



HAL
open science

Dynamic and Modular Thermal Feedback for Interactive 6DoF VR: Implementation and Evaluation

Sophie Villenave, Pierre Raimbaud, Guillaume Lavoué

► To cite this version:

Sophie Villenave, Pierre Raimbaud, Guillaume Lavoué. Dynamic and Modular Thermal Feedback for Interactive 6DoF VR: Implementation and Evaluation. 32nd IEEE Conference on Virtual Reality and 3D User Interfaces, Mar 2025, Saint Malo, France. pp.1204-1205, <10.1109/VRW66409.2025.00248>. <hal-05049552>

HAL Id: hal-05049552

<https://hal.science/hal-05049552v1>

Submitted on 28 Apr 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Dynamic and Modular Thermal Feedback for Interactive 6DoF VR: Implementation and Evaluation

Sophie Villenave

Pierre Raimbaud

Guillaume Lavoué

Ecole Centrale de Lyon, CNRS, INSA Lyon, Université Claude Bernard Lyon 1, LIRIS, UMR5205, ENISE, 42023 Saint Etienne, France*

ABSTRACT

Thermal effects in Virtual Reality (VR) can provide sensory information when interacting with objects, or create a thermal ambiance for a Virtual Environment (VE). They are critical to a range of applications, such as firefighting training or thermal comfort simulation. Existing ambient thermal feedback systems revealed limitations: most of them lack proper sensory characterization, are intrusive and/or limit movements, and are difficult to replicate. In this context, our contribution is a reproducible room-scale system able to provide dynamic ambient thermal feedback for 6 Degrees of Freedom VR experiences. We present its psychophysical study on thermal sensation, latency, and noise ($n=10$).

Index Terms: Thermal Feedback, Virtual Reality, Perception

1 INTRODUCTION

Thermal feedback in VR is used for diverse applications such as giving directional cues, weather simulation, fire evacuation training, and more generally providing thermal display interfaces to interact with virtual objects. Existing systems can be categorized into wearable devices that usually provide localized feedback via Peltier elements and non-wearable systems to procure ambient feedback [1]. In this work, we focus on non-wearable systems. Early prototypes of non-wearable systems, such as Dionisio’s fan-and-lamp-based system [2], provided ambient thermal feedback but were limited to non-immersive VR. More recent and complex systems such as Han et al.’s “Hapmosphere” [4], combined infrared lamps, fans, and mist makers to create steerable thermal ambiances, albeit with difficulties targeting the lower body. For scenarios where fire needs to be simulated, high-power infrared radiators with motorized shutters have been used [1], though their energy consumption (i.e., 1–2 kW) can pose challenges. Despite the multitude of implementations, thermal feedback systems for VR still face challenges in terms of reproducibility, usability for dynamic interactions, and accurate sensory characterization. In this context we propose an open and simple modular system for ambient thermal stimulation suitable for 6DoFs VR experiences and its psychophysical study evaluating perceived thermal effects, latency and noise.

2 SYSTEM IMPLEMENTATION

2.1 Objectives and Constraints

Our design focused on the following: i) non-intrusive, i.e. it must be imperceptible (with the exception of the thermal feedback); ii) not hinder movement and interactions; iii) feedback must be dynamic and responsive, i.e. user’s position or actions must influence the thermal feedback in interactive time. As creating true ambient effects using wearable systems is not well documented and because of their intrusiveness, we opted for a non-wearable solution. Our system builds upon Hülsmann et al.’s work [5], which combined

*e-mail: name.surname@liris.cnrs.fr

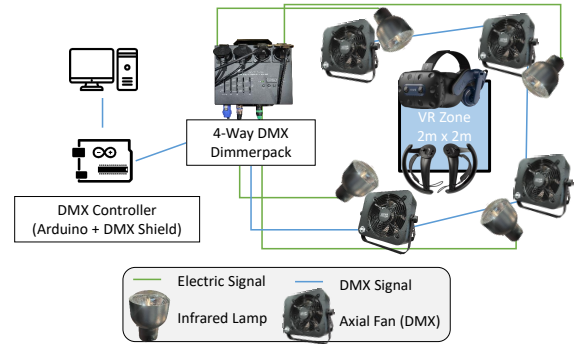


Figure 1: Schematic overview of our thermal feedback system.

infrared lamps and fans in a CAVE setup but required outdated hardware. Our updated and simplified design described in Fig. 1 is dedicated to VR HMDs, leverages off-the-shelf components for affordability, provides flexibility in actuator placement, and is easy to reproduce. Design and software are open and available on GitHub¹.

2.2 Thermal Actuators

Infrared lamps prioritize heat over light output, making them ideal for thermal stimulation. Our system uses 300W bulbs (ref. Philips IR300CH) that are dimmable, cost-effective (\$30 each), and compatible with standard E27 fixtures. Filters can be used to reduce visible light. Cold feedback is provided by axial fans that can be controlled remotely (ref. ADJ Entour Cyclone). Although fans do not change the air temperature significantly, they provide a cooling effect by removing the warmer air surrounding the skin and replace it with ambient air that is cooler, moreover sweat evaporates faster resulting in an effective cooling of the body. However, maximum sensation of cold is dependent on the ambient temperature of the room and mechanoreceptors of the skin detect the presence of wind.

2.3 Control and Communication

Communication between the VR application and thermal actuators is done via DMX-512 protocol² which is standard in the entertainment industry and enables control over 32 daisy-chained devices. Our main DMX controller is Arduino board (ref. Mega 2560) coupled with a DMX shield (ref. DFR0260). Controller is plugged to the VR computer via USB and programmed to receive messages from Unity via the serial port. Firmware for the DMX controller uses the Arduino DMX library³ to send instructions on the DMX channels. We use a 4-channel DMX dimmer (ref. Stairville DDS-405 LC) to power and control IR lamps. Selected fans integrate their own controller, are plugged to electrical outlet for power and are daisy chained to the dimmer pack using 3-pin XLR cables (ref. Stairville PDC3CC) for control.

¹<https://github.com/liris-xr/6dof-vr-thermal-feedback>

²USITT DMX512-A - Asynchronous Serial Digital Data Transmission Standard for Controlling Lighting Equipment and Accessories

³<https://docs.arduino.cc/libraries/dmxserial/>

3 PSYCHOPHYSICAL STUDY

This study aims to link the lamps intensity and the fans speed, i.e., variables that can be controlled by the VE, to thermal perception. Because it is multi-factorial [3], thermal perception can't be predicted only using lamp radiance intensity or fan wind speed.

3.1 Procedure

Participants (n=10, 8M, 2F) were recruited from the staff of our institution. After completion of the consent form, they were instructed to expose their arms. Participants were equipped with a VR HMD (HTC Vive Pro 2) and associated controllers (Valve Index) as well as active noise-canceling headphones (Sony WH-1000XM5) that played quiet background music. They stood upright or rested on a high stool in the middle of the VR zone, equidistant to every thermal actuators. Room temperature was controlled between 20°C and 22°C and participants were immersed in an empty gray-scale VE so as to not influence their expectations in terms of thermal sensations. Before performing the stimuli evaluation tasks (Sec. 3.2), participants completed a tutorial run without thermal feedback. They evaluated both thermal modalities, hot and cold, one after the other, the order balanced between participants. For each modality, they evaluated 8 distinct intensities, in a pseudo-random order following a balanced Latin square. In total, participants performed the stimuli evaluation tasks a total of 16 times (2 thermal modalities x 8 intensities), which took around 45 minutes. Measurements of our system's sound level depending on feedback intensities were performed using a sonometer (PCE-322A) positioned at the center of the system, and 1.3m above the ground. This study was approved by the research ethics committee of Université de Lyon's ComUE, under approval number 2023-09-21-005.

3.2 Stimuli Evaluation Task

Participants were presented with the stimuli for 30s. For the cold stimuli, 4 fans were activated at a determined intensity (between 1% and 50%). For the hot stimuli, 4 infrared lamps were activated at a determined intensity (between 12.5% and 100%). While exposed to the stimuli, participants were asked to click on "Detected" when they first felt a variation of their thermal perception and "Stabilized" when they stopped feeling a variation. After stimuli exposure, there was a 30s wait to give time for the thermal sensation to go back to normal. Participants were asked to click on "Neutral" when they did not feel the influence of the system on their thermal perception. Then, participants had 15s to answer the following question: "How intensely did you feel the heat/cold created by the device? (0 if none, 1 - very low to 6 - very high)". For the fan system, they were also asked whether they perceived the generated wind or not.

3.3 Results

Thermal perception, reaction times and noise intensity results for the fan system are shown in Fig. 2, blue for fans and red for lamps. The fan system provides a slight cooling sensation when activated at minimum, and this sensation is more intense as the fans speed increases. When activated at 50%, the fan system can provide a thermal sensation of 4.2 out of 6. Around half of participants perceived wind at intensities below 20%, and almost all of them perceived wind at higher intensities. Regardless of intensity, latency of the fan system revolves around 10s from instruction to a change in thermal sensation. Sound level measurements show that it increases as the feedback intensity does, and reaches 55 dBA at 50% which becomes uncoverable. Moreover, a peak at 49dBA was measured when the fans start up, i.e., going from 0% to any intensity. With the lamp system participants experience a sensation of warmth, and this sensation is more intense as lamps intensity increases. Most users did not perceive the heat produced by the lamps below 25% intensity. At maximum intensity, the combination of 4 infrared lamps provided a thermal sensation of 4.1 out of 6. Reaction time for

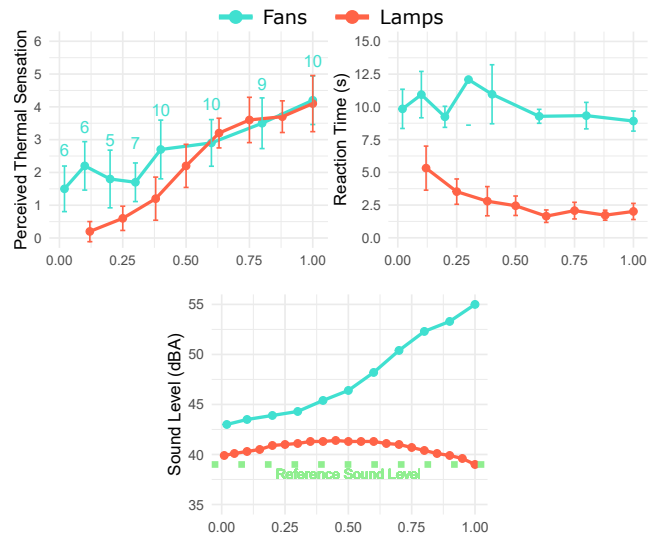


Figure 2: Psychophysical and sound level measures vs. thermal actuator intensity. Fan intensity (0–50%) and lamp intensity (0–100%) are normalized to [0, 1]. N° of participants (out of 10) perceiving wind is shown on the perceived thermal sensation graph.

the lamps is under 2.5s when the intensity is above the determined perception level (25%). Infrared lamps are quiet, however they produce a slight noise when phase dimmed.

4 FUTURE WORK

Several avenues could be explored to improve the fan system: i) replace fans with higher-end options, potentially both less noisy and more responsive; ii) install mechanical blinds controlled by the VR application in front the fans to reduce latency; iii) intensify thermal sensation by modifying the temperature of the air propelled by the fans, e.g. an array of adequately cooled Peltier modules. Leveraging our system's modularity, adding lamps and/or fans may improve both spatial and temporal resolution, enabling the simulation of localized sources of thermal ambiance, such as a fire or a waterfall.

ACKNOWLEDGMENTS

The authors wish to thank participants. This work was supported in part by the RENFORCE project (ANR-22-CE38-0008).

REFERENCES

- [1] A. C. da Silveira, E. C. Rodrigues, E. B. Saleme, A. Covaci, G. Ghinea, and C. A. S. Santos. Thermal and wind devices for multisensory human-computer interaction: An overview. *Multimedia Tools and Applications*, 82(22):34485–34512, Sept. 2023. doi: 10.1007/s11042-023-14672-y 1
- [2] J. Dionisio. Virtual hell: a trip through the flames. *IEEE Computer Graphics and Applications*, 17(3):11–14, May 1997. doi: 10.1109/38.586012 1
- [3] P. O. Fanger. Thermal comfort. analysis and applications in environmental engineering. In *Thermal comfort. Analysis and applications in environmental engineering*, 1970. 2
- [4] P.-H. Han, Y.-S. Chen, C.-E. Hsieh, H.-C. Wang, and Y.-P. Hung. Hapmosphere: Simulating the Weathers for Walking Around in Immersive Environment with Haptics Feedback. In *2019 IEEE World Haptics Conference (WHC)*, pp. 247–252, July 2019. doi: 10.1109/WHC.2019.8816140 1
- [5] F. Hülsmann, J. Fröhlich, N. Mattar, and I. Wachsmuth. Wind and warmth in virtual reality: implementation and evaluation. In *Proceedings of the 2014 Virtual Reality International Conference, VRIC '14*, pp. 1–8. Association for Computing Machinery, Apr. 2014. doi: 10.1145/2617841.2620712 1