FIRE: Mid-Air Thermo-Tactile Display

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Figure 1: Users' point of view while interacting with (a) campfire scene, (b) water fountain scene, and (c) kitchen scene

ABSTRACT

We demonstrate an ultrasound haptic display-based mid-air thermo-tactile feedback system. We design a proof-of-concept thermo-tactile feedback system with an open-top chamber, heat modules, and an ultrasound display. Our method involves directing heated airflow toward the focused pressure point produced by the ultrasound display to deliver thermal and tactile cues in mid-air simultaneously. We present this system with three different virtual environments (*CampFire*, *Water Fountain*, and *Kitchen*) to show the rich user experiences of integrating thermal and tactile feedback.

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1 INTRODUCTION

In recent years, a great amount of emphasis has been given to providing thermal feedback in a VR application [Günther et al. 2020; Son et al. 2023] because it makes the experience more immersive and enhances presence. Thermal feedback can be used as an ambient communication channel to create a more realistic perception of virtual objects or increase realism. Similar to the physical world, many VR scenarios can benefit by incorporating thermal feedback – people feel the ambient warmth of a fire in a fireplace, use hot water from the faucets or showers, or even perceive falling snow.

Many studies on non-contact thermal and humidity feedback have been conducted in a number of ways, and much of this research has used thermal devices such as heaters, blowers, projector lights, and infrared lamps. Hülsmann et al. [Hülsmann et al. 2014] delivered wind and thermal feedback using IR lamps and fans to the interaction space. Motoyama et al. [Motoyama et al. 2022] used mist to provide cold sensations on the fingertip. Kamigaki et al. [Kamigaki et al. 2020] proposed using an ultrasound display to create a focal point in mid-air on a hand-worn glove to provide thermal sensations. However, due to their underlying mechanisms, most of the above-mentioned approaches have the limitation that it is difficult to control the thermal cues in 3D space. Other approaches which provide controllability do not offer bare-hand interaction.

Our perception-based approach integrates localized ultrasound tactile feedback with global thermal feedback, creating a thermo-tactile sensation on bare hands in mid-air. Tactile stimulus is perceived through mechanoreceptors and processed in the somatosensory cortex, whereas the thermal stimulus is perceived through thermoreceptors and processed in the insula cortex. When these two stimuli are interplayed without masking each other while stimulating the same area of the human's hands, humans can perceive it as a unified thermo-tactile feedback, allowing thermo-tactile cues in 3D space at an arbitrary location. Our approach combines vibrotactile and thermal stimuli without interfering with each other by creating ambient thermal cues through a heated chamber. By presenting acoustic pressure points with ambient thermal cues, we can achieve integrated thermo-tactile sensations in mid-air for barehand interaction. Visual information is tightly coupled with thermo-tactile cues (see Figure 1). Further details regarding this system and the experiments conducted to verify our approach can be found in [Singhal et al. 2021].

2 SYSTEM

2.1 Hardware

Figure 2 illustrates our setup that provides thermo-tactile feedback in mid-air. The system delivers tactile stimulus modulated at 200 Hz on the user's palm using the ultrasound haptic display (STRATOS Explore, Ultraleap, UK), which could render different haptic patterns compatible with the VR scenes. The user's hand was tracked

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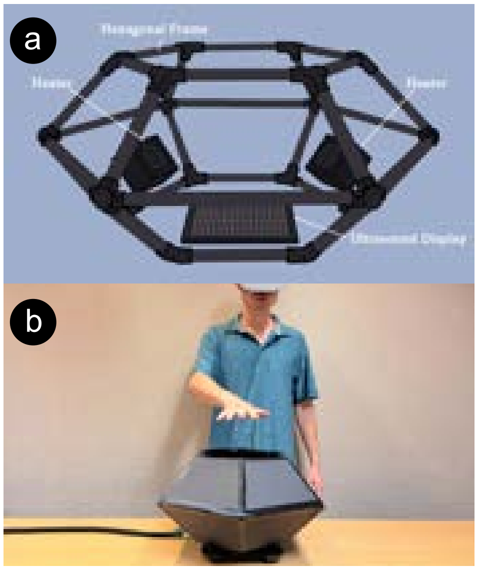

Figure 2: (a) Labeled diagram of the proposed system and (b) a user interacting with the real system

by using Oculus hand-tracking system. The system delivers thermal stimulus on the user's hand using a PTC (Positive Thermal Coefficient) heating element to proportionately raise its resistance in order to maintain a constant temperature. The temperature of the heater is controlled by a power supply. The chamber has a hexagon shape, which maintains thermal flow, and was built using 30 aluminum beams for the frame of the structure and insulation foams for the surface cover. The system controls temperature by adjusting the digital power supply voltage applied to the PTC heater through a microcontroller. An Oculus Quest 2 VR headset was used along with our prototype system.

2.2 Visual Scenes

We demonstrate our approach using three VR scenes, each providing unique thermo-tactile feedback. We describe each environment in detail below:

CampFire: Figure 1 (a) shows the campfire scene. In this scene, the user interacts with the fire embers and smoke rising from the fire with their virtual hands. An ultrasonic cue with 200 Hz and 0.7 intensity for haptic rendering is provided for 500 ms whenever an ember collides with the virtual hands. The temperature for this scene is set to 44°C to maximize the heat effect without reaching the pain threshold to resemble the fire. A crackling fire sound is played with the virtual scene to enhance the user experience.

Water Fountain: In this scene, a hot water fountain with a water stream is presented in a park (see Figure 1 (b)). When the water stream collides with the user's hands, the height of the water stream is dynamically adjusted depending on the hand's position with the water splash. A continuous circular haptic sensation with a radius of 2 cm with a frequency of 200 Hz and an intensity of 1.0 is presented to the user's palm. A temperature of 38°C is selected to emulate the feel of warm water hitting the palm.

Kitchen: The users find themselves in a kitchen and see a teapot on the stove with steam coming out of it (see Figure 1 (c)). The participants can interact with the steam by using their virtual hands. A haptic cue of radius 4 cm with a frequency of 200 Hz and intensity of 0.4 is presented on the user's palm to provide haptic sensations of steam interacting with the palm. The temperature for this scene is set to 40°C to provide the heat effect that resembles the steam.

3 DEMO EXPERIENCE

For the demonstration at the Emerging Technologies, we made some significant improvements over our previous work [Singhal et al. 2021]. We have changed the heating mechanism to a PTC heating element. The PTC element is commonly known for providing a more stable and constant temperature. We also redesigned the system and made it smaller for better heat retention. We replaced the previous tracking system with the Oculus hand tracking system for better accurate hand interaction.

We tested our prototype system with a number of participants to receive their feedback and further improve the demo experiences. Based on their feedback, we improved the integration of visual and thermo-tactile cues with more realistic rendering schemes to enhance the VR experience. After several iterations, we could achieve more realistic and compelling thermal experiences.

At the conference, we will demonstrate the proposed thermo-tactile display with a VR setup. The attendees interested in the interactive demo will be briefed on interacting with the system. Then, they will be asked to stand in front of the system and put on the headset. The demonstrators will then perform the calibration process to synchronize the attendee's physical and virtual world positions. The attendees can start interacting with the prototype to interact with all the interactable objects. The demo will take at most 5 minutes per attendee, including calibration and briefing.

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