Swing Analysis of Body-parts Motion Accompanied by Apparent Movement

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Abstract: In this research, we examined the tactile sense for sensory substitution in people who have lost a certain sense. We considered use of apparent movement to communicate something via the tactile sense. It is necessary to measure the apparent movement objectively and quantitatively because apparent movement is normally a subjective thing. We extracted swing motion, a vital reaction characteristic accompanied by the apparent movement, using an EMG. We presented individual stimuli and performed a t-test with a combination of the presented stimuli. From the t-test results, the difference in vital reaction characteristic for each combination of presented stimuli was not small. The result presented here was obtained using only one subject; it will be necessary to increase the number of subjects in future.
Keywords: EMG, Apparent Movement, Tactile stimuli, Tactile sense**.**

I. INTRODUCTION

People depend on various senses in life. However, some people may have lost a certain sense due to congenital or postnatal handicaps. The lost sense can often be made up for with another sense, a concept known as *sensory substitution*. Examples of this include sign language, which the hearing impaired use, or Braille, which the visually impaired use. One human sense system is the tactile sense, which is a cutaneous sense that lies scattered over the whole body, allowing us to sense pain, warmth and so on. Complete loss of the tactile sense over the whole body is rare, although there are sometimes obstacles in a partial sense; nevertheless, it an efficient sense organ for sensory substitution.

Tactile displays have been developed as a sensory substitution for the visual sense and acoustic sense. Most of them involve placing many tactile stimulation elements in an array, and the main topic of study has been how to realize high-density implementations [1][2][3]. However, if the information to be conveyed can be transmitted adequately by limited tactile stimuli, high-density arrays of tactile stimulation elements are not necessary [4][5][6]. In addition, if the portability, convenience, maintainability, and cost of these information presentation devices could be improved, there is a possibility that tactile displays will grow as new means of transmitting information.

With the tactile sense, there is an illusion called *apparent movement*. Apparent movement is a phenomenon whereby, when tactile stimuli are presented at two points on the body with an appropriate time delay between the two stimuli, a person feels as if the sensation due to the presented stimuli moves between the two points. In advanced studies of apparent movement, a basic characteristic, such as the frequency characteristic, of the apparent movement has been examined [7][8][9]. Many of these studies have focused on how to evaluate a subjective quantity corresponding to the perceived apparent movement. It is also important to examine the origin of the apparent movement from a physiological viewpoint.

In this study, we examined a method to measure apparent movement objectively and quantitatively with a simple operation. We focused on the swinging motion occurring when apparent movement was perceived in the stimulated body part. We developed a method to measure the swinging motion of this body part based on the skin surface line electric potential from electromyography (EMG) and examined its effectiveness experimentally.

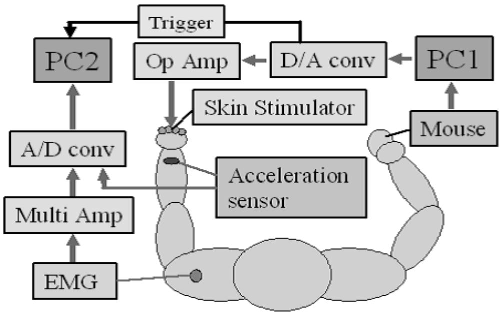

Fig. 1 System setup.

II. EXPERIMENTAL METHOD

1. Experimental system

Figure 1 shows the setup of the experimental system. A personal computer (PC1) recorded on its hard disk drive (HDD) the tactile stimulus generated to produce apparent movement and the subject's response when they recognized the apparent movement (the subject is directed to click a mouse attached to PC1). The output waveform (amplitude 5 V) generated with the digital-to-analog (DA) board of PC1 (Interface Co., PCI-3310) was amplified to about three times with an op-amp to serve as a vibration stimulus applied with a vibration generator. The data recorded in PC1 were the type of presented stimulus, whether or not a mouse click occurred, and the time from presenting the stimulus to the mouse click.

Electromyography (EMG) amplified with a living body amplifier (Digitex Lab. Co., Ltd., MA1132US) was recorded on the HDD of personal computer (PC2) through an analog-to-digital (AD) board (Interface Co., PCI-3176). The two computers were synchronized by sending a trigger signal from PC1 to PC2.

2. Presented stimuli

The four rectangular waves (amplitude 5 V) shown in Fig. 2 were output from PC1 through the DA board and were amplified by a factor of three with the op-amp, and the vibration stimuli were generated with the vibration generator.

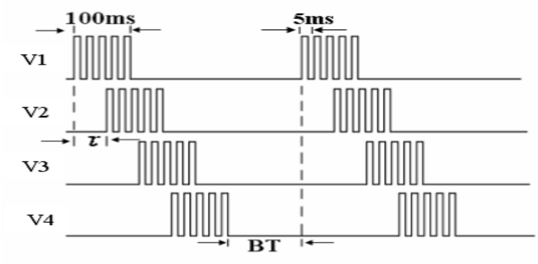

Fig. 2 Presented stimulus.

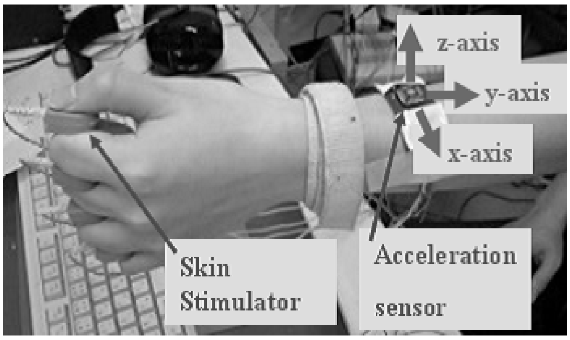

Fig. 3 Placement of vibration elements and acceleration sensor.

The period of the presented stimulus was 5 ms, the vibration duration was 100 ms, and the time difference τ was used as a parameter, as shown in Fig. 3. The relation to the perceived apparent movement was examined in this experiment.

3. Experimental method

The subject was asked to sit still with his/her eyes shut, and wearing noise-canceling headphones. The vibration generator used was Skin Stimulator manufactured by Audio Logical Engineering Co. The subject held four Skin Stimulators between the knuckle joints of adjacent fingers and between the index finger knuckle and the tip of his/her thumb, and extended his/her arm forward, where he/she held it in position, as shown in Fig. 3.

In PC1, the time difference τ was set at random, and the stimulus was presented to the subject as a vibration lasting for $3t$+100 ms. The subject clicked the mouse connected to PC1 only when the apparent motion was recognized. The time from the end of the presented stimulus until the mouse click is called *click time*.

The procedure described above constituted a single trial.

4. EMG measurement

The subject extended his/her arm, on the side where the stimulus was presented, forward horizontally and held it in position. Therefore, any shaking of the arm induced by the apparent movement is expected to be observed as a peculiar change in the EMG around the shoulder.

Eight electrodes were placed around the shoulder, and EMG was measured with a total of 14 channels, as shown in Fig. 4.

The electrode fixing points were as follows. The length L below is assumed to be the standard length from the corner of the eye to the base of the earlobe. Electrode 1 was placed at a distance L on the extension

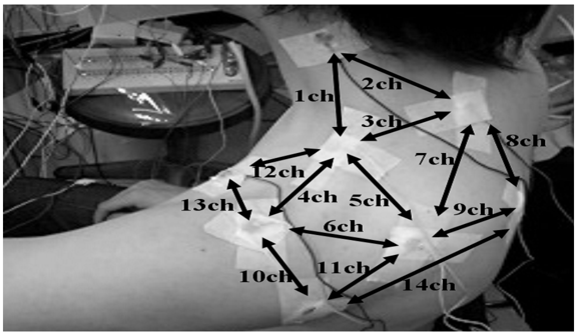

Fig. 4. Placement of the electrodes

line from the base of the earlobe. On a straight line connecting a certain shoulder peak, Electrode 2 was placed a distance L from Electrode 1, and Electrode 3 was placed at a distance $2L$. Electrodes 4 to 8 were placed based on Electrodes 1 to 3 so that the length formed an equilateral triangle with sides of length L, as shown in Fig. 4.

III. PSYCHOPHYSICAL MEASUREMENTS

1. Analysis method

The level of subjectivity corresponding to the perceived apparent movement was evaluated based on the mouse click data recorded in PC1. The ratio of subjects who recognized a stimulus when the time difference τ = 0, 20, 40, …, 160 ms (nine values in total) was calculated; this value is called the *recognition rate*.

If the recognition rate was found for each presented stimulus, the time difference τ at which the subjects recognized the apparent movement can be captured from a psychophysical viewpoint. One set consisted of 300 trials, and a total of eight sets were conducted, allowing sufficient rest in between. Therefore, there were a total of 2400 trials in the experiment. Because the presented stimulus was selected from the nine available types at random, each stimulus will be presented in about 270 trials on average.

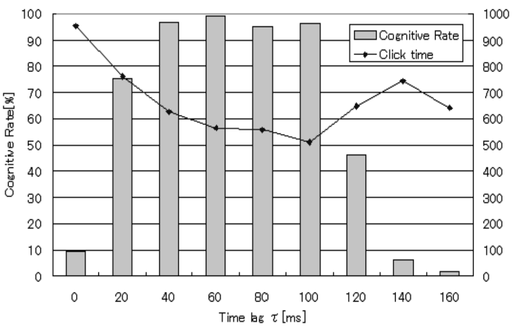

Fig. 5 Result of psychophysical measurements.

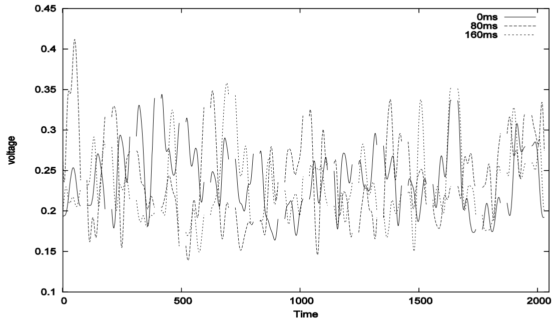

Fig. 6 Average envelope curves.

2. Measurement results

The results of the psychophysical measurements are presented in Figure 5, which shows the recognition rates for the time differences τ.

When the time difference τ was 40–100 ms, the recognition rate became 90 % or more, showing that the apparent movement was easily recognized. For the time differences 0 ms, 140 ms, and 160 ms, the recognition rate was less than 10 %, indicating that the presented stimulus was seldom recognized as an apparent movement. Note that the time difference of 0 ms showed a recognition rate of about 10 %, even though this time difference is incapable of causing any apparent movement. This is thought to be because this experiment is limited to only the downward direction of the apparent movement, and the subject was informed of this fact beforehand. For a similar reason, for the time difference of 20 ms, there is a possibility of showing a higher value than the original recognition rate. A negative correlation was seen between the recognition rate and the click time. The calculated correlation coefficient was -0.66.

IV. EMG MEASUREMENT

1. EMG Preprocessing

EMG measures the muscle electric potential ${}^{ch}_{s}x^{tr}[t]$ (*ch* is the channel number, 1,2,…,14; *tr* is the trial frequency, 1,2,…,300; and *s* is the set frequency, 1,2,…,8; and *t* is the time from the end of the presented stimulus) for a period of 2000 ms from the end of the presented stimulus at a sampling frequency of 1024 Hz. Each muscle electric potential was subjected to preprocessing to square the waveform envelope.

2. EMG analysis

Figure 6 shows examples of average envelope curves for three kinds of presented stimuli, ${}^{ch}_{s}x^{tr}[t]$.

A wave-like difference can be observed between the different kinds of stimuli, but it is difficult to find each

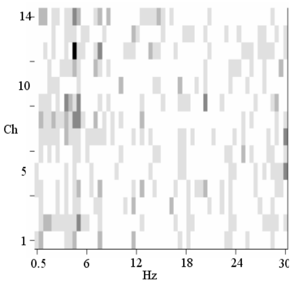

Fig. 7 T^{0}_{80}

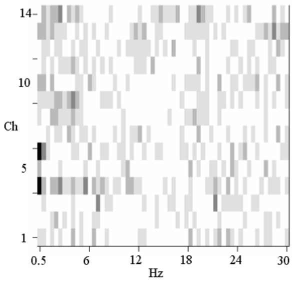

Fig. 8 T^{0}_{160}

characteristic at this step. The characteristic was extracted by frequency analysis. A Fast Fourier transform (FFT) was performed on each trial ${}^{ch}_{s}x^{tr}[t]$; a total of 60 frequency elements for f =0.5–30 Hz were extracted. As results, ${}^{ch}_{s}x^{tr}[t]$ are shown by matrix ${}_{s}P^{tr}$ containing 14 ch × 60 elements. Each procession element and each mean value of classified $\overline{{}_{s}P^{tr}\big|_{\tau=0}}$, $\overline{{}_{s}P^{tr}\big|_{\tau=20}}$, …, $\overline{{}_{s}P^{tr}\big|_{\tau=160}}$ is assumed to be ${}_{s}P^{tr}\big|_{\tau=0}$, ${}_{s}P^{tr}\big|_{\tau=20}$, …, ${}_{s}P^{tr}\big|_{\tau=160}$ in the case of τ in each set. We performed a T-test of ${}_{s}P^{tr}\big|_{\tau=\tau 1}$ and ${}_{s}P^{tr}\big|_{\tau=\tau 2}$, which gave a P-value (significant difference) of 5 %, when assuming τ_1, τ_2 = 0, 20, …, and 160 ms. We defined matrix $T^{\tau_1}_{\tau_2}$ as the sum (over s)of matrix ${}_{s}D^{\tau_2}_{\tau_1}$, where each matrix element was 1 when the P-value was above 5 % and 0 when the P-value was below 5 %:

$$T^{\tau_2}_{\tau_1} = \sum_{s}^{8} {}_{s}D^{\tau_2}_{\tau_1} \qquad (1)$$

For example, Figs. 7 and 8 show the results for τ_1 = 0 ms and τ_2 = 80 ms and 160 ms. The values of the procession element are shown by shading (light = low, dark = high). There were many sets with a P-value was above 5%, as shown by the thick black regions.

3. Cluster analysis

T^{0}_{20}, …, T^{0}_{160} each consisted of 840 elements in a 14 × 60 matrix. These 840 elements were subjected to cluster analysis. Figure 9 shows the obtained dendrogram. A cluster was formed with high uniting levels T^{0}_{20}, € 46 T^{0}_{100} and T^{0}_{120}, € 46 T^{0}_{160}. Agreement with the psychophysical measurements (Fig. 5) was confirmed from the results of the cluster analysis.

V. CONCLUSIONS

In this paper, we examined a body part that was stimulated, causing apparent movement, with subsequent shaking of the stimulated body part when apparent movement under a specific experimental environment was recognized. We proposed a method of measuring the shaking of this body site using the EMG potential of a muscle near the skin surface.

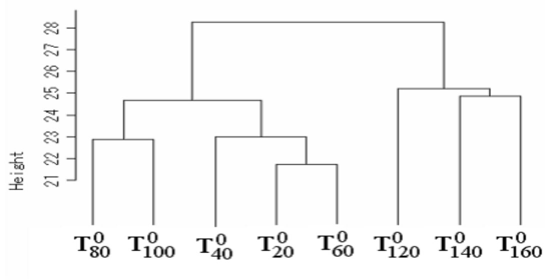

Fig. 9 Results of cluster analysis.

From the results of cluster analysis, agreement was seen with the psychophysical EMG measurements, suggesting a relation between the apparent motion and the EMG measurements.

ACKNOLEDGMENTS

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