external stimuli, and practical measurements using a force platform and inertial sensors. However, this model is insufficient because it ignores the suppression of the head acceleration. If COM control and suppression of head acceleration can be evaluated simultaneously, important clues can be obtained about "sensory re-weighting," which has been a subject in the medical field for a long time.

The purpose of this study is to accurately measure standing behavior using force platforms and inertial sensor measurements, and to perform the following analyses from the data

(1) To characterize in detail the balance of the elderly and patients with various diseases[1].

(2) To construct and identify individual balance control models from steady-state responses to sway stimuli[2].

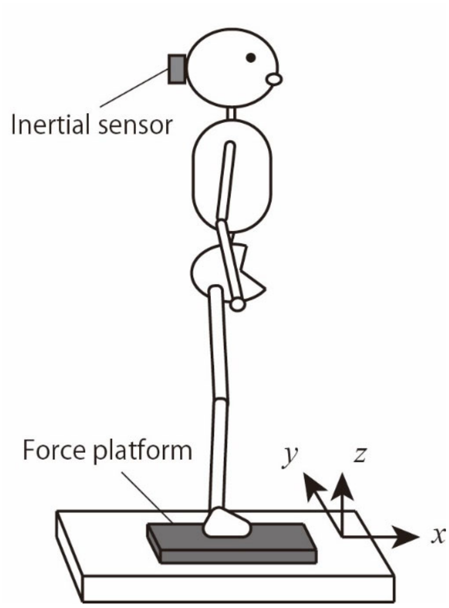

Fig. 1 Instruments used at standing balance test

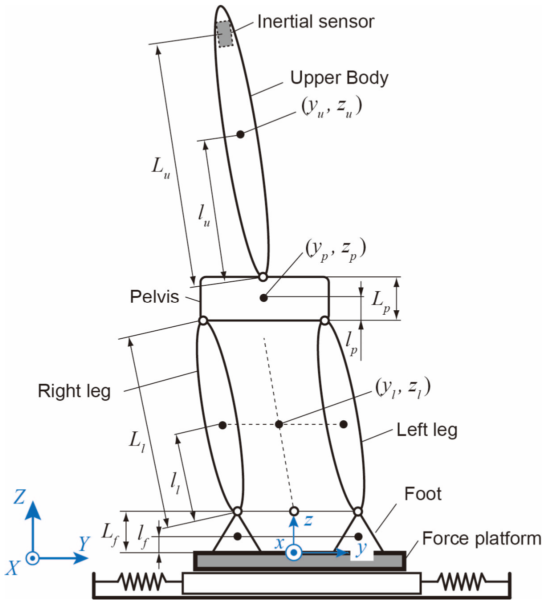

Fig. 2 Multi link model for analyzing the balance control in the frontal plane.

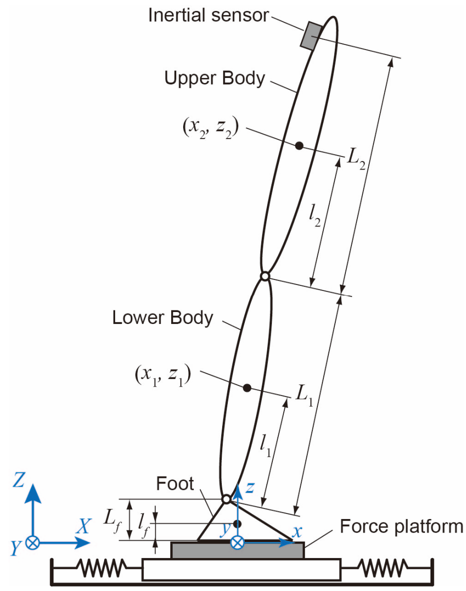

Fig. 3 Double pendulum model for analyzing the balance control in the sagittal plane.

Target in this project:

- From quiet standing test, we try to evaluate the contribution of joint strategies (ankle and hip strategies) in head acceleration as well as the sagittal and frontal COM displacement movements and head acceleration variability in the sagittal and forehead planes.
- We evaluate somatosensory perception from the behavior of the center of gravity and vestibular perception from the contribution of each joint strategy in head acceleration.
- In the sway test of the support surface, we try to build balance models considering COM control and head acceleration control in the sagittal and frontal planes, respectively.
- Measurements are made with a force platform under the feet and an inertial sensor mounted on back head.
- The obtained model must be stable in control engineering and reproducible (i.e., the same model can be obtained from the same subject).
- If the modeling is achieved, we would like to develop a new smart vehicle by adding appropriate feedback controls.

We have developed the equipment needed for this experiment. The balance control modeling considering only COM control has already been completed in our study.

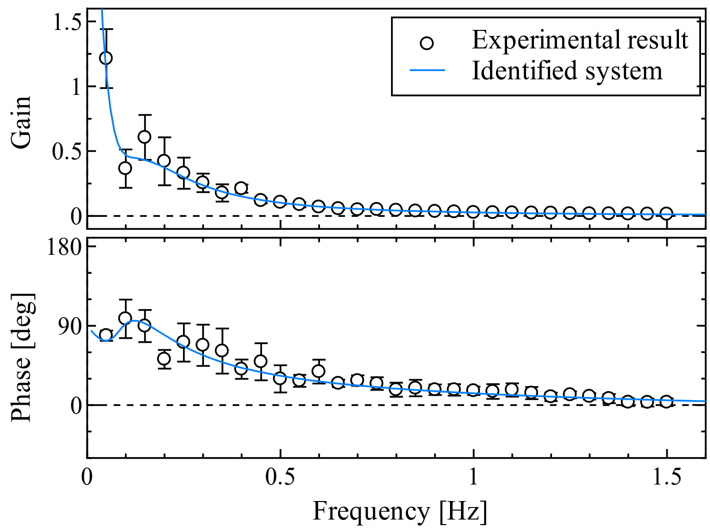

Fig. 4　Frequency response diagram (circle) from the experiment and identified system using our assumed model (line) when the input is the acceleration of the support surface and the output is the relative displacement of the COM

Impact of this study:

- Because this study is based on practical measurements, it is possible to measure any patient or elderly person. It does not require the skill of the examiner and can be performed in a small space, making large scale measurements possible.
- Our study is novel because there have been no previous studies quantifying joint strategies.
- The Sway test has been shown to provide a highly reproducible model for COM control below 1 Hz. A 2-DOF model for the standing position and a 1-DOF model for the seated position would clarify the sensory organ weighting for various subjects.

Reference:

(1) Sonobe, M., Inoue, Y. "Center of Mass Estimation Using a Force Platform and Inertial Sensors for Balance Evaluation in Quiet Standing", *Sensors*, Vol. 23, No. 10 (2023), pp. 4933.

(2) Tsuneda, J., Sonobe, M. "Reliability of standing model and identification technique in response to support surface perturbation", *Asia-Pacific Vibration Conference 2021* (2022)