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Sit-to-Stand Intention Estimation Method Using the Angle of Forward Trunk Inclination and Leg Electromyograms

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Abstract: In this study, we propose a sit-to-stand intention estimation method and verify its effectiveness. The proposed method uses the trunk forward inclination in sit-to-stand movements and the order of the associated activity of the lower limb muscles to estimate the sit-to-stand intention without learning data or recalibrating. The evaluation results of the proposed method on three subjects, who performed the sit-to-stand movements, including three types of noisy movements, shows that the movement is predicted 211 ms before it commences with a 98.3% accuracy.

Keywords: Sit-to-stand Assistive Technology, Human Machine Systems, EMG, AFI

1. INTRODUCTION

With an aging population, recently there research and development has been conducted for developing devices to assist the movements of the elderly and laborers (Kawamoto et al. 2010, Muramatsu et al. 2013). One of these assisted movements is standing up. Standing movements are performed on multiple occasions in daily life; however, standing up may be associated with knee pain in the elderly, and there are some individuals who have difficulty standing up because of muscle weakness. Support measures for standing movements include external robots, which are assumed to be primarily used indoors (Tsusaka et al. 2015), and devices that are attached to the user (Tsukahara et al. 2009). These user-attached support devices move by recognizing the movement intention of the user. The most common method of user movement intention recognition is recognizing the initiation of the actual user movement; however, this method of recognition requires the strength, on the user's part, to initiate and sustain the movement until support is provided by the device. If the intended movement could be estimated from the preparatory movement, then support might be provided from the start, thus reducing the effort required by the user.

The present study was performed to estimate the user's standing movement intention before it commences (i.e., before rising from a chair). Rising from a chair involves a forward trunk inclination because the center of gravity moves anteriorly (Schenkman et al. 1990). Therefore, we propose recognizing this forward trunk inclination as a preparatory movement for standing, and attempt to use it as a method of estimating standing movements. The proposed method involves using changes in both the angle of the trunk inclination during forward trunk inclination and the myogenic potential, which corresponds to specific muscles in the lower limbs. We use the myogenic potential because errors in estimation occur when using methods that only measure changes in the angle of forward trunk inclination (AFI) because forward trunk inclination occurs in daily life in contexts other than standing as well. Furthermore, the myogenic potential is the potential induced by muscle contraction; therefore, estimating movement intention earlier is possible because the measurement occurs before muscle contraction.

In this study, we first present experiments that were performed to clarify the changes in AFI and the muscle activity in the lower limbs during standing movements, particularly when rising from a chair, and then we analyze the experimental results. Next, we propose a method of predicting sit-to-stand intention using changes in the AFI and the myogenic potential of the lower limb muscles, and we present the prediction precision estimation results of the proposed method, including noise generated by movements other than standing.

2. AFI AND LOWER LIMB MUSCLE ACTIVITY DURING STANDING MOVEMENTS

2.1 Specifications for measurement experiments

We performed experiments to measure changes in AFI and lower limb muscle activity. Three subjects (hereafter referred to as PIN 1–PIN 3) participated in this study. After the purpose of the study and the details of the experiments were sufficiently explained to them, consent for participation in this study was obtained from these subjects. The subjects were healthy adult men with no history of conditions that could have a particular effect on standing or sitting movements. The mean age of the subjects was 32.25 ± 7.46 years (mean value ± standard deviation), the mean height was

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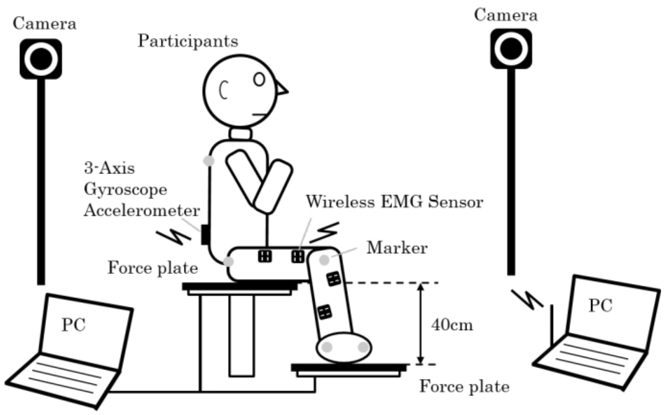

Fig. 1 Experiment system configuration

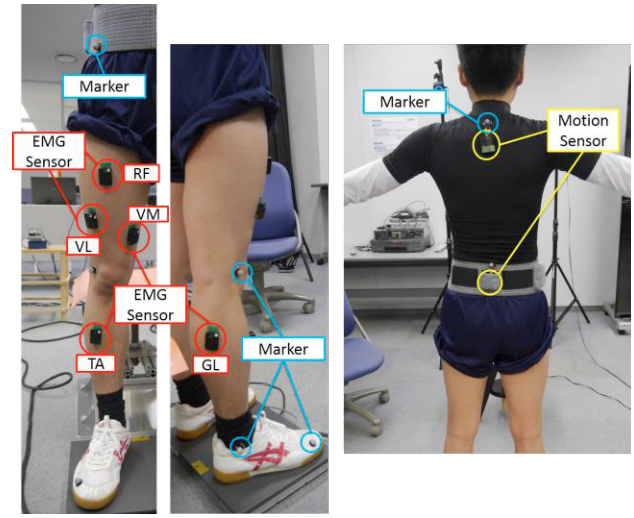

Fig. 2 Placement of sensors

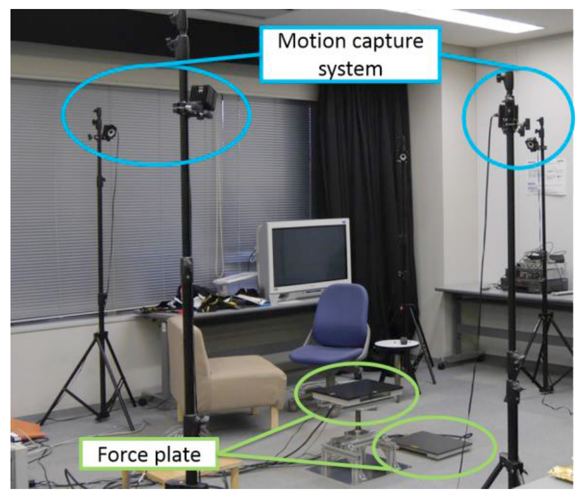

Fig. 3 Photograph of experiment environment

172.38 ± 6.68 cm, and the mean body weight was 63.18 ± 7.77 kg.

The configuration of the experiment is shown in Fig. 1. To reduce the effects of movements of the upper limbs during the experiment, the subjects folded their arms in front of their trunk and repeated 10 standing and sitting movements at intervals of 7 s, which were timed with a metronome. On this occasion, we measured body movement and muscle activity. Note that each subject performed the movements twice; thus, a total of 20 standing and sitting movements were measured. There were no particular instructions regarding movement speed or foot position during the standing and sitting movements. Therefore, the subjects performed the movements at their natural speed and in their natural foot position; however, foot position was determined during previous practice sessions, and subjects were asked to try not to move their feet from the predetermined position during the experiment.

A force plate was adjusted on the seating surface chair, on which the subjects sat on, and another force plate was placed beneath the subject's feet. The rising time from the chair was calculated on the basis of the size of the counterforce measured by the force plates. Note that the distance between the force plate beneath the feet and the force plate on the chair was 40 cm.

The subjects were attached to a wireless electromyography (EMG) sensor (Trigno EMG Systems, Delsys, Inc.) to measure the muscle activity of the lower limbs; a nine-axis wireless motion sensor (IMU-Z2, ZMP Inc.) to measure the angle of trunk inclination; and markers for a 3D real-time motion measurement system (VENUS3D, Nobby Tech. Ltd.) to measure joints. The attachment locations of the sensors and markers on the subjects are shown in Fig. 2. Activity was recorded using an EMG sensor from five muscles in the right leg: rectus femoris (RF), vastus medialis, (VM) vastus lateralis (VL), gastrocnemius lateral (GL), and tibialis anterior (TA). The markers for the 3D motion system were attached to the following: the center of the shoulder, the center of the hip, the center of the knee joint, the lateral malleolus, and the right fibular metatarsal. The angle of the trunk was calculated from the centers of the shoulder, the hip, and the knee joints; the angle of the knee was calculated from the center of the hip, the center of the knee joint, and the lateral malleolus; and the angle of the ankle joint was calculated from the center of the knee joint, the lateral malleolus, and the right fibular metatarsal. The experimental setup is shown in Fig. 3.

2.2 Measurement results

Fig. 4 shows an example of the AFI and angles of the knee and ankle during standing, and the vertical counterforce measured using the force plates on the seating surface of the chair and under the feet. Leaving of the buttocks (Fig. 4) was determined when the ground reaction force, which was measured by the force plate on the seat of the chair, was minimum. According to Fig. 4, anteflexion of the trunk occurs first during standing movements, thereby reducing the AFI. Next, there is gradual extension of the knee joint, the angle of the knee enlarges, and the buttocks are separated from the seat of the chair. After the buttocks leave from the chair, retroflexion of the trunk occurs, enlarging the AFI. The angle of the knee undergoes further extension, after the buttocks have left from the chair, and the person reaches a standing position.