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Quantitative Estimation of Exercise Effect using Numerical Simulation and Multi-sensory System on Human Leg

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1. Introduction

A reliable method for estimating the effect of rehabilitation or exercise is needed to improve the QOL in this aging society. For this purpose, we proposed a method to quantify the amount of the propagating wave inside inferior limb of human bodies using multi-sensory system: the system consists of force sensors, spatial three-dimensional acceleration sensor, and contact vibration sensor. By using the multi-sensory system, the characteristics of walking and jogging were observed.

2. Method

Figure 1 shows the measurement system. Two pressure sensors (Interlink Electronics, 402) were inserted between the insole and shoe sole of right foot. The spatial acceleration of ankle region was measured with 3-D acceleration sensor (Freescale, MMA7361L). In addition, one contact acceleration sensor (Ono Sokki, NP-3211), which can detect the surface vibration, was sealed on the skin near the greater trochanter of the right leg of the participant. The derived waveforms from these various sensors were recorded by a data logger (NI, USB6212) connected to a PC. The sampling rate of data logging was 4 kHz.

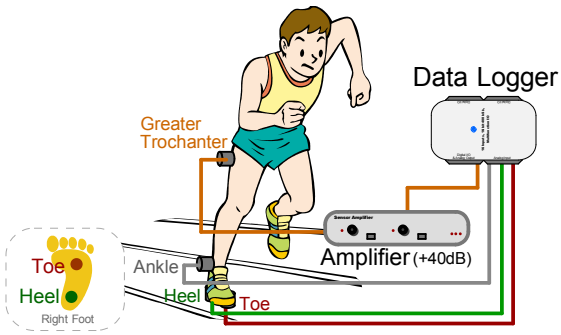
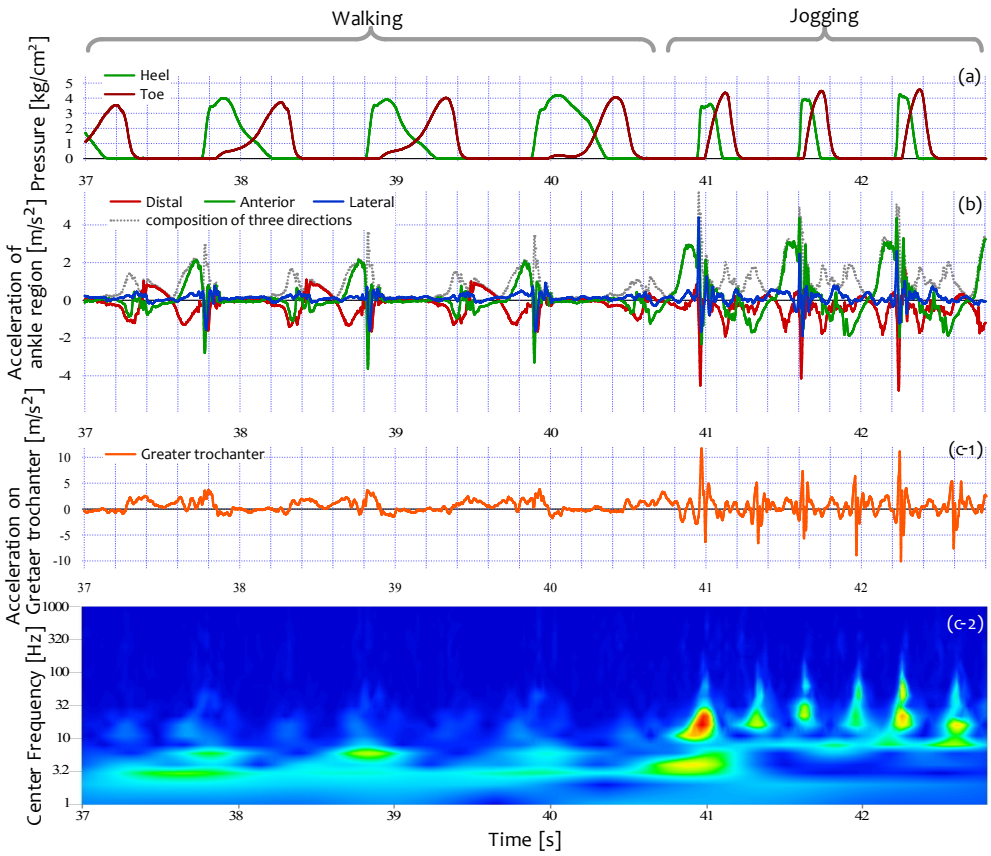


Figure 1: Measurement system.

3. Results and Discussion

Figure 2 shows the observed data. Alternating step stroke of heel and toe step could be seen in (a). Around the step timing, dynamic change of spatial acceleration is seen in (b). In (c-1), strong peak of vibration is clearly observed at the timing of heel stroke of jogging. Here, higher frequency component appears in scalogram (c-2). The higher frequency component may contain some additional information of the wave propagating inside the inferior limb.

Considering the claim by Nagatani *et al.*[1,2] that the frontal part of received vibration wave corresponds to the acoustic wave inside inferior limb (Fig.3), which was confirmed using FDTD simulation of 3-D human model [3]), the amplitude of the received waveform possibly reflects the amount of the acoustic wave (or mechanical vibration) inside bone part which is evoked by the step stroke of walking or jogging. This concept should be confirmed carefully in future work.



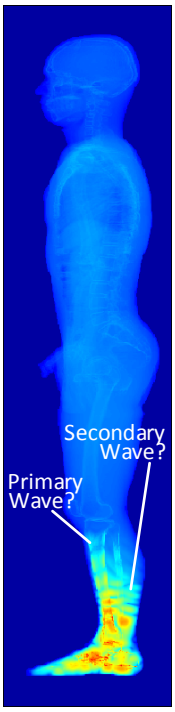


Figure 2: **(a)** Pressure measured with force sensors between insole and shoe sole of right foot. **(b)** Spatial acceleration measured with 3-D acceleration sensor at ankle. **(c)** Surface acceleration (vibration) on the skin near greater trochanter of right leg (c-1) and its wavelet transform (c-2). The waveform shown in c-1 was transformed into scalogram by continuous wavelet transform using complex Morlet wavelet.

Figure 3: Wave distrubition inside 3-D human model. Single sinusoidal pulse at 20 kHz was virtually impressed to the right heel of the model.

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