Demonstrating Trigeminal-based Interfaces

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Figure 1: We demonstrate two trigeminal-based interfaces. The first (left) is a thermal display that does not utilize heat or cold but instead creates an illusion of temperature by stimulating the trigeminal nerve in the user's nose with different chemicals. This nerve is responsible for detecting temperature shifts but also reacts to chemicals such as menthol or capsaicin, which is why breath mints feel cold and chilis feel hot. Here, how our device renders (a) the warmth of a desert by emitting a capsaicin-based scent and (b) the coolness of an icy mountain by emitting eucalyptol. The second (right) is a novel type of olfactory device that renders readings from external odor/gas sensors into stereo-smell *trigeminal* sensations by means of *electrical stimulation*. By stimulating the trigeminal nerve, it allows for smell augmentations or substitutions without the need for implanting electrodes in the olfactory bulb.

ABSTRACT

We demonstrate two trigeminal-based interfaces. The first provides a temperature illusion that uses low-powered electronics and enables the miniaturization of simple warm and cool sensations. Our illusion relies on the properties of certain scents, such as the coolness of mint or hotness of peppers. These odors trigger not only the olfactory bulb, but also the nose's trigeminal nerve, which has receptors that respond to both temperature and chemicals. The second is a novel type of olfactory device that creates a stereo-smell experience, i.e., directional information about the location of an odor, by rendering the readings of external odor sensors as trigeminal sensations using electrical stimulation of the user's nasal septum. We propose that electrically stimulating the trigeminal nerve is an ideal candidate for stereo-smell rendering. We demonstrate these interfaces by allowing an audience to stimulate an author and receive an explanation of the sensations.

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1 INTERACTIVE SYSTEMS USING THE TRIGEMINAL NERVE

We demonstrate two interactive systems that leverage the underutilized trigeminal nerve, both as virtual demonstrations in which audience members can stimulate an author who then describes and explains the underlying mechanism for the sensations. These two prototypes focus on the two contributions of trigeminal-based interfaces: (1) their use for temperature illusions; and (2) their use in olfactory human-computer interaction to provide stereo-smell cues.

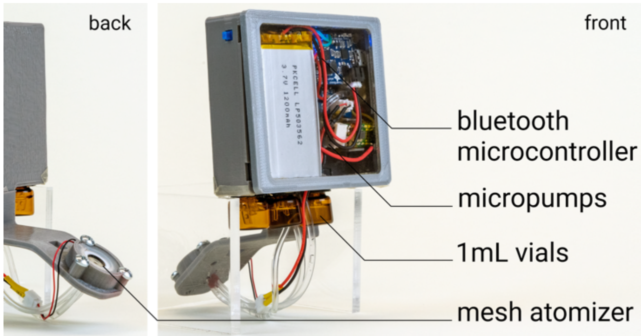

Figure 2: The key insight that enables our approach to achieve dexterity is that the lumbrical and interossei muscles, at the back of the user's hand, are more easily accessible to EMS than the standard forearm flexor muscles.

1.1 Trigeminal-based Temperature Illusions

Haptic feedback allows virtual reality experiences to match our sensorial expectations beyond just visual realism [1, 14]. Today, researchers focus on engineering wearable devices that deliver realistic haptic sensations, such as touch [1, 2], force feedback [6, 9]. More recently, researchers started also focusing on stimulating new senses, such as olfaction [7, 8, 19] and thermoception—the sense of changes in temperature [10]. The latter has proven extremely hard to miniaturize into wearable devices because, in order to create the sensation of temperature, researchers rely on heat lamps [5] or thermoelectric materials [12] (e.g., Peltier modules), which consume substantial power and require large batteries.

In our approach, we explored a temperature illusion that can be achieved with low powered electronics (see Figure 2) and enables the miniaturization of simple ambient warm or cool sensations. This illusion, depicted in Error! Reference source not found., is based on the properties of certain scents, such as mint, which not only stimulate our olfactory bulb (which feels the "smell" of mint) but also stimulates our *trigeminal* nerve-endings in the nasal cavity, which feel the "freshness" of mint. Our approach allows users to feel ambient temperature changes, much like a Peltier element would achieve. However, unlike the traditional thermoelectric materials that consume a lot of power (e.g., 4-13W per Peltier [11, 13]), our approach uses low-power electronics (only uses 0.25W), and, thus, enables the miniaturization of simple warm or cool sensations.

In our original paper, we demonstrated its usage in a virtual reality (VR) experience featuring several temperature changes. Our device delivers the trigeminal stimuli by pushing the scents using micropumps onto a vibrating mesh atomizer, which in turn emits the scents as a fine spray. The scents used in this experience were engineered to minimize their odor recognizability while maximizing their trigeminal "thermal" effect. This allows a user to navigate a simple scene in which a room starts off warm (Figure 3 left a, b) and later feels the cold air rush in when the storm cuts the electricity and swings the cabin door wide open (Figure 3 right).

1.2 Stereo-Smell via Electrical Trigeminal Stimulation

The sense of smell is what allows us to understand a wide range of everyday experiences, from pleasurable ones (such as enjoying good food) to detecting potential hazards (e.g., smell of rotten food, microbial threats, and non-microbial threats such as from hazardous gases) [16].

Traditionally, olfactory interfaces physically push odor molecules into the user's nose. This methodology is limiting: it requires olfactory interfaces to be built from bulky actuators (tubes, pumps, and transducers) that redirect smell from containers to the user's nose. While this works in scenarios where one can hide a large device (e.g., smells as notifications while driving [11]) these actuators are impractical for ubiquitous everyday use because their form-factor is dictated by the size of reservoirs and actuators. One of the most promising ways to break from size-limitations is to shift from analog (i.e., pushing odor molecules to the nose) to digital (i.e., stimulating the olfactory bulb to generate the odor perception) actuation. This approach has gained some attention in the HCI community [15]. While this approach digital actuation is certainly promising, it involves risky insertion procedures with little success at reproducing smells.

Instead, we approach digital actuation from a new angle by searching for a less-invasive location to apply electrical nose stimulation, one that still works without the need for invasive and risky electrodes attached to the olfactory bulb.

The principle behind our approach is the fact that while, previously, the sense of smell was attributed to the function of the olfactory bulb alone, this notion has been revised once the contributions of the trigeminal nerve to smelling were understood. In fact, the trigeminal nerve, which has nerve-endings lodged in the nasal cavity, works in tandem with the olfactory bulb to detect the warmth, freshness, astringency, etc. of incoming odors (e.g., the freshness of mint) [3]. In other words, we do not perceive the "freshness of mint" in isolation from the "odor of mint" because the experiences of the trigeminal nerve and the olfactory bulb are often *fused* together into what we experience as a "smell." In fact, some of our examples for the role of smell included situations in which the trigeminal sensations are key, for instance, in detecting potential hazards via the smell of noxious gases [16].

Building on this perceptual fusion between the sensations of the trigeminal nerve and olfactory bulb, we propose a novel type of olfactory substitution device that renders readings from odor or gas sensors as trigeminal sensations by means of electrically stimulating their trigeminal nerve. Our device is a new alternative to olfactory devices that stimulate the olfactory bulb via electrodes deep in the nose [18], which unfortunately require trained personnel. Our device sits across the user's nasal septum, where it can *already* access the trigeminal nerve, unlike other devices that require the insertion of electrodes up the nasal cavity. While our device does not create an entire "digital smell," because it does not extend to the olfactory bulb, it does create sensations typically associated with smelling: trigeminal sensations.

Our device measures 10x23 mm and communicates with external sensors via Bluetooth, allowing it to fit entirely inside the user's nose (including battery, sensors, wireless, stimulator, electrodes)

Figure 3: Two scenes from our virtual reality demonstration. The user beings in the cabin (left). We see (a) the user's first-person view of our "cabin in the woods" scene and (b) the composited mixed reality view, showing the user warmed by a furnace, our device atomizes a cayenne pepper tincture (capsaicin) to create a warming sensation. As the user walks outside into the cold of the mountain (right), our device atomizes eucalyptol faster to induce a colder ambient temperature than in the cabin.

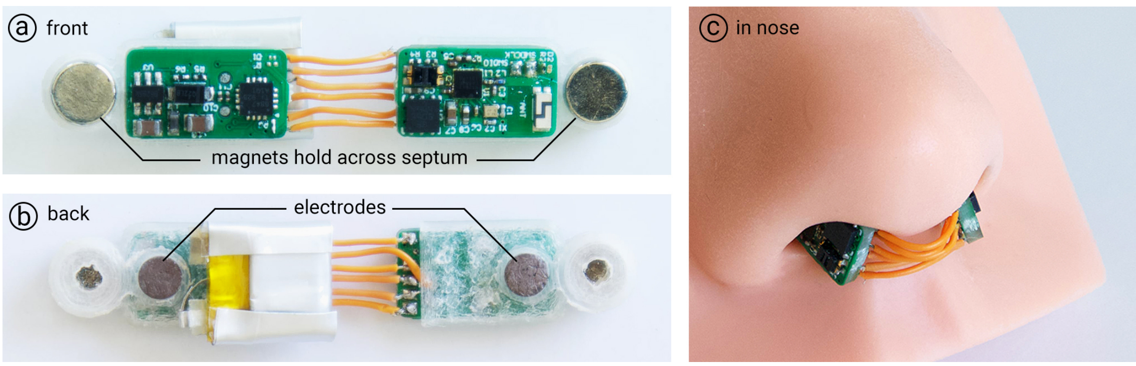

Figure 4: (a, b) Our device is comprised of two printed circuit boards (PCB), one in each nostril. (c) Small magnets on each side allow the device to hold securely to the user's nose by means of magnetism.

like a nose-ring across the septum, as depicted in Figure 4. While our device is entirely self-contained, it is only capable of electrical trigeminal stimulation and depends upon a connection to external odor sensors (via Bluetooth) to obtain odor or gas readings. It stimulates the trigeminal nerve using an electric, biphasic waveform (using a positive and negative current) with computer-controlled pulse-width, depicted in Error! Reference source not found.. This electrical waveform design is key to how our device allows users to feel via trigeminal cues: not only the intensity of the odor but also its direction, i.e., stereo-smell, such as in Figure 2

2 DEMONSTRATION OF TRIGEMINAL-BASED INTERFACES

Our CHI demonstration provides attendees with an interactive platform to test the systems on an author. In the virtual booth, we will provide the audience with several links: (1) a website to actuate either or chemical or electrical trigeminal interface; (2) links to both paper videos to further show uses for each device; (3) links to both repositories with all resulting code, schematics, and documentation to reproduce the interfaces; and (4) links to both published papers.

3 CONCLUSION

In this virtual demonstration of our trigeminal-based interfaces, we highlight two distinct sensations afforded by the same nerve: (1) the ability to produce temperature illusions using chemical stimulation and (2) the nerve's unique ability to perceive stereo-smell cues via electrical stimulation. Temperature illusions via the trigeminal nerve have the additional benefit of providing an alternative means of producing thermal feedback while requiring substantially less power than traditional approaches (e.g., with Peltier modules, air conditioning, or heat lamps). Our second contribution is the first wearable device that fits in the user's nose to electrically stimulate their trigeminal sense. This device enables users to feel, via trigeminal cues, not only the intensity of an odor but also its direction (i.e., to their left or right), as well as provides an alternative means for trigeminal stimulation without the use of chemical reservoirs. We validated these findings by means of user studies [4].

To conclude, our trigeminal-based interfaces enable new interactive experiences via the trigeminal nerve. We demonstrate both devices virtually via an interactive experience in which the audience can stimulate an author either chemically (to produce temperature sensations) or electrically (to produce stereo-smell sensations).

Figure 5: (a) Our user burnt their toast while making breakfast, which unfortunately emits a strong odor that masks the actual danger, a gas leak in their stove. (b) As the user inhales, our device renders the smell of methane by stimulating the user's trigeminal nerve electrically and to the left—indicating the location of the methane gas leak, which is tracked via an external odor sensor that relays these readings to our sensor via Bluetooth. (c) This allowed the user to find the leak.

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