ELECTROTACTILE HAPTIC DISPLAY ON THE FINGERTIPS: PRELIMINARY RESULTS

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Abstract

Electrical stimulation of the sense of touch may be used to display pictorial information to blind computer users via a fingertip-scanned (haptic) touch tablet containing embedded electrodes. This might be particularly useful to users of systems with graphical user interfaces, or with drawing and layout software.

Electrotactile (electrocutaneous) stimulation on the fingertip, however, differs substantially from that on other body locations. We will discuss the implications of designing a practical graphics haptic display by addressing the high-resistance and variable nature of the fingertip electrode–skin interface.

Introduction

The increasing use of computer graphics and pictorial displays (Macintosh® and Microsoft Windows® environments) presents a major problem for blind computer users. Text output from a speech synthesizer is not suitable for presentation of complex pictorial or spatial information (organizational charts, flowcharts, electrical or mechanical drawings).

Our goal is to create a flat, smooth tablet with embedded electrodes and external driver circuitry that can electrically display pictorial information from a computer directly to the skin. A controlled, localized current (1–10 mA) through the skin excites afferent touch fibers to produce sensations of vibration, tingle, and pressure. A blind user will then be able to interpret the percepts that s/he acquires by scanning the display with the fingertips.

Several previous articles review the principles and application of electrotactile stimulation [1, 2, 3, 4]; only one article to date specifically addresses fingertip stimulation [5].

Fingertip electrotactile stimulation

Figure 1 shows the flat part of the finger pad in contact with a coaxial electrode; the tip of the finger may also be used. The coaxial geometry is necessary to localize the current pathway, and hence the perceived sensation. Stimulation pulses may be functionally-monophasic (with a shifted baseline for zero dc current), or balanced-biphasic, with two phases of equal magnitude and opposite polarity. Groups of three 40–100-μs pulses, repeating at a 200-Hz rate, are gated into bursts repeating at approx. 50 Hz in order to maximize the range of perceived vibratory intensities [6]. Because of the wide variations in electrode–skin resistance, stimulation current is controlled.

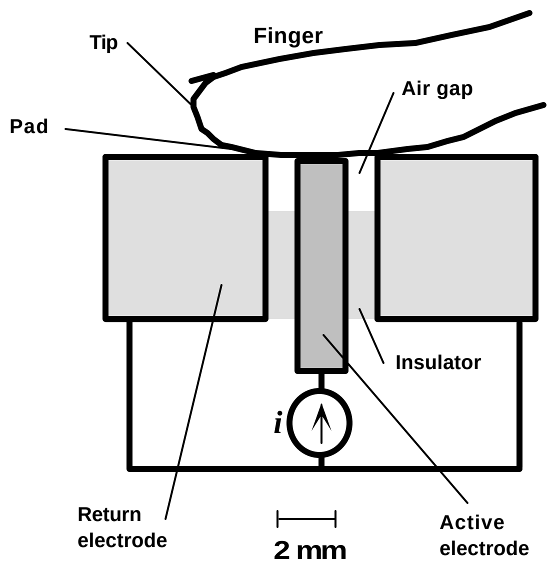

Fig. 1. Side view of electrode–skin interface. Most of the stimulation current flows from the active center electrode through the skin and subcutaneous tissues and returns through the surrounding ground electrode. Some current flows across the conductive sweat film on the finger surface. The air gap prevents high voltage tracking across the insulator surface.

High voltage and high skin resistance

Active-electrode-to-ground potentials of 150–500 V are required for adequate current control. Most investigators have reported that control of stimulation intensity on the fingertip is difficult. This can be expected if a current control circuit has inadequate voltage capability, making the stimulation current, and hence, perceived intensity, dependent upon skin resistance.

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Mild arcing upon incipient contact between the electrode and the fingertip (<10 μm) occurs when the stimulation voltage exceeds approximately 350 V. Although no skin damage has been visually evident, efforts to reduce this phenomenon are ongoing. At even lower voltages (300 V), several materials used for the concentric insulator exhibited localized dielectric breakdown and subsequent tracking (similar to arcing) as they accumulated skin secretions. In approximate order, machinable ceramic (Macor®), acrylic (Plexiglas®), and polycarbonate (Lexan®), exhibited the least tracking, while epoxy and polyamide-imide (Torlon®) showed the most severe tracking.

The resistive part of the electrode–skin impedance is rather high, typically 150–300 kΩ. If the skin is moist, a film of conductive sweat shunts current across the fingertip and insulator surfaces, reducing the *effective* stimulation current. This was particularly a problem with insulator widths less that 2 mm.

As shown in Fig. 1, we finally decided to use an air gap insulator to minimize the arcing, tracking, and shunting problems. This, however, allows the accumulation of debris in the cavity around the active electrode.

Pulse polarity

In contrast to results reported for other stimulation sites, we have found that positive functionally-monophasic (zero-dc) pulses are superior to negative pulses. On the abdomen, forearm, and forehead, electrotactile sensation thresholds are lower for negative-going monophasic pulses than for positive ones, and higher perceived intensity has been reported for negative pulses [7]. However, our results on the fingertip have shown that negative pulses produce a weak, diffuse sensation that is different, not only in magnitude, but in quality, from positive pulses. At stimulation currents insufficient to elicit the usual tingling or vibratory percept, itching is sometimes felt, possibly indicating that different types of tactile receptors are involved. Finally, we observed that balanced-biphasic pulses feel much like positive monophasic pulses.

While the density and distribution of tactile receptors is different in (glabrous) fingertip skin than it is in (hairy) abdominal skin, one would still expect negative pulses to preferentially depolarize the afferent nerves nearest the active electrode. We presently have no explanation for this discrepancy.

Stimulation locus

The extreme fingertips are more sensitive to electrotactile stimulation than the central, flatter regions of the finger pad; the lateral aspects of the finger pad are also more sensitive. These results are consistent with earlier studies [5]. However, the explanation is elusive because *mechanical* tactile sensitivity is quite uniform over these regions. Interestingly, while the tips require less current (× 0.5–0.7) to achieve sensation threshold, they require more voltage × 1.3–1.5) due to their higher resistance.

Contact area

In contrast to electrode arrays that are fixed on the skin, as the finger slides over a given active electrode, the contact area will change. Furthermore, decreasing the contact area while keeping constant current will increase the perceived stimulus intensity, presumably due to the greater current density. However, since the peak stimulation voltage also increases with smaller areas, it may be possible to use peak voltage as a predictor of contact area, and thus control for the effect of changing area. We are presently pursuing such a control mechanism.

Acknowledgments

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