Electrostatic and Electrotactile Presentation Using Low Voltage Electrical Stimulation *

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***Abstract*— Recent studies have demonstrated the feasibility of electrotactile presentation utilizing low-voltage stimulation, specifically below ±30V, through the employment of amplitude-modulated waves. Based on the consideration that this method may utilize the capacitance of the skin, we considered that concurrent electrostatic tactile presentation is achievable. Preliminary findings from this research substantiate this hypothesis and additionally present a simplified circuit design for the low-voltage electrical stimulation.**

I. Introduction

Electrostatic and electrotactile modalities represent two distinct approaches for tactile presentation on planar surfaces (Figure 1). The electrostatic displays involve covering of an electrode's surface with a non-conductive layer. This configuration facilitates the accumulation of electric charge, thereby inducing an attractive force between the electrode and the skin [1][2]. Conversely, electrotactile displays use bare electrodes, and directly stimulate sensory nerves via the transmission of electric currents from the electrodes [3][4].

The objective of this study is to explore the potential integration of the two methodologies. Recent advancements have introduced a technique for eliciting electrotactile sensations using comparatively low voltages (±30V or lower) using AC signal [5]. In conducting a replication study, we observed that the movement of a finger over electrodes also generates a frictional vibration sensation, akin to that experienced in electrostatic displays. There was a previous endeavor to merge electrostatic and electrotactile, yet it employed separate electrodes for each technique [6].

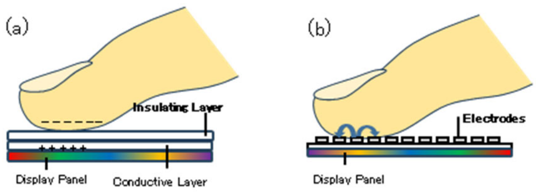

Figure 1. (a)Electrostatic and (b) electrotactile display.

II. Principle

Figure 2 illustrates a schematic representation of the stimulation waveform utilized in low-voltage electrical stimulation [5]. This waveform comprises a sine wave at 50 Hz, which is modulated by a square wave of around 10 kHz, and the stimulation waveforms of opposite polarity are input to two (or more) electrodes.

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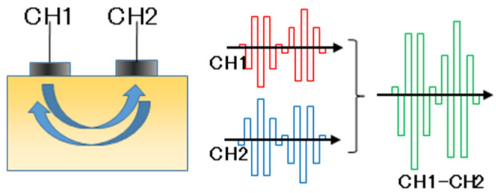

Figure 2. A schematic representation of Low-voltage electrical stimulation.

The plausible mechanism of this stimulation technique is as shown in Figure 3. Noting that the two electrodes are always driven in positive-negative pairs, a pair of ±30V produces a potential difference of 60V. Owing to the capacitive properties of the skin's stratum corneum, the initial phase effectively 'charges' the capacitance, and subsequently, the stored charge and the inverted external voltage co-produce a twice as large potential difference, thereby facilitating a higher-voltage stimulation. Essentially, this approach capitalizes on the skin's capacitive element. This also explains possibility of electrostatic stimulation. While the conventional electrostatic display stores charge in a dielectric film on the surface, here the charge is stored in the skin.

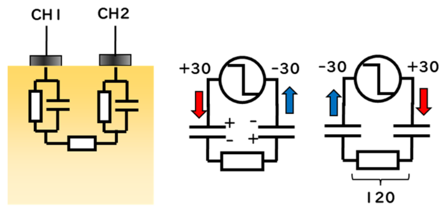

Figure 3.Principle of stimulation.

This methodology necessitates both positive and negative voltage sources for the output of analog waveforms. However, as shown in Figure 4, an equivalent stimulus can be generated utilizing Pulse Width Modulation (PWM) waveforms. In this alternate approach, although a single power supply with double the voltage is required, the resultant circuitry is markedly simplified.

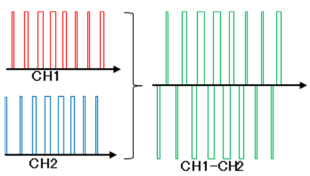

Figure 4. PWM-based amplitude modulation.

III. Experiment

A. Apparatus

The experimental system's architecture, as depicted in Figure 5, includes a PC, a microcontroller, an 80 V voltage source, and an AD converter dedicated to current measurement. The system also incorporates FET switches, which are utilized to alternate the state of each electrode between the power source and ground. The electrodes are designed with a diameter of 2.0 mm, positioned at a center-to-center distance of 2.54 mm, and are systematically arranged in an 8 by 8 matrix configuration.

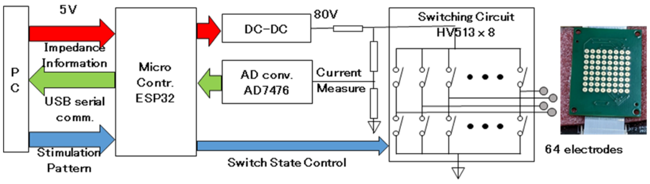

Figure 5. Experimental setup.

B. Procedure

The experiment aimed to validate the concurrent realization of electrotactile and electrostatic tactile sensations. Figure 6 presents a schematic of the stimulation pattern. This involves each electrode being alternately connected to either the anode (+80V) or the cathode (ground) in a striped arrangement. High-frequency modulation was employed for switching purposes. A 125 Hz square wave was modulated using high-frequency pulses (50 kHz, 25 kHz, 10 kHz, 5 kHz, 2.5 kHz, 1 kHz, and 500 Hz). Consequently, the stimulus waveform comprised a 4 ms square wave train punctuated by a repeating 4 ms pause interval.

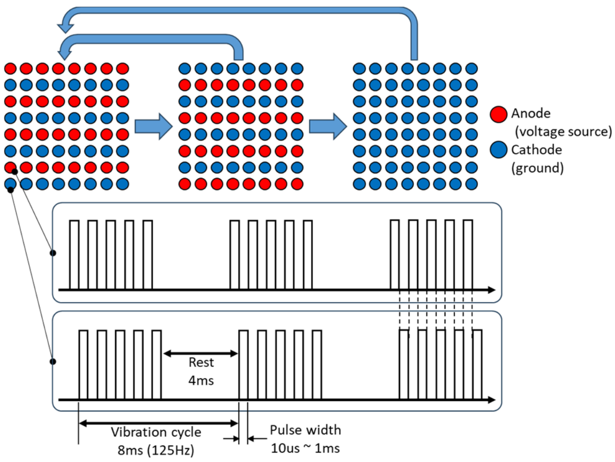

Figure 6. Schematic drawing of stimulation pattern.

Participants were instructed to rest their fingers on the electrodes without movement and to report presence and intensity of pressure and vibration sensations, recorded on a 5-point Likert scale. Subsequently, they were asked to glide their fingers in a circular motion over the electrodes, reporting both the presence and intensity of the sensations in a similar fashion.

This procedure was repeated for each of the seven modulation frequencies. In an additional measure, an accelerometer (BMX055, Bosch) was affixed to the fingernail to record acceleration during the finger movements. The participant group comprised seven male individuals aged between 22 and 26 years. The experiment was approved by the ethical board of the author's institution (H23041).

C. Result

Figure 7 presents data reflecting the acceleration measured on a fingernail during a tracing action across the electrodes, specifically under a 10 kHz modulation setting. Obviously, the finger's movement is coupled with distinct mechanical vibration. The frequency of this observed vibration is noted as 125 Hz, aligning with the square wave frequency utilized in the study. In this particular case, the peak acceleration amplitude was recorded at 0.4 G, indicating a significant mechanical response associated with the tracing motion.

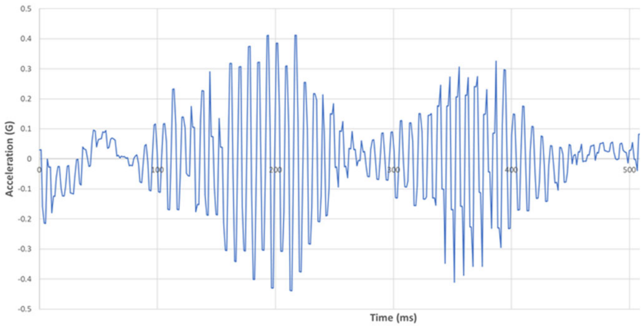

Figure 7. Acceleration measured on the nail during finger tracing motion.

This paper does not include a detailed account of the subjective evaluation, but it was noted that at a 50 kHz modulation frequency, no tactile sensation was elicited under any condition. Conversely, at other modulation frequencies, both pressure and vibration sensations were observed, with the vibration sensation intensifying during movement. This demonstrates that the current setup is capable of generating both electrotactile and electrostatic tactile sensations.

A significant limitation of the current setup is the instability of the electrostatic stimulation, influenced by variables such as finger pressure, speed, contact angle, and skin moisture. Future challenges include stabilizing this aspect and achieving distinct separation between electrotactile and electrostatic stimulation.

References

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