Envisioning Haptic Design for Immersive Virtual Environments

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Abstract
Current techniques for haptics in immersive virtual environments (IVEs) allow users to perceive materials while exploring virtual surfaces. However, these experiences are usually restricted to the properties defined during the design phase of the IVE. Analogous to drawing in virtual reality (VR), we propose the concept of haptic design by granting users the ability to (re-)configure haptic feedback in their IVEs through changes of virtual objects' material properties. To study this concept, we considered how fabric sample books provide insights of material configurations by allowing us to explore different visual-haptic combinations. As an initial approach, we created the Haptic Palette, a dynamic passive haptic feedback controller where visual augmentations on top of physical textures allow users to experience mixed material perceptions. In this work, we posit the notion of haptic design for VR and present the results of an initial study using our Haptic Palette controller.

Author Keywords
Haptic design; virtual reality; haptic feedback.

CCS Concepts
•Human-centered computing → Human computer interaction (HCI); Interaction design theory, concepts and paradigms; *Virtual reality;*

Figure 1: A sample book to explore different fabrics

Figure 2: Example of a painter's palette to prepare paint colors for transfer to the canvas.
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Introduction

Research has investigated different methods for providing appropriate haptic feedback in order to increase the plausibility of the experience in immersive virtual environments (IVEs). Commonly, haptic feedback is defined during the design phase by the designer while outside the IVE. This results in cumbersome and time-consuming procedures to perform alterations and fine-tune different object properties.

Analogous to visual design, we propose the notion of haptic design for IVEs. Here, users are able to reconfigure the visual-haptic properties of virtual objects while being immersed. Tools supporting haptic design would therefore decrease the time required to (re-)configure haptic feedback, as changes would be experienced in-situ and propagated directly to the virtual environment. Additionally, haptic design is able to appropriate different well-known techniques from other areas of design, such as the notion of copy&paste. This opens up new potential for mixed material perception as visual and haptic properties can be re-mixed, similar to how colors can be expressed as a mix of different base colors. As far as we know, there has not been any research focus on how users can design their own haptic material experiences for virtual environments.

As an initial approach to support the notion of haptic design, we considered the concepts of a fabric sample book and a painter's palette. Fabric sample books, such as the one shown in Figure 1, are commonly used tools for exploring different visual-haptic combinations of surface textures in the real world. On the other hand, a painter's palette is able to store and mix existing colors to prepare them for transfer to the canvas. To study haptic design using these two concepts, we designed the Haptic Palette, a controller for virtual reality (VR) able to convey material properties using a dynamic passive haptic feedback approach [11].

Our controller aims to allow users to configure and perceive mixed material perceptions through visual-haptic sensations in order to prepare the resulting feedback for transfer to virtual objects inside the virtual environment. In this work, we posit the notion of haptic design for VR and present the results of an initial study using our Haptic Palette controller.

Related Work

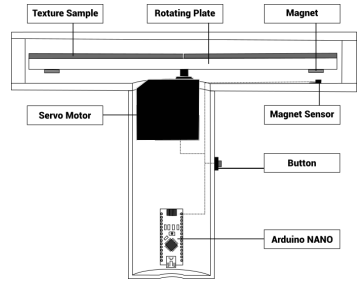
We briefly review research related to haptic feedback for VR and our concept of haptic design.

Haptics for VR

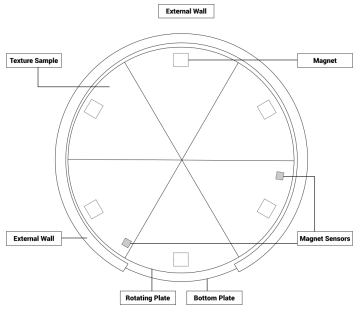
Haptic research in the context of VR has considered a variety of different approaches in the past. Investigated techniques can be classified according to the degree of involved computer-controlled actuation in an Active-Passive Haptics continuum [11]. The continuum ranges from active haptic solutions, which usually involve robotic actuators conveying forces on the user [9], to passive haptic approaches that leverage physical proxy objects [5, 8]. Our design of the Haptic Palette is based on a mixed feedback concept that aims to combine the flexibility of actuation with the realistic feedback conveyed through physical props, called Dynamic Passive Haptic Feedback (DPHF) [11, 12]. As a DPHF prop, the Haptic Palette uses simple actuation to physically re-configure itself during the VR experience. By dynamically adapting its passive haptic feedback, the Haptic Palette changes the texture perception based on the selected virtual object.

To study the notion of haptic design, we considered related work on texture rendering devices for VR, such as the Haptic Revolver [10], and opted for the form-factor of a handheld interaction device. In order to foster creative texture interactions in the context of haptic design, the Haptic Palette was designed for texture exploration with the entire hand.

Figure 3: Inspired by a painter's palette, the Haptic Palette is a controller for mixed texture perception in Virtual Reality.



(a) Side view.



(b) Top view.

Figure 4: Inner schematics of the Haptic Palette.

Mixed Texture Perception

Besides the tactile perception of surfaces through the sensors in our skin, also our visual impression of a material plays a central role when the brain combines the sensory input of our visual and tactile sensory system during touch. When the visual and tactile stimuli seem to mismatch, the sensory channels are combined in a way that weighs them according to their reliability [3]. Since the visual senses are usually rated very high, the visual appearance of objects we interact with can affect how we perceive them – a phenomenon typically referred to as visual dominance [4]. Previous research investigated how visual dominance can be leveraged for enhancing the perception of IVEs, e.g. through novel interaction techniques based on the visual dominance effect in VR [1, 7]. Studying texture perception, researchers explored how physical materials are perceived when overlaid with different virtual texture renderings [6].

Findings of previous research on mixed visual-haptic material perception show that certain physical surface structures, e.g. 3D-printed hair, can be used to convey a variety of different materials when overlaid with visual textures [2]. To realize effective haptic design, research must leverage such manipulations to create mixed visual-haptic perceptions.

Haptic Design

In the physical world, we instinctively and consciously consider the haptic design of the environment around us. This is illustrated by our understanding that we are able to choose the objects in our daily lives not only based on how they *look*, but also how they *feel* to us. For example, as sitting in a couch stimulates the tactile senses, its *feeling* in terms of fabric and material is extremely important. Therefore when deciding on a new couch, we utilize tools such as fabric sample books, see Figure 1, to explore different options available to us. While research has realized the importance of haptics to enhance virtual experiences, it remains lacking in the understanding and the tools for configuring haptic properties of virtual objects while the user is immersed.

To this end, we propose the notion of *haptic design*, describing the freedom of users and designers to re-configure the haptic feedback presented to them when exploring physical properties of virtual objects. Intuitively, altering the haptic properties of the IVE and contained virtual objects, means that such feedback must also be communicated towards the user. In a simple form, haptic feedback in IVEs is provided through vibration of the controllers held by the user. In terms of haptic design, such feedback might be redefined by altering its frequency, power and duration to customize the user's understanding of the IVE.

As an initial approach, our work directs itself towards the design of surface materials. While our understanding of materials is dictated by different visual and haptic factors, a device for haptic design of material perception should allow users to define and experience various combinations of these properties. Similar to mixing paint on a painter's palette, haptic design consists of mixing visual and haptic properties to prepare them for transfer to virtual objects.

Haptic Palette Study

To investigate the concept of haptic design, we created the Haptic Palette, see Figure 3. The controller consists of a circular rotating disc inside a wooden enclosure (⌀ 10cm, H = 3cm) with a 55° recess to access the active texture, balanced out by a handle to the bottom (⌀ 5cm, H = 9cm). Rotating the inner disc would change the presented material, while all other 5 materials remain hidden. The prototype, see Figure 4, uses a servo motor driven by an Arduino Nano, and weighs 523g excluding the HTC Vive tracker, while Hall effect sensors correct for drift.

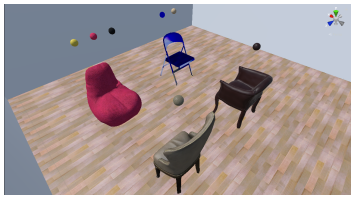


Figure 5: The virtual scene presented during the study. Here, 4 virtual chairs with varying textures can be seen. Note the texture spheres floating above the virtual objects.

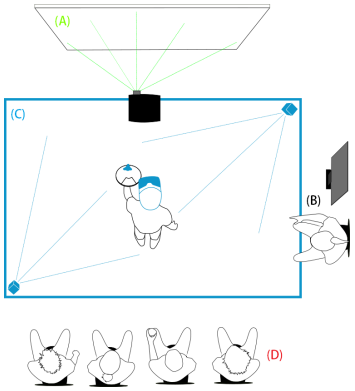


Figure 6: The study setup showing (A) a projection screen depicting the VR user's view, (B) the experimenter, (C) the VR area, and (D) observing participants.

The Haptic Palette as a controller for material exploration and haptic design was explored in a focus group. We recruited a total of of 5 unpaid participants (2 female), aged between 20 and 27, with backgrounds in Computer Science and Design. The main task of the group was to elaborate on the usability aspects of our controller, to assess different material visualization techniques, and to collect interaction ideas based on different material visualisations.

Participants interacted with varying surface materials in a virtual scene consisting of different chairs and texture spheres, see Figure 5. Inside the environment, users explored physical material properties with the Haptic Palette by "scanning" virtual objects. For each chair, different configurations could be activated by scanning one of the texture spheres on top of the chair. While the virtual chair would visually assume the selected texture, the Haptic Palette would activate the appropriate visual-haptic sample. The experimenter recorded the participants' discussion using an audio recorder. A projector visualized the view of the immersed user onto a projection screen such that all participants were able to follow, see Figure 6.

Findings and Discussion

The results of our study underline the usability of the Haptic Palette for exploring haptic properties of virtual surfaces, as interaction with the controller was rated to be very intuitive. Participants noted that the "scanning" interaction method positively encourages users to navigate inside the virtual space and inspect objects up close. In comparison to the HTC Vive controller, participants noted they were able to make a better judgments of the materials inside the virtual environment. Four out of five participants preferred the Haptic Palette over the HTC Vive controller for our use-case of virtual surface exploration, i.e., when buying a new furniture piece at a furniture store.

As our virtual scene consisted of more virtual textures than physical materials presented by the Haptic Palette, some physical materials were reused for different virtual textures. During our study, it was noticed that textures can be substituted without having a negative impact on the credibility of the virtual scene. None of the users noticed a match of the physical material samples used for two different virtual representations. One participant specifically noted the Haptic Palette was an improvement compared to fabric sample books as colors could easily be substituted on top of fabric. This emphasizes the Haptic Palette is suited to investigate haptic design concepts for mixed material perception.

Conclusion and Future Work

In this work, we posit the concept of haptic design by granting users the ability to configure haptic feedback inside their IVEs through changes of virtual objects' material properties. Haptic design tools would decrease the time required to streamline haptic feedback essential to the plausibility of the virtual experience. This concept is able to appropriate different well-known techniques from other areas of design, such as the notion of copy&paste, and opens up new potential for mixed material perception as visual and haptic properties can be re-mixed, similar to how colors can be expressed as a mix of different base colors.

As an initial approach towards supporting haptic design, we created the Haptic Palette, a dynamic passive haptic feedback controller inspired by the versatility of a fabric sample book and the portability and functionality of a painter's palette. The results of our focus group underline the usability of the device, as participants evaluated the physical design positively and found the interaction with the device to be intuitive. Using this controller, we will investigate haptic design scenarios to expand our knowledge of mixed visual and haptic perception.

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