SeeingHaptics: Visualizations for Communicating Haptic Designs

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ABSTRACT

Rendering haptic feedback in virtual reality is a common approach to enhancing the immersion of virtual reality content. However, current editing tools allow developers to access the haptic feedback only through physical contact with the actuators, making it difficult to fast iterate haptic interaction designs. This paper introduces SeeingHaptics, an authoring tool which visualizes haptic properties in 3D scenes. The active area of certain feedback is simulated with mesh shapes, while the 2D icons allow for indicating the type of haptic sensation. Our evaluation showed that SeeingHaptics helps developers rapidly create haptic feedbacks after a short training session.

CCS CONCEPTS

• **Human-centered computing → Visualization toolkits**.

KEYWORDS

haptics design; visualization; virtual reality

1 INTRODUCTION

Haptic feedback has been extensively explored for decades for a wide range of applications. The efforts were primarily focused in two directions: 1) toward the simulation of realistic haptic experience, e.g., for virtual reality (VR) [1, 7, 8] and 2) toward haptic feedback as an informative display, e.g., communicating symbolic [5, 6] or affective information [3].

In contrast to designing visual and sound feedback, designing haptic feedback faces unique challenges because haptics is unobservable and not shareable with others nearby. Receiving a haptic effect often requires a physical connection having been established between a user and the feedback source. Furthermore, this creates a communication gap between haptics designers and haptics users because whether a haptic design has been successfully perceived is not directly observable.

Figure 1: The visualization design of SeeingHaptics. (a) Wireframe of haptic area. (b) Iconic image representing haptic type. (c) Re-introducing the outside icon. (d) Radially shifting the inside icon to peripheral vision. (e) The outline and corresponding icon's image shows when the user is receiving haptics.

To solve this problem, we propose visualizing haptic design and present an authoring tool as shown in Figure 1. Two main properties are considered in our design: 1) the effective area of a certain type of haptic feedback and 2) the haptic feedback type. We indicate the effective area of haptic feedback to be deployed in the virtual environment with 3D mesh shapes, e.g., once reaching their hands into the capsule

area of a scalding pan, users will receive the intended haptic feedback. In addition, various types of haptic feedback, such as thermal, vibrotactile, and airflow, are included; each was presented with a 2D iconic pattern (Figure 1b). According to the type of haptic feedback, different properties, such as the intensity and frequency of the vibrotactile feedback, and the direction of the airflow feedback, are considered.

In this authoring tool, *Haptic Source* allows designers to install a haptic feedback on a virtual object, and *Haptic Listener* is a virtual actuator that generates corresponding haptic feedback when it collides with a feedback in Haptic Source. Our work visualizes the haptic element of interactions in a way to enhance the mobility of designers because they can now inspect the overall haptic design of a scene from a distance.

To evaluate the usability of the tool, we conducted an evaluation session with 10 participants who were involved in the development of haptic interaction for VR applications in past projects. They were asked to generate a haptic experience for a set of interactions we prepared in a virtual environment. We reported their experience with our tool and analyzed how SeeingHaptics helped the design process.

2 RELATED WORK

To visualize haptics, the mapping of properties needs to be defined. Haptic glyphs [9] introduced hylphs, which visualize information through touch by providing a map between haptic feedback and graphed structures. Junji et al. [11] visualized the tactile sensation of a material by using the concept of onomatopoeia, which was reportedly intuitive based on the subjective impressions in their study, but this approach may be more appropriate to receive a sound rather than a visual pattern. Chakrabarti et al. [10] investigated mapping between color and vibrotactile feedback. They rendered haptic feedback under finger touches using color information.

As for visualization, Kaper et al. [4] visualized sound information with a virtual sphere interface that displayed properties such as frequency, amplitude with the sphere's 3D position and size, and tremolo or vibrato with the sphere's orientation. Rather than visualizing the overall value of the entire surface, Scan & Paint [2] used a heat map to visualize large-scale frequency and temporal-spatial information.

3 VISUALIZATION DESIGN

The visualization should consist of the essential properties of a haptic effect. Yet they should be understandable and noticeable so the effect will not be confused with the original virtual objects in a virtual environment. For this goal, we refined visualization through iterative design. The final design is reported in the following.

Haptic Area

The active area of a haptic feedback is visualized to indicate where the haptic feedback generates and how far it spreads. We used a wireframe to display the area of a Haptic Source (Figure 2a) because a wireframe allows the user to precisely describe the area's geometry while displaying information such as local intensity while embedding colors in the lines or vertices of the wireframe. A Haptic Listener is installed on the VIVE controller. A green highlight appears on the Haptic Listener when it encounters a Haptic Source on which the icon augmenting with the highlight represents the received haptic type (Figure 2b).
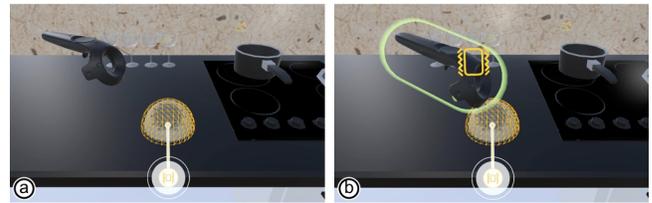

Figure 2: (a) The area of Haptic Source shown as a wireframe shape. (b) An outline reminder of interacting with a Haptic Source.

Haptic Type

An icon of a Haptic Source consists of an iconic image of the haptic type and a circular white background to distinguish it from objects in the virtual environment (Figure 3).

Figure 3: Icons for each type of Haptics (hot, cold, vibration and wind respectively).

Placing an icon at the center of a Haptic Source can indicate the 3D position of a haptic source, but the icon may move into off-screen space while the area of a Haptic Source (e.g., its mesh geometry) is still visible on the screen (e.g., the viewport to the virtual environment). The problem commonly appears when the haptic area is large. We address this problem by reintroducing the icon to the boundary of the viewport so it will remain visible for the whole time that designers need to examine the entire design (Figure 3).

When an icon is located at the center of the haptic area, it may occlude an important part of the area, such as the virtual object the haptic feedback belongs to. Changing the transparency and size of the icon is not an appropriate design.
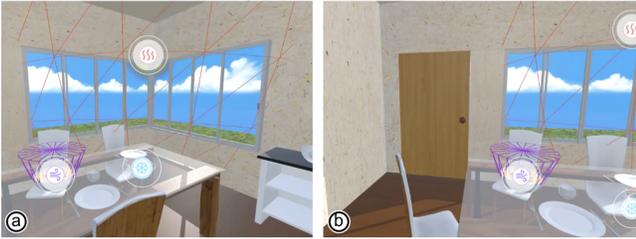
Figure 4: Icons will be re-introduced into the viewport when leaving the center of the area. (a) Icons stay at the center of the haptic area. (b) The hot icon and cold icon at right re-introduce into the viewport.

Hence, we place all icons in the peripheral region of the viewport and indicate the linkage with a line connecting the icon to its source in the virtual environment (Figure 5). The location of an icon is calculated by extending the vector of the screen center and the source center to the viewport boundary. As a result, the icons are spread around the viewport's boundary. Moreover, the icon positions also considered the spatial distribution of the Haptic Source(s) and are placed in a predefined range.
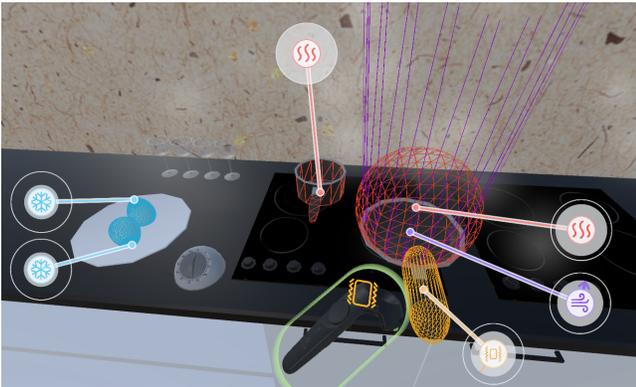

Figure 5: Radially distributed icons in peripheral vision.

Augmented Information

Along with the layout of the area and the type, additional information can be augmented by changing the look and feel of the icon, such as displaying the area's geometry with a heat map to illustrate local differences [2].

In our design, additional information is displayed around the icon. For instance, each icon is surrounded with a circular range that scales with the intensity of the source (Figure 6b). That is, the radius of the circle indicates the icon's current strength. A circular outline appearing at an outer bound indicates a maximal strength (Figure 6c), while the size of the icon's image indicates a minimal strength (Figure 6a).

Finally, the circular area around the icon can display a signal spectrum (e.g., visualizing FFT) in the case of designing vibrotactile feedback, display color to show cold or hot in the case of designing thermal feedback, and display the direction (e.g., 3D arrow) in the case of designing a wind feedback.

Figure 6: Visualization of changing intensity. (a) Minimal intensity. (b) Intensity at level 4. (c) Maximum intensity.

Figure 7: Augmented information surrounds the icon image. (a) Sound visualizations shows when an audio file is assigned to a vibration source. (b) Wind blowing backward. (c) Wind blowing forward.

The Fast Fourier Transform (FFT) visualization of a vibrotactile feedback can be displayed with a circular distribution of 32 bands around the icon; each band indicates the corresponding spectrum (Figure 7a). For the visualization of direction, we converted the wind direction to two dimensions by projecting the direction to the viewport. Moreover, we considered whether a wind source is blowing toward the player's face or the other way around and displayed it with either of the two arrow images: bigger in the head (Figure 7b) or thinner in the tail (Figure 7c).

Implementation

Our toolkit is a Unity plugin that provides a set of haptics primitives for users to compose visualizations during the edit mode, similar to editing a 3D scene. Each haptic feedback's geometry has a property panel that contains controls for the parameters of the haptic output, such as for intensity and the frequency spectrum. However, our current toolkit did not handle dynamic mapping (e.g., the parameters will not change according to the distance to the haptic source), which should be addressed in future work. As such, the toolkit supports iteration, testing, and playback with the same process as editing a 3D scene in Unity.

4 EVALUATION

This evaluation is to demonstrate the usability of the Seeing-Haptics toolkit. After participants created their haptic design on some target objects (Figure 8) in a virtual environment, users' feedback was recorded. We recruited 10 participants (4 female) aged 21-25 for this study. Participants were grouped in male-female pairs, except for P8 which had two male participants. All participants had experience of VR development.

Figure 8: Design targets of evaluation. (a) Refrigerator with door open animation for training. (b) Fan located on end table with working animation. (b) Whole counter environment.

Freeform usage (40-60 minutes). After participants were trained to use the toolkit for designing a single object, they were asked to design a counter region in a kitchen environment (Figure 8c). Seven interactions in the scene are embedded in the stationaries thereof. An experimenter would briefly go through all objects and animations in the environment then leave users to design haptic experiences of cooking interactions with the toolkit. Participants were tasked with generating haptic designs for predetermined interactions, similar to sound designers generating sound effects. Our current implementation lets users generate the design with the editor in the screen mode, not in the VR mode.

Along with the training session, we prepared a scene to demonstrate the usage, including the knife and tomato interaction introduced in the previous section , which can "listen" to all of the haptics received by the knife. Users would feel a strong vibration when the knife cut into the tomato and an even larger vibration when the knife hit the cutting board.

At the design session, participants were instructed to complete a Likert-scale survey (1- strongly disagree to 7- strongly agree) about their experiences with SeeingHaptics, the design and examination sessions, and their overall impressions of haptic design and interaction.

Results and Discussion

In the training stage, though the design content was guided as a cold wind blowing out when opening the door and felt as a constant gentle vibration coming from the body of a refrigerator, some participants came up with interesting

design ideas. P9 was the only pair who thought the wind would be blocked by the refrigerator door, causing the cone shape to tilt to the open side (Figure 9a). P6 had another idea: "The cone shape of the wind should be reversed, so we decided to have the in-fridge side bigger" (Figure 9b).
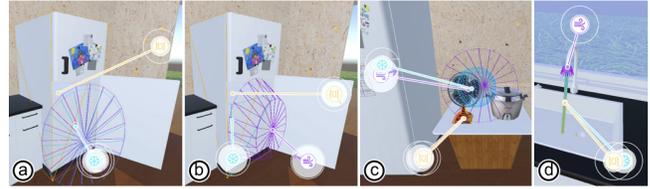

Figure 9: Special designs created by users. (a) P9 rotated the cone of cold and wind haptic to tilt with the open side of the refrigerator door. (b) P6 created a reverse cone for the wind that blows out of the refrigerator. (c) P6 also created a capsule for a relatively concentrated cold. (d) P9 designed varied haptics for water that comes out of the faucet.

When designing the fan on the table, all participants started with the effect of the wind (P4). Some participants (P3, P9) thought the fan just provided wind, while P2 mentioned the temperature of the wind should be considered in regard to its surrounding activities, e.g., with an electric pot on the side, the wind should feel warm. Others applied cold wind according to their experience. P6 created two co-located capsule shapes with different sizes to simulate that the wind spreads from the fan and feels colder when it is closer to the fan (Figure 9c). Some participants added vibrotactile feedback to the base and head of the fan, while P3 and P9 thought they usually would not touch the fan and just designed the wind aspect. Each participating pair created three haptic designs on average (SD = 1.3, MIN = 1, MAX = 5) (Figure 10 left).
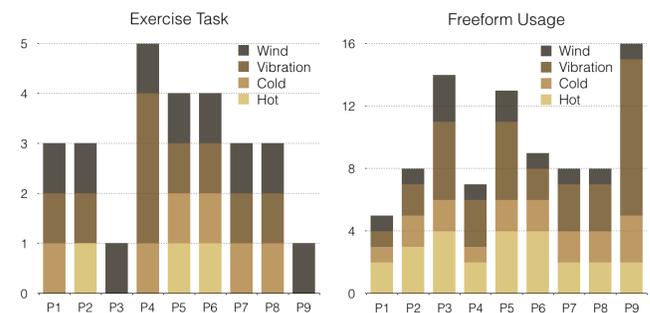

Figure 10: The total number of haptic effects created by each user in the exercise task and in freeform usage. Reduce counting on repeated things, e.g., windows, glasses.

In the stage of designing the counter, P2 preferred to start from the haptic aspect of the environment. They considered

that "the kitchen might be hot and the primary source of heat would be located at induction cooking and spread to the surrounding" area. Some started their designs from the windows. Each participant pair created 10 haptic designs on average (SD = 3.8, MIN = 5, MAX = 16) (Figure 10 right). They reported, "According to the purpose of this design, like for a cooking game, I would just design the primary experience, because if we had to consider all the details, it would be time-consuming and complicated." On average, participants could generate designs for a single object in a few minutes. P9 took a longer time than average participants to design many interesting details, e.g., for water coming out of the faucet, they added not only a cold sensation and slight vibration when the user touches the water but also a faint wind coming from the faucet mouth (Figure 9d).

Our current implementation lets users generate the design with the authoring tools in the screen mode, not in the VR mode. Future work may explore having the design directly in the VR mode to further streamline design iterations. Moreover, this work did not include haptic devices on which designers could test the end perception. Future studies are needed to learn how to effectively incorporate haptic devices in the process.

5 CONCLUSION

The SeeingHaptics toolkit mainly assists designers in the planning of haptic interaction design. We wish for this to allow designers to focus on the exploration of design possibilities. On-site testing and adjustment of the haptics visualizations with haptics devices are needed to minimize the gap between the visuals and the actual perceptions. That is to say, SeeingHaptics should work as a middleware that connects the haptics (visual) design to the end hardware. This work focused on the former part. The latter part needs further study to handle potential mismatches in actual perception concerning the capability of end haptic devices.

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