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Quantitative Evaluation of Body-sway Caused by Tactile Apparent Movement

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Abstract: The recognition of tactile apparent movement is normally a subjective sense. However, when applying tactile apparent movement to an engineering system, quantitative evaluation is necessary. In a previous study, we examined the body-sway caused by tactile apparent movement under fixed experimental conditions; however, the body-sway characteristics were not fully investigated. In this study, we investigated the body-sway caused by tactile apparent movement under fixed experimental conditions. We focused on biological information and body-sway, and compared cases where the apparent motion was recognized and not recognized. Our findings will help to improve the performance of systems that use tactile apparent movement.

Keywords: Tactile Apparent Movement, Body-sway, EMG,

I. INTRODUCTION

The tactile sense of our skin is one sense that is being investigated for sensory substitution because the possibility of losing the tactile sense is lower than the possibility of losing sight, hearing, and other senses due to congenital or acquired causes. Sensory substitution means substituting a remaining sense for a lost sense. For example, a tactile display can transmit information using the tactile sense instead of the visual sense.

Apparent movement is a sensory illusion mainly studied and reported in the field of vision. However, it is known that apparent movement also appears in the tactile sense. When two stimuli appear one after another with an appropriate time lag, we sense movement of the stimulus; that is to say, we sense that one stimulus moves to the other stimulus.

The frequency characteristics of tactile apparent movement have been investigated [1]–[3]. Ueda *et al.* proposed a tactile display that combined tactile apparent movement and phantom sensation [7],[8]. Park *et al.* designed aperson identification authentication system based on a tactile stimulus using a tactile display [9]. When applying tactile apparent movement to a tactile display in which stimulation elements are arrayed, the number of stimulation elements increases as a result of increasing transinformation [10],[11]. By applying apparent movement to tactile displays, it should be possible to realize smaller displays.

The recognition of apparent movement is normally a subjective sense. On the other hand, when applying tactile apparent movement to an engineering system, quantitative evaluation is necessary. In many previous studies, however, evaluation of the recognition of apparent movement was based on statistical techniques, and quantitative evaluation was difficult.

In our previous study, we reported the body-sway of an upper limb caused by tactile apparent movement under fixed experimental conditions [4]–[6]. If quantitative evaluation of the body-sway becomes possible, we will be able to evaluate the tactile apparent movement. The characteristics of the body-sway were analyzed using an averaged electromyography (EMG) waveform when apparent movement was recognized based on frequency analysis. In that study, however, the body-sway was not fully evaluated quantitatively.

In this study, we focused on the frequency characteristics of body-sway and investigated the body-sway caused by tactile apparent movement.

II. MEASUREMENTS

Fig. 1 shows the measurement system used in our study. It consists of two PCs and five components: (1) an EMG measurement system, (2) a three-axis acceleration sensor, (3) a tracking system, (4) a stabilometer, and (5) a vibrotactile stimulation presentation system.

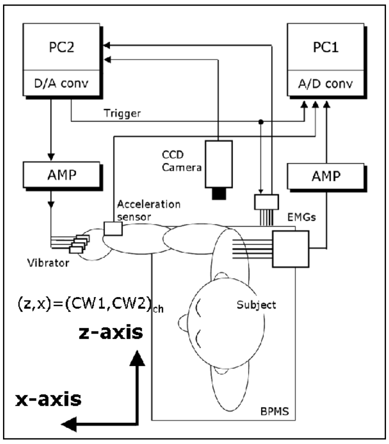


Fig. 1. Measurement system.

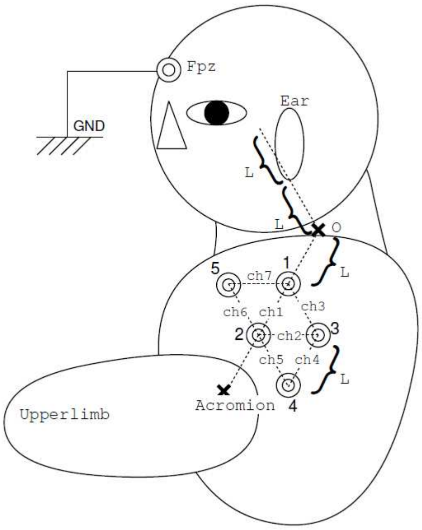


Fig. 2. Arrangement of 5 electrodes and body earth.

The sampling frequencies were different in each system. In detail, biological information and three-axis acceleration were acquired via the same A/D converter, whose sampling frequency was 2000 Hz. The tracking system's sampling frequency was 60 Hz, and the stabilometer's sampling frequency was 80 Hz. PC1 was synchronized with PC2 via a synchronization signal that PC2 generated.

The number and positions of the EMG measurement channels were defined as shown in Fig. 2. The number of EMG channels was 7. The sampling conditions are shown in Table 1.

The tracking system consisted of a CCD camera (Library Corp.: GE60). Positions of tracking markers are shown in Fig. 3. The tracking points were the upper limb, shoulder, body, and below the ear lobe. Tracking results were recorded on PC2 as coordinate data (X, Y). The three-axis acceleration sensor was worn on the right wrist.

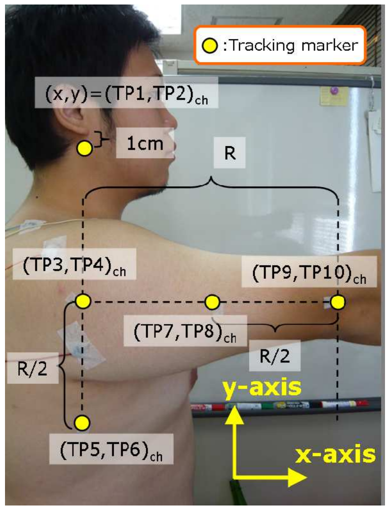


Fig. 3. Arrangement of 5 tracking markers.

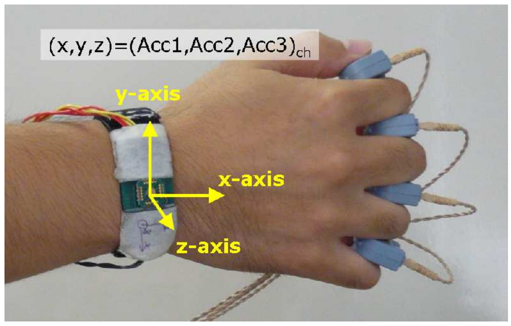


Fig. 4. Arrangement of four vibrators and accelerometer.

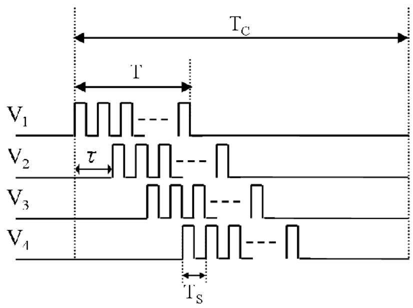
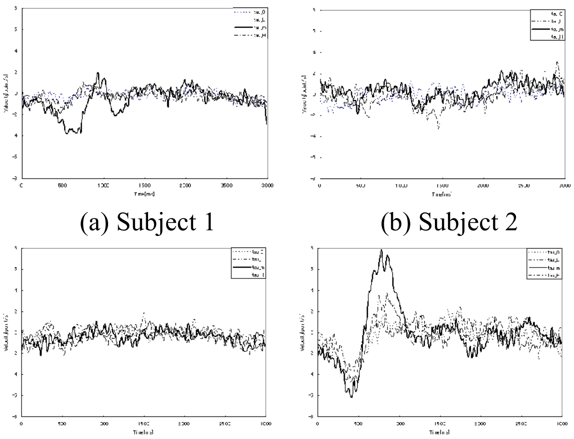


Fig. 5. Drive waveform of vibrator.

A stabilometer (Nitta Corp.: BPMS) measured the subject's center of gravity while standing still. The posture on the stabilometer was based on stabilometry defined by the Japan Society for Equilibrium Research.

The vibrotactile stimulation presentation system consisted of four vibrators (Audiological Engineering Corp.: Skin Stimulator). The subject held four vibrators (SS1, SS2, SS3 and SS4) as shown in Fig. 4. The vibrators were driven by the drive waveform shown in Fig. 5. The drive waveform had four parameters, T, T_S, T_C, and τ. In this study, tactile apparent movement was generated by adjusting only the parameter τ. The other parameters, T, T_S, and T_C,



(a) Subject 1 (b) Subject 2

(c) Subject 3 (d) Subject 4

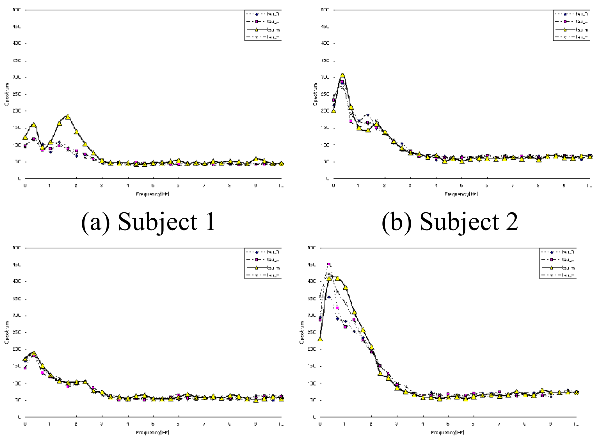
Fig.6. Averaged waveform of TP10ch

were fixed at T = 100 ms, T_S = 4 ms, and T_C = 3000 ms. One trial was assumed to consist of driving vibrators SS1 to SS4 in sequence. One set consisted of 30 trials, and ten sets in total were performed.

The value of parameter τ when the subject felt the apparent movement the most is τ_m. The values of parameter τ representing the difference threshold for the apparent movement are τ_L and τ_H. They were measured by employing an adjustment method used in psychophysics measurements. In this study, vibrotactile stimulations each composed of τ_0, τ_L, τ_m, and τ_H were presented to the subject. The body-sway caused by the tactile apparent movement was evaluated by comparing and examining the subject's reaction at this time. The parameters τ_0, τ_L, and τ_H do not cause any apparent movement while τ_m causes tactile apparent movement. Here, the relation of the τ parameters is $\tau_0 < \tau_L < \tau_m < \tau_H$. One of the τ parameters was selected randomly in each trial, and a vibrotactile stimulation was presented to the subject using that parameter. In the measurement, the subject stood on the stabilometer, with their eyes closed, wearing noise canceling headphones and holding their dominant arm horizontally.

III. ANALYSIS

The body-sway caused by apparent movement reported in the previous study caused the upper limb to move in the direction in which the stimulation image was moved when the subject recognized an apparent movement. In the present experiment, the subject held his or her upper limb horizontally. If body-sway is caused, it is expected that the arm would center on the shoulder and shake periodically. Therefore, we focused on the frequency of the measurement data. When periodic shaking appears upon recognizing apparent movement, a significant difference should be observable in



(a) Subject 1 (b) Subject 2

(c) Subject 3 (d) Subject 4

Fig.7. Averaged spectrum of TP10ch

the spectrum at a specific frequency compared with the case where the apparent movement is not recognized.

As preprocessing, the EMG was filtered from 20 Hz to 500 Hz and subjected to envelope processing, the acceleration value was filtered from 0 Hz to 45 Hz, and the velocity of the tracking points and the center of gravity were analyzed using the finite difference method. Then, the preprocessing data for 3000 ms (for center of gravity only: 2500 ms) from the beginning of the stimulation was averaged. The frequency spectrum was calculated from the preprocessing data, averaged over all trials for every τ. The spectral intensity of each frequency was compared to examine the difference between recognized and non-recognized apparent motion, and a statistically significant difference was found.

IV. RESULTS

Table 1 shows the results of psychophysics measurements. The parameter τ that each subject selected was different, indicating that the recognition of tactile apparent movement is subjective.

Table 1. Results of the psychophysics measurement.

	τ_L [ms]	τ_m [ms]	τ_H [ms]
Subject 1	20	70	120
Subject 2	10	70	120
Subject 3	30	70	110
Subject 4	10	80	160

As one example of the result, Fig. 6 shows the average waveform of the preprocessing data for the tracking point 10ch (TP10ch, Fig. 3). It is thought that TP10ch contains a lot of information about the body-sway because TP10ch is an element in the same direction as the direction in which the stimulation image is moved. From Fig. 6, subject 1 and subject 4 exhibited periodic shaking. This result suggests the possibility of the body-sway having periodicity. Fig. 7 shows the averaged spectrum of TP10ch. From 0 Hz to 10 Hz, the difference in spectral intensities by a factor of 2 or more between the recognized and non-recognized apparent motions for subjects 1 and 4 was statistically significant ($P < 0.01$, t-test). From the above result, it is possible that the body-sway has periodicity because both subjects showed a significant difference at a specific frequency. Here, the channel on which the frequency with a significant difference existed was extracted from all channels, and the results are shown in Tables 2–4. Table 2 shows the result of comparing τ_m with τ_0, Table 3 shows the result of comparing τ_m with τ_L, and Table 4 shows the result of comparing τ_m with τ_L. From the results, besides TP10ch, other channels are expected to show a periodic response. However, these are not reactions common to all subjects.

Table 2. Extracted channels for τ_m vs. τ_0

Subject	TP	CW	EMG	Acc
1	ch3,ch4 ch7,ch8 ch9,ch10	ch1	ch1, ch2	ch1, ch2
2	ch6	---	---	---
3	ch7	---	ch6, ch7	ch1
4	ch5, ch8 ch10	---	ch1	ch1

Table 3. Extracted channels for τ_m vs. τ_L

	TP	CW	EMG	Acc
1	ch3,ch4	---	ch6	---
2	ch3,ch9	ch1,ch2	---	ch2
3	ch8	---	ch6,ch7	---
4	ch3,ch5	---	ch2,ch5	---

Table 4. Extracted channels for τ_m vs. τ_H

	TP	CW	EMG	Acc
1	ch9	---	ch2	---
2	ch5,ch6 ch7	ch1,ch2	ch2,ch5	---
3	---	---	---	ch1
4	ch6	---	ch7	---

This is thought to be due to the fixed parameter T in the presented stimulation, because the parameter T is an important parameter causing apparent movement. Therefore, it will be necessary to conduct an experiment that considers the influence of parameter T in the future.

V. CONCLUSION

In this study, we investigated the body-sway caused by tactile apparent movement. Focusing on the frequency characteristics of the body-sway, we tried to evaluate the body-sway quantitatively. The results show the possibility that periodic shaking occurred when apparent movement was recognized. In future work, the T parameter of the presented stimulation will be examined, and quantitative evaluation of the body-sway caused by tactile apparent movement will be attempted.

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