Sparkle: Towards Haptic Hover-Feedback with Electric Arcs

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ABSTRACT
We demonstrate a method for stimulating the fingertip with touchable electric arcs above a hover sensing input device. We built a hardware platform using a high-voltage resonant transformer for which we control the electric discharge to create in-air haptic feedback up to 4 mm in height, and combined this technology with infrared proximity sensing. Our method is a first step towards supporting novel in-air haptic experiences for hover input that does not require the user to wear haptic feedback stimulators.

Author Keywords
In-air haptic feedback; Electric discharge; High-voltage transformer; Hover sensing; Infrared proximity sensor.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: User Interfaces—Haptic I/O.

INTRODUCTION
Hover sensing technologies have enabled users to control a variety of computing devices with finger gestures performed above the input surface (e.g., mobile devices' touchscreens [2], touchpads [3], tabletops [5], and keypads [7]). Unlike touch, hover interactions lack natural tactile feedback, which can make it hard for users to precisely perform a gesture and to manipulate the displayed content [10]. This difficulty is most apparent in close proximity to the surface when users have to position and maintain the height of their input finger, or move their finger during the interaction without performing a touch or leaving the hover range.

Here we demonstrate SPARKLE, a self-contained technology that enables haptic feedback for hover input with controlled electric arcs that are safe to touch (see Figure1). To stimulate the fingertip we augment a finger sensing input device with electric discharges from a high-voltage resonant transformer and trigger the discharge when the finger is near the surface. We control the moment when the discharge occurs and the duration of the discharge, and we modulate the discharge from resonant frequency down to a frequency detectable by the receptors in the fingertip to alter its intensity and to create haptic stimuli of discrete and of continuous trains of arcs that can elicit pulsing, tickling, and hot sensations.

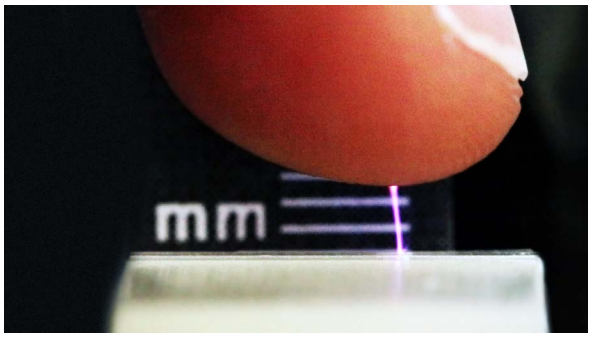

Figure 1. Touchable electric arcs spark haptic sensations in air.

Unlike previous attempts to facilitate the input and to give haptic feedback for hover gestures, we do not attach an actuator to the finger (e.g., a piezo [6] or a magnet [11]), which is undesirable to wear for casual interactions. Neither do we focus air-borne ultrasound, which does not work for hover due to the large distance needed to focus the beams on the target (15–20 cm) [1]. Very recently, body-carried electrostatic charge was proposed to give users a controlled electric shock when touching a conductive object [4]. The problem is that the user is continuously charged with a wearable high-voltage DC charger and cannot selectively prevent the discharge (e.g., when touching another person or grasping a door handle). Moreover, this approach does not scale from giving a momentary shock to in-air feedback on demand, or over a longer time period. Finally, the integration with a hover sensing technology has not been shown.

IMPLEMENTATION

Hardware
Figure 2 shows the hardware we built. We use a high-voltage resonant transformer (a ferrite rod, 11.5 cm long, 1 cm in diameter) and a custom-designed driver circuit. The transformer works through electromagnetic induction. When an alternating current flows through the primary winding, it generates a changing magnetic field that induces an alternating current in the secondary winding. Here we use a step-up transformer to boost the voltage from a few volts to several kilovolts and to decrease the current as follows (see Figure 3):

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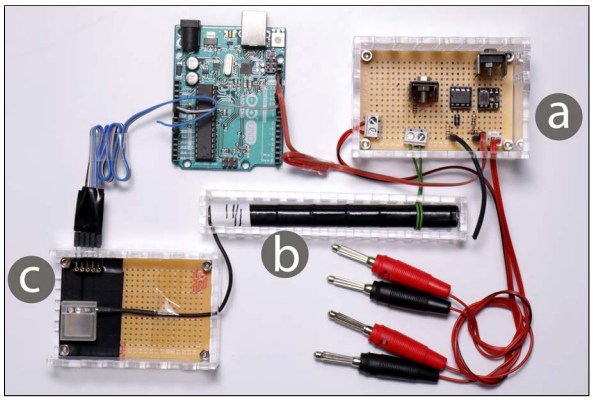

Figure 2. Sparkle's key components: (a) custom-designed driver circuit; (b) high-voltage transformer; (c) proximity sensing device.

The self-resonating circuit we built drives the transformer at resonant frequency (1 MHz) using a current limited DC supply (30 V, 500 mA). The alternating current induced in the secondary winding decreases with the turn ratio (2:450), while the voltage increases with the turn ratio. When the potential difference to ground surpasses the dielectric strength of air ($\approx$ 3 kV/mm), the electric current ionizes the air around the output terminal and causes a plasma discharge that becomes visible as an electric arc. The self-resonating circuit enables peak performance during regular operation when the resonant frequency of the transformer changes due to additional load capacitance from the interacting finger.

Safety

Stimulating the human body with electricity is dangerous. However, the transformer we use does not store DC charge. To meet the safety rules for working with AC voltages (2 mA rms for voltages above 1 kV rms [9]) we limit the supply current at the primary winding and thus the current induced in the transformer at the output terminal. In addition, we use pulse width modulation and switch the transformer with an Arduino to modulate the discharge from resonant frequency down to much lower frequencies and duty cycles. With this approach the discharge lasts for only a fraction of a second with an average current that is safe to touch.

Grounding

Unlike using body-carried electrostatic charge users do not need to be equipped and charged with a high-voltage DC charger, nor directly linked to ground, nor discharged to perceive a haptic sensation [4]. The resonant transformer induces alternating current and voltage. The electric arcs consist of charged particles with approximately equal numbers of electrons and positively charged ions, which do not significantly charge the user during the interaction.

HAPTIC SENSATIONS

Electric arcs have very high temperatures and can burn the skin. In a controlled environment, however, they open up a new design space of haptic stimuli with touchable arcs. Preliminary findings from informal pilot testing suggest that the arcs feel different from an electrostatic shock and were associated with sensations that were barely perceivable, tickling, pulsing, or hot. The design of the transformer (e.g., turn ratio) and the DC supply voltage provide a means to control the length of the arc, which corresponds to the rms voltage output of the transformer.

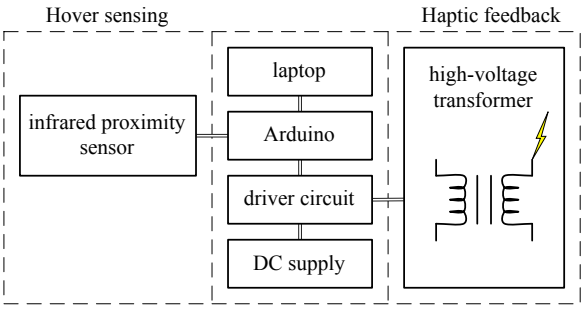

Figure 3. System diagram for controlling electric arcs during hover.

EXAMPLE APPLICATION

Our current prototype is limited to one wire tip and can create visible electric arcs 3 mm in length with haptic sensations up to 4 mm above the surface. Due to corona discharge before dielectric breakdown and relatively high power requirements this hardware is not suitable for handheld devices. We expect, however, to be able to optimize the transformer and to scale up our prototype to give haptic feedback on a palm-sized interactive surface. With our current setup we designed the following application scenario to demonstrate the implementation and to highlight the potential we foresee for SPARKLE:

A Proximity Sensing Device with Haptic Hover-Feedback

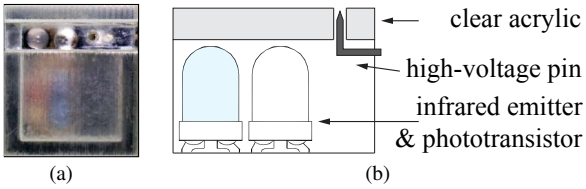

Figure 4. (a) Top view and (b) diagram of infrared proximity sensor with high-voltage pin for emitting electric arcs.

Inspired by related work on proximity sensing keypads [7], we built an input device that can sense hover and provide haptic feedback with electric arcs. Similar to the Power-up button [8], we sense finger proximity with one infrared emitter and one phototransistor (940 nm wavelength, 3 mm diameter) located under the surface. Adjacent to the proximity sensor is one pin that outputs the electric arcs (see Figure 4). With this new configuration we can give users discrete and continuous haptic feedback when the finger is above the surface (see Figure 1). In future, this technology could augment keypads, keyboards, mouse buttons, and interactive surfaces.

CONCLUSION

We demonstrated touchable electric arcs and a proximity sensing device that can stimulate a hovering finger with haptic feedback without using body-carried stimulators.

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REFERENCES

1. Carter, T., Seah, S. A., Long, B., Drinkwater, B., and Subramanian, S. Ultrahaptics: Multi-point mid-air haptic feedback for touch surfaces. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, ACM (New York, NY, USA, 2013), 505–514.

2. Chen, X. A., Schwarz, J., Harrison, C., Mankoff, J., and Hudson, S. E. Air+touch: Interweaving touch & in-air gestures. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*, UIST '14, ACM (New York, NY, USA, 2014), 519–525.

3. Gu, J., Heo, S., Han, J., Kim, S., and Lee, G. Longpad: A touchpad using the entire area below the keyboard of a laptop computer. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, ACM (New York, NY, USA, 2013), 1421–1430.

4. Mujibiya, A. Corona: Interactivity of body electrostatics in mobile scenarios using wearable high-voltage static charger. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '15, ACM (New York, NY, USA, 2015), 435–444.

5. Rekimoto, J. Smartskin: An infrastructure for freehand manipulation on interactive surfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '02, ACM (New York, NY, USA, 2002), 113–120.

6. Rekimoto, J. Senseablerays: Opto-haptic substitution for touch-enhanced interactive spaces. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '09, ACM (New York, NY, USA, 2009), 2519–2528.

7. Rekimoto, J., Ishizawa, T., Schwesig, C., and Oba, H. Presense: Interaction techniques for finger sensing input devices. In *Proceedings of the 16th Annual ACM Symposium on User Interface Software and Technology*, UIST '03, ACM (New York, NY, USA, 2003), 203–212.

8. Spelmezan, D., Appert, C., Chapuis, O., and Pietriga, E. Controlling widgets with one power-up button. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, UIST '13, ACM (New York, NY, USA, 2013), 71–74.

9. The National Institute of Standards and Technology (NIST). EEEL safety rules for moderate and high voltages. Online, October 2008. Retrieved July 7, 2016 from `http://www.nist.gov/el/isd/mmc/upload/high_voltage_rules_revised.pdf`.

10. Wacharamanotham, C., Todi, K., Pye, M., and Borchers, J. Understanding finger input above desktop devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, ACM (New York, NY, USA, 2014), 1083–1092.

11. Weiss, M., Wacharamanotham, C., Voelker, S., and Borchers, J. Fingerflux: Near-surface haptic feedback on tabletops. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology*, UIST '11, ACM (New York, NY, USA, 2011), 615–620.