Face/On: Actuating the Facial Contact Area of a Head-Mounted Display for Increased Immersion

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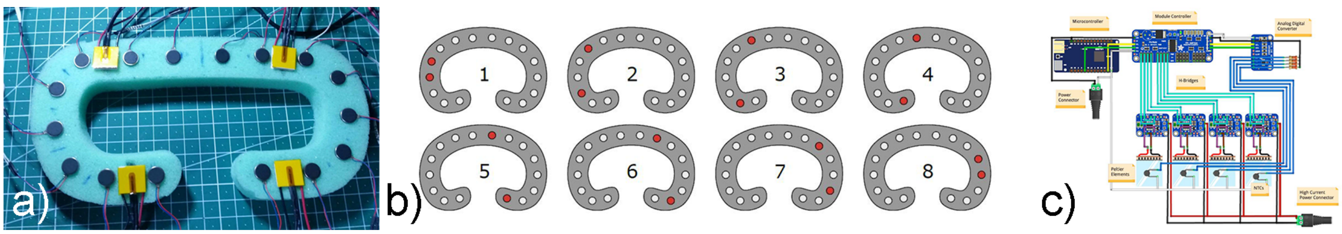

Figure 1: a) Inside the cushion, Face/On consists of an array of 16 vibro-tactile and 4 thermal actuators. b) The high resolution of vibro-tactile actuators allows the rendering of complex patterns that can be perceived as a continuous stroke, e.g. from left to right (1 to 8). c) A modular architecture of micro-controllers handles each type of actuator separately and can be extended by additional modules with little effort.

ABSTRACT

In this demonstration, we introduce *Face/On*, an embedded feedback device that leverages the contact area between the user's face and a virtual reality (VR) head-mounted display (HMD) to provide rich haptic feedback in virtual environments (VEs). Head-worn haptic feedback devices have been explored in previous work to provide directional cues via grids of actuators and localized feedback on the users' skin. Most of these solutions were immersion breaking due to their encumbering and uncomfortable design and build around a single actuator type, thus limiting the overall fidelity and flexibility of the haptic feedback. We present *Face/On*, a VR HMD face cushion with three types of discreetly embedded actuators that provide rich haptic feedback without encumbering users with invasive instrumentation on the body. By combining vibro-tactile and thermal feedback with electrical muscle stimulation (EMS), *Face/On* can simulate a wide range of scenarios and benefit from synergy effects between these feedback types.

CCS Concepts

•**Human-centered computing → Haptic devices;** *Empirical studies in HCI;* Virtual reality;

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Keywords

VR; multi-modal; heat; vibration; haptic; feedback;

1. INTRODUCTION

We envision a future where near-eye displays (NEDs) will replace screen-based devices like smartphones and desktop computers. While augmented reality (AR) NEDs could reach the compact form factor of regular glasses or even contact lenses to achieve maximum mobility and comfort, VR NEDs will be limited in their miniaturization due to their requirement to block out exterior light [6]. This inherent limitation implies that there will always be a contact area between VR NEDs and the users' skin. We see this limitation as an opportunity to leverage this contact area with haptic feedback, and therefore increase immersion in virtual environments.

In 1965, Ivan Sutherland proposed his visionary idea of an ultimate display that would offer users total immersion by altering the matter in a room [7]. While our current ability to materialize virtual objects is limited to 3D-printing, there have been many suggestions on how to increase immersion in VEs [6]. Usually, these solutions include wearable devices like haptic gloves [1], grounded force-feedback devices [3] or ambient feedback generators [5]. Most of these solutions have two common limitations: 1. users are always aware of the additional instrumentation and 2. their single modality design provides only one type of feedback, e.g. vibration or heat, and is thus limited in the scenarios it can simulate.

With *Face/On*, we present an approach to tackle both aforementioned limitations. Similar to how users get accustomed to perpetual skin contact with wrist-watches, clothes,

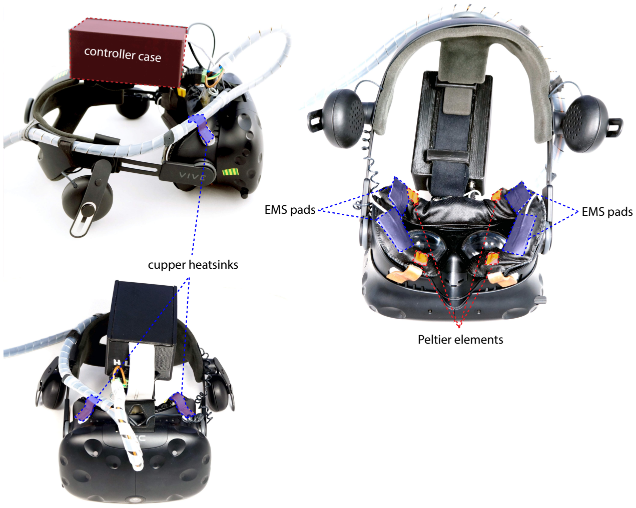

Figure 2: The hardware components for actuation that are attached to the HMD.

and glasses, they can be expected to shift their attention from the NED itself towards the VE. This allows *Face/On* to provide haptic feedback that blends with the virtual experience rather than distract from it with encumbering instrumentation. In fact, the presence of a *Face/On* extension in a NED is only noticeable during haptic feedback. The second limitation, the low variety of feedback that can be provided, is loosened through a combination of thermal, vibro-tactile, and EMS to leverage synergy effects between these actuator types and adapt the feedback mode to the current context.

2. FACE/ON DESIGN

In an iterative design process, *Face/On* was designed and implemented as three main components: a modular hardware architecture, a high- and low-level programming interface for the actuation, and a physical model that interprets events in the VE into actuation commands.

2.1 Hardware Architecture

During the design of Face/On, we drew from findings of related work regarding the optimal distribution of vibrotactile actuators to create 'ghosting' sensations [4] (see figure 1 a), feasibility of thermal actuation in the facial region and comfortable temperature intervals [5], and findings that even 'unrealistic' haptic feedback can increase immersion in VEs [2]. Figure 2 shows the final distribution of actuators across the cushion surface. *Face/On* is plugged into the HTC Vive's serial port and communicates via an Arduino micro controller. All hardware components such as H-bridges, EMS controller, and the Arduino are contained in a controller case and mounted on top of the HMD for optimal weight distribution.

2.2 Programming Interface

To assist developers with the integration of *Face/On* haptic feedback in their VEs, a layered software architecture provides high-level controls inside Unity3D projects that are interpreted into low-level commands for the Arduino controller. This way, complex feedback types like a random vibration pattern to simulate rain can be sent as a single high-level command instead of multiple instructions to actuate individual vibration motors. By introducing these special modes in a low level the amount of traffic on the serial connection and the resulting delay can be reduced significantly.

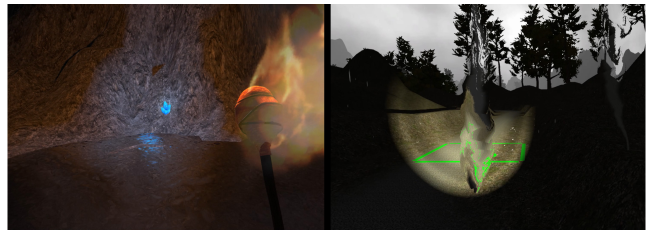

Figure 3: In the demonstration scenes, users will feel sources of heat like a torch (left) and drive through stormy environments feeling cold rain drops and static charges from lightning strikes on their skin (right).

2.3 Physical Model

To accurately match the haptic feedback with real-world sensations, physical laws and models were applied for each calculation. We defined two distinct modes of actuation: impact and ambient mode. These modes are by no means exclusive as projectiles can have ambient properties, e.g. a cold snowball or a hot fireball. To define the area of actuation, a virtual representation of the actuators is present in the scene. During the impact of a projectile, the projectile speed, point of impact and mass is considered, resulting in the actuators closest to the point of impact being actuated more than distant actuators. To compensate for software and hardware delays, the collider size of projectiles is adapted to their speed, resulting in a synchronized visual and haptic feedback. Ambient feedback calculation considers the laws of thermo-dynamics to include radiation of heat and the temperature of the user's skin into the calculation process.

3. DEMONSTRATION SCENES

We implemented a show-reel consisting of several scenes that make intensive use of all actuator types. During a train ride, users pass through several environments and climate zones that cover a range of haptic experiences like heat waves of explosions, cold rain drops on the skin or the rush of wind caused by high speed. To prevent unnecessary motion sickness, the scenes are viewed in a seated position and there is no acceleration in the linear movement of the train. All scenarios have been created after researching the game-play of top selling VR games.

4. CONCLUSION

We have presented *Face/On*, an embedded feedback system for VR HMDs that leverages the contact surface between an HMD and the user's face to provide rich haptic feedback in VEs. By combining three actuators types, namely vibro-tactile, thermal, and EMS, *Face/On* can render a wide range of complex feedback types like cold raindrops falling on the user's face.

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