Haptic ChairIO: A System to Study the Effect of Wind and Floor Vibration Feedback on Spatial Orientation in VEs

Mi Feng* — Worcester Polytechnic Institute
Robert W. Lindeman† — Worcester Polytechnic Institute
Hazem Abdel-Moati‡ — ExxonMobil Research Qatar
Jacob C. Lindeman § — Worcester Polytechnic Institute

ABSTRACT

In this poster, we present the design, implementation, and evaluation plan of a system called Haptic ChairIO. A design space is first introduced, classifying sensory cues, and describing the potential usage of haptic cues on cognitive tasks in virtual environments (VEs). Then follows the design and implementation of Haptic ChairIO, which is extendable in providing various sensory cue types, consisting of a VR simulation, chair-based motion-control input, and multi-sensory output, including visual, audio, wind, and floor vibration feedback. A plan of evaluation has been made to study the effect of wind and floor vibration on spatial orientation in VEs.

Keywords: 3D display, sensory feedback, wind, floor vibration.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1 INTRODUCTION

Humans experience the world through various sensory channels, i.e., we see, hear, touch, etc. It stands to reason that we should experience virtual worlds in the same manner, where we are convinced to be occupying another space with the help of sensory cues. There are five types of cues based on the human senses (Table 1, first column). Most cue types can be further differentiated into four categories, i.e., ambient, object, movement, and other types. *Ambient Cues* provide information surrounding the user. *Object Cues* come from objects placed in the scene. *Movement Cues* are based on one's motion. Apart from the three types common across most sensory channels, the final category includes attributes unique to a given sensory channel. For visual cues, three examples are ambient light, a streetlight, and visual flow. For haptic cues, the three examples could be atmospheric wind, vibrating machinery, and movement wind. Guiding wind indicating free paths in a maze [1] would fall into "*Other*."

Table 1 Classification of Sensory Cues Based On Sense and Feature (★: Wind and Floor Vibration Cues in Haptic ChairIO)

Sense \ Type	Ambient	Object	Movement	Other
Visual	√	√	√	√
Auditory	√	√	√	√
Haptic	√	√	★	√
Olfactory	√	√	√	√
Gustatory	N/A	N/A	N/A	√

e-mail: {*mfeng2, †gogo, § jclindeman}@wpi.edu
e-mail: ‡hazemm.abdelmoati@exxonmobil.com

IEEE Symposium on 3D User Interfaces 2015
23 - 24 March, Arles, France
978-1-4673-6886-5/15/$31.00 ©2015 IEEE

On the other hand, as shown in Figure 1, sensory cues can also be classified based on functionality. One group, *Natural Cues*, such as atmospheric wind, resembles what we have in the real world, and helps to improve the user experience such as presence and realism in VEs. Another group, *Informational Cues*, such as a tactile guide path, helps improve user performance by providing additional information. A third group, *Hybrid Cues*, such as the wind and floor vibration feedback in our proposed Haptic ChairIO system, has both natural and informational elements, and has the potential to improve the user's cognitive abilities in VEs, such as spatial orientation. With the lack of real walking during non-fatigue travel, people tend to get lost in VEs due to the insufficiency of sensory cues [2].

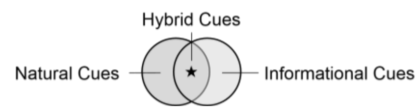

Figure 1: Classification of Sensory Cues based on Functionality (★: Wind and Floor Vibration Cues in Haptic ChairIO)

Most existing wind and floor vibration systems have been designed for improving the sense of presence and realism. The exploration of effects on cognitive performance is at the beginning stages, and has not been studied in any detail. Wind display systems include the Sensorama Simulator [3], WindCube [5], Head-Mounted Wind [6] and Atmospheric Wind [6]. One of the main drawbacks of current wind systems is latency, which means the delay from the moment the wind trigger starts until the user can feel the wind. This is mainly caused by the time it takes the fan motor to spin up to speed. Instant wind feedback based on changes in the user's movement is thus hard to implement and study. Footstep simulation systems, which include a combination of visual (head movement), audio, and haptic feedback, have also been proven to enhance the realism and sensation of walking [7][7]. In Haptic ChairIO, the wind and floor vibration feedback are both haptic movement cues. We have devised a low-latency solution to the control of wind speed based on changes in user movement, and the floor vibration simulates user footsteps in the VE. We will use the system to study the effects of the wind and vibration feedback on cognitive performance, e.g., spatial orientation in VR.

2 IMPLEMENTATION

Haptic ChairIO enables the user to travel in an immersive virtual environment with chair-based motion-control input, i.e., by leaning his or her seat, and experience visual, audio, wind, and floor vibration cues.

2.1 System Layout and Architecture

The physical space layout is shown in Figure 2. In a cage, the user sits on the Swopper Chair, transformed into a non-fatiguing motion-control input device using an orientation sensor, and wears an Oculus Rift DK2 head-mounted display, which works as a head motion tracker as well as a visual display. An audio headset is responsible for audio display. The user is surrounded by eight pan-tilt fan units mounted on the cage, and four vibration actuators hidden under a raised floor.

A VR Simulation, based on Unity3D, acts as the control center software, responsible for receiving user input, processing data, and sending sensory output. Various sensory cue types, e.g., wind and floor vibration feedback, can be implemented as independent modules, and integrated into the whole system by communicating with the VR Simulation through a network.

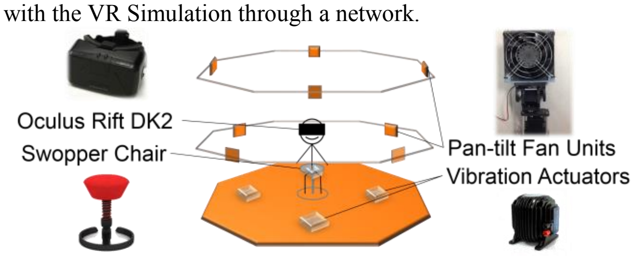

Figure 2: The Physical Space Layout and Four Hardware Devices

2.2 Wind and Floor Vibration

As shown in Figure 3, the wind and floor vibration feedback are two subsystems integrated into the VR system. Both subsystems include hardware, firmware, and software, installed in a physical space, talking with the VR Simulation through a network. Both subsystems can support Ambient, Object, and Movement cues. The movement feedback is used in Haptic ChairIO.

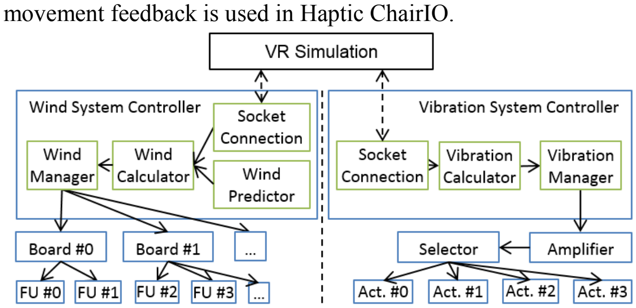

Figure 3: The Parallel Workflow of the Wind and Floor Vibration Subsystems (FU=Fan Unit, Act.=Vibration Actuator)

The parallel workflow of each subsystem is also shown in Figure 3. The VR Simulation produces the necessary commands (e.g., user data such as the position and orientation in the virtual environment, and specified cue data such as ambient wind speed and object vibration radius) that are sent to the wind and floor vibration subsystems, which convert the commands into control of the physical feedback devices.

The wind subsystem is a group of pan-tilt fan units installed on an octagonal frame around the user, controlled by two Arduinos connected to wind control software on a computer through USB. Each fan unit (Figure 4) has a 120mm DC fan mounted on a pan-tilt platform controlled by two servo motors. The speed level of each unit controlled by PWM ranges from 0 to 255 (MAX), of which the MAX speed is 4 m/s with a half meter distance. It takes about 3s for the fan speed to change from 0 to MAX, but less than 1s to change from 100 to MAX. To address the significant lag faced by most wind systems due to PWM control, the fans on the pan-tilt platforms always spin at level 100 without facing the user when resting, and can instantly turn to the user when activated. With such a design, instant movement wind feedback can be generated. The movement wind is calculated based on the user's motion direction and speed (Figure 4). Certain fan units within range turn toward the user, blowing with weighted speed. The fan speed is also adjusted based on the physical distance between the unit and the user to compensate for the falloff of the perceived speed from the fan.

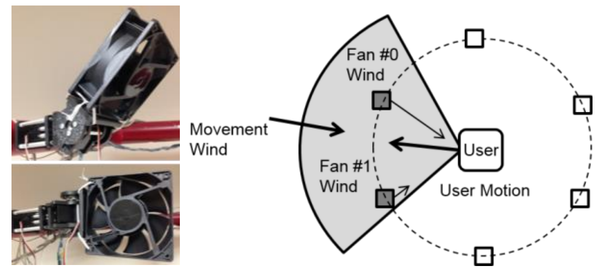

Figure 4: Activated Fan Unit (Upper Left), Resting Fan Unit (Lower Left), Movement Wind Calculation (Right)

The hardware control of the floor vibration subsystem is implemented by sending calculated audio signals (Frequency+Amplitude) to a group of low-frequency audio actuators installed under a raised floor to generate ground shaking. Alternatively, a mono audio signal can be sent directly to the amplifier from the VR Simulation, bypassing the Vibration System Controller.

3 Evaluation Plan

The evaluation of the user's spatial orientation uses the triangle-completion task, which is a simple and well-defined path integration task, from which the distance and angle errors are measured [8] (see Figure 5). In the triangle-completion task, there are three spheres in the scene. The user is asked to move from the first to the second to the third sphere, and asked to return to the first one without looking at it (blindfolded). The study will be a mixed between-/within-subject design, with three independent variables, with/without wind, floor vibration, and step sounds. There will be objective (distance and angle error) and subjective (presence and preference) measures.

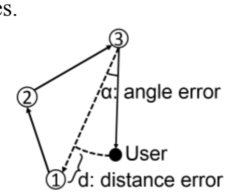

Figure 5: The Measure of the Triangle-completion Task

References

[1] Debarba, Henrique G., et al. "WindWalker: UsingWind as an Orientation Tool in Virtual Environments."

[2] Riecke, Bernhard E., and Jan Malte Wiener. "Can people not tell left from right in vr? point-to-origin studies revealed qualitative errors in visual path integration." Virtual Reality Conference, 2007. VR'07.

[3] Heilig, Morton L. "Sensorama simulator." U.S. Patent No. 3,050,870. 28 Aug. 1962.

[4] Moon, Taeyong, and Gerard J. Kim. "Design and evaluation of a wind display for virtual reality." Proceedings of the ACM symposium on Virtual reality software and technology. ACM, 2004.

[5] Cardin, Sylvain, Daniel Thalmann, and Frederic Vexo. "Head mounted wind." No. VRLAB-CONF-2007-136. 2007.

[6] Kulkarni, Sandip D., et al. "Design, sensing, and control of a scaled wind tunnel for atmospheric display." Mechatronics, IEEE/ASME Transactions on 17.4 (2012): 635-645.

[7] Väljamäe, Aleksander, et al. "Vibrotactile enhancement of auditory-induced self-motion and spatial presence." Journal of the Audio Engineering Society 54.10 (2006): 954-963.

[8] Tan, Desney S., et al. "Physically large displays improve path integration in 3D virtual navigation tasks." Proceedings of the SIGCHI conference on Human factors in computing systems. ACM, 2004.