HapticBox: Designing Hand-Held Thermal, Wetness, and Wind Stimuli for Virtual Reality

Kedong Chai
Design School
Xi'an Jiaotong-Liverpool University
Suzhou, China

Yue Li *
Department of Computing, School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China

Lingyun Yu
Department of Computing, School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China

Hai-Ning Liang
Department of Computing, School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China

Figure 1: (a) HapticBox, the experimental device. (b) A user wearing the VIVE Pro HMD, holding the HapticBox in the left hand, and a VR controller in the right hand. (c) System architecture of HapticBox.

Abstract

Experiences in virtual reality (VR) through multiple sensory modalities can be as rich as real-world experiences. However, many VR systems offer only visual and auditory stimuli. In this paper, we present *HapticBox*, a small, portable, and highly adaptable haptic device that can provide hand-held thermal, wetness, and wind haptics. We evaluated user perception of wetness and wind stimuli in the hand and to the face. The results showed that users had a stronger perception of the stimuli and a higher level of comfort with haptics in the hand. While increasing the voltage enhanced the wind perception, the results suggested that noise is an important side effect. We present our design details and discuss the future work.

Index Terms: Human-centered computing - Human computer interaction (HCI) - Interaction devices - Haptic devices

1 Introduction

There is a growing interest in experiencing virtual environments through multisensory modalities. Creating similar perceptual experiences based on real-world multisensory experiences is necessary for the development of interactive technologies that aim to provide users with rich sensory feedback and overall experience. Virtual Reality (VR) research and development is rapidly pushing the boundaries of audiovisual technology by integrating vibration haptics, force feedback, as well as thermal, wetness, and wind stimuli in multisensory experiences. Existing work has shown that multisensory experiences have a significant impact on immersion and presence.

Recently, researchers have explored ways of providing thermal feedback, creating the illusion of wetness, and exploring the effects of wind stimuli in VR. However, most haptic devices in previous work have intrusive designs that need to be attached to people's bodies with relatively complex settings, thus making these devices of limited flexibility and portability. In this work, we extend this line of research by designing a novel flexible and portable haptic device, *HapticBox*, that can support multisensory VR experiences based on users' hand (see Figure 1). HapticBox integrates thermal (warm and cold), wetness, and wind stimuli into a compact 50mm*50mm*60mm box and can be linked to a device with Wi-Fi. We present our evaluation of relevant hardware and parameters, accordingly detail the design of HapticBox.

*Corresponding author: yue.li@xjtlu.edu.cn

2 Evaluation of Hardware and Parameters

2.1 Thermal stimuli

Previous research has tested many thermal stimuli modules. Peltier is a commonly used one for lightweight, small-size, and low power supply devices. However, limited information can be found for the temperature change over time, and the results can vary for different prototype designs. Therefore, we conducted a series of objective data measurements for our prototype design (see Figure 2, left).

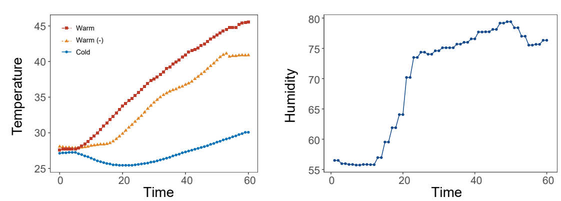

Figure 2: Left: continuous recording of temperature changes of the warm and cold Peltier modules in 60 seconds; Right: continuous recording of wetness changes in 60 seconds.

We used a DS18B20 temperature sensor (with an accuracy error of $\pm 0.5°C$) to measure the change in temperature over 60 seconds. Previous research showed that human skin can be damaged by prolonged contact with hot surfaces, and 43.2°C is the threshold temperature for perceiving the thermal pain [2]. We tested the warm thermometric Peltier module (see Figure 2 left, red line) and found it necessary to attach an insulation sheet to mitigate the risks of overheating (see Figure 2 left, orange line). It is worth noting that at the cost of compact design, there is no heat dissipation structure in our prototype design. After ~40 seconds of use, one has to wait ~20 seconds for the next operation.

979-8-3503-4839-2/23/$31.00 ©2023 IEEE
DOI 10.1109/VRW58643.2023.00279

2.2 Wetness and wind stimuli

Perceived wetness and wind stimuli may differ in different skin areas [1]. In addition, while increasing the voltage of the mini fan increases the fan's power and speed, it also causes noises.

Therefore, we investigated the perceived wetness, wind and noise at different voltages and presented a detailed parameter configuration reference.

We conducted a laboratory study with a room temperature of 25±1°C and a relative humidity of 55±5%. Participants sat at a table and held the HapticBox to feel the stimuli (see Figure 1b) and provided their evaluations right after each trial on "*how noticeable did you find the stimuli/noise?*" and "*how comfortable did you find the stimuli?*". Ten participants (age M=22.2, SD=1.96, 6 males, 4 females) took part in this study. Participants' self-evaluated knowledge about haptic feedback was moderate (M=2.9, SD=1.1) on a 5-point Likert scale. Figure 3 shows the evaluation results.

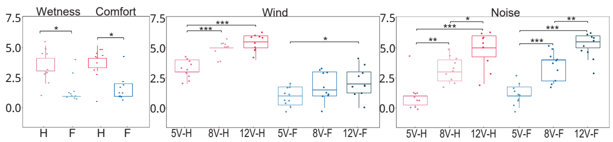

Figure 3: User perceptions of the stimuli, comfort and noise.

Wetness stimuli. Participants evaluated perceived wetness stimuli and comfort under two position settings (face and hand). For the face condition, we asked participants to hold the box 5-10 cm towards their face; for the hand condition, the spray module produces a mist onto the palm. Participants reported a significantly greater level of wetness (z=2.23, p=0.026) and comfort (z=2.54, p=0.011) in the hand than to the face. Most participants (N=9) preferred to have wetness stimuli in the hand than to the face. An objective measure of humidity is shown in Figure 2 (right).

Wind stimuli. We evaluated users' perceived wind stimuli and noise under two position settings (face and hand) and three levels of voltages (5V, 8V, and 12V). A two-way ANOVA showed that users' perceived a greater sense of wind in the hand than to the face, $F(1,54)=141.05$, $p<0.001$; and perceived wind was significantly greater when the voltage was higher, $F(2,54)=18.18$, $p<0.001$. Significant differences were found between 5V-8V and 5V-12V, but the difference between 8V-12V was not significant (p=0.281). Similarly, users perceived significantly greater noises when the voltage increased, $F(2,54)=60.07$, $p<0.001$. The difference was significant for all pairwise comparisons ($p<0.001$). Most participants (N=9) found that wind stimuli in the hand was better than to the face. Eight participants identified that a voltage at 5V has noticeable feeling of the stimuli, and many (N=7) reported that the noises on the 8V and 12V conditions negatively affected the experience, making hand+5V the most selected combination for the wind stimuli (N=8).

3 System Design and Implementation

Based on the evaluation results, we explain our design of HapticBox. The prototype costs ~20 USD and ~1 week time to build and test.

3.1 Haptic module

The prototype includes four Peltier modules, a spray module and a fan, assembled into a 50mm*50mm*60mm box (see Figure 4, left). The Peltier modules were distributed on the four sides of the box. The mini fan was attached to one side, and a VIVE tracker was attached to the other side. A spray module and a PVA water-absorbent sponge stick were used to provide water mist and wetness stimuli. It operates to control the vibration of the ceramic plates when it is powered, and converts the water from the sponge stick into mist. This haptic module was made small so that users could hold it with one hand. Users could feel thermal stimuli at the fingertips, and wetness and wind stimuli at the palm (see Figure 1b).

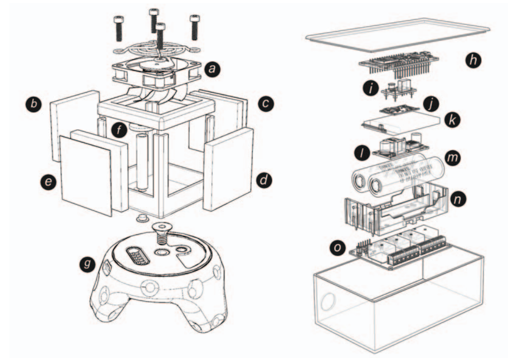

Figure 4: Design of HapticBox. Left: the haptic module consisting of (a) a mini fan, (b-e) four thermometric Peltier modules, (f) a spray module, (g) a VIVE tracker. Right: the control module consisting of (h) an MCU controller, (i) a buck converter step up module, (j) a charging protection board, (k) a 3.7V lithium battery for the controller, (l) a buck converter step down module, (m) two 3.5V batteries, (n) a battery compartment, and (o) a relay module.

We experimented with several out-of-the-box options for tracking and positioning the HapticBox in VR, including VR controllers and the VIVE tracker. Having a VIVE tracker attached to the HapticBox matched its position with the virtual objects relatively well. Other smaller options such as reflective markers and magnetic trackers may provide room of improvement in future work.

3.2 Control module

We used a NodeMCU V3 microcontroller (ESP8266 main controller with 2.4Ghz Wi-Fi support). This allows the transmission of haptic commands between Unity and the microcontroller via wireless networks. Two Panasonic lithium batteries (NCR18650B 3.5V 5A) and buck converter modules were used for the power supply. Together with the relay, these modules were integrated into a flat 130mm*73mm*50mm box (see Figure 4, right). The control module was connected to the haptic module via cables. It can be tied to the arm or placed on a table while holding the haptic module.

4 Conclusion and Future Work

In this paper, we present our design of HapticBox, a small, portable, and highly adaptable haptic device that can provide thermal, wetness, and wind stimuli. The non-intrusive and lightweight design allows a wide range of uses outside the laboratory environment. The system design of HapticBox was informed by experimental findings. We found that participants perceived a greater sense of wetness and wind stimuli, and a higher level of comfort in the hand than to the face. Our design provide insights for researchers and practitioners who are interested in designing haptic experiences, tangible interfaces, and improving user experience in virtual reality. We will further refine the design of the HapticBox and evaluate its use in VR.

Acknowledgment

This work is supported by the National Natural Science Foundation of China (62207022), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (22KJB520038), and the Xi'an Jiaotong-Liverpool University (RDF-20-02-47). We thank our participants for their time and valuable comments in the user studies.

References

[1] D. Filingeri and G. Havenith. Human skin wetness perception: psychophysical and neurophysiological bases. *Temperature*, 2(1):86–104, 2015.

[2] A. Stoll, M. Chianta, and J. Piergallini. Thermal conduction effects in human skin. *Aviation, space, and environmental medicine*, 50(8):778–787, 1979.