Exploring the Potential of Sensory Illusions for Haptic Interfaces

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Advanced haptic interfaces can provide very realistic and accurate feedback, but are not able to cover the whole range of our haptic perception. This position paper proposes to enrich and extend the capabilities of existing haptic interfaces using sensory illusions. In particular, we focus on the alteration of the perceived stiffness of materials through methods generating haptic illusions, as this aspect is hard to achieve using conventional devices. We discuss existing approaches, such as visual texture deformation or auditory simulations. We then present a novel technique based on manipulating movement gains of users' hands visually using Mixed Reality technologies. With this work, we aim to contribute to the design of more holistic haptic interfaces which can cover a broader spectrum of haptic feedback.

CCS Concepts: • **Human-centered computing → Interaction techniques**; **Haptic devices**.

Additional Key Words and Phrases: haptic illusions, haptic interfaces, haptic devices

ACM Reference Format:
Yannick Weiss, Florian Müller, and Albrecht Schmidt. 2022. Exploring the Potential of Sensory Illusions for Haptic Interfaces. In *CHI '22: Workshop Proceedings Sustainable Haptic Design, April 28, 2022, New Orleans, LA.* ACM, New York, NY, USA, 4 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION

Haptic feedback offers manifold opportunities to enrich experiences when interacting with interactive systems. Human haptic perception comprises many cutaneous sensations, such as tactile or temperature, as well as proprioception and kinesthesia. However, the current state-of-the-art of haptic feedback devices still mostly relies only on vibrotactile actuators, which cannot fully exhaust the entire range of haptic perception. To extend the spectrum of haptic feedback, many novel technologies have been proposed, which can generate more accurate and realistic haptic experiences (e.g., [1, 2, 7]). However, these devices and systems usually target specific purposes or focus on displaying a small subset of haptic sensations very accurately. One opportunity to enhance the spectrum of possible haptic experiences while using haptic devices is the use of sensory, often multisensory, illusions. Hayward [6] defines an illusion to be a perception generated by static stimuli, with the perception changing based on variable conditions. Consequently, haptic illusions are sensory illusions concerned with an altered percept of haptic experiences resulting from a discrepancy between reality and perception.

Haptic illusions can enrich haptic experiences in ways, which would be difficult or even impossible to achieve using conventional haptic output devices. As these illusions are elicited by methods addressing different sensory modalities, they offer the possibility to extend current haptic interfaces without compromising the haptic device's specialized purpose and rendering quality. One aspect haptic illusions are capable of enriching is the simulation of stiffness or compliance of materials, which is hard to produce reliably and in a scalable manner with conventional hardware. In this work, we discuss how haptic illusions can alter our perception of stiffness and how this might benefit existing haptic interfaces and devices. Additionally, we propose a novel method of altering the perceived stiffness of objects based on a visuo-haptic illusion elicited using Mixed Reality technologies and discuss its application to existing haptic interfaces.

2 ADAPTING STIFFNESS

Research regarding the dynamic adaption of a material's stiffness has largely been driven by the field of soft robotics, where it is used in robotic parts to adapt their grip to handle different objects or tasks. In Human-Computer Interaction (HCI), some of these techniques have been adapted for tangible interfaces. For instance, pneumatic actuation (e.g., [12]) and particle jamming (e.g., [14]) allow for easily controllable and reversible states but require additional, strong actuation devices. Smart Materials (e.g., [5]), such as Shape Memory Materials (SMM), react to external stimuli, such as temperature or light, with changes of stiffness or viscosity. However, these stimuli are oftentimes hard to control accurately in different environments. Grounded encounter-type haptic interfaces (e.g., [2]) are able to actively adapt their forces during an interaction to suggest stiffness, but are limited by delays originating in tracking and actuation, in addition to their limited mobility and interaction space. Additionally, all these methods of providing dynamic alterations of stiffness are challenging to integrate into or combine with other haptic devices, because they might influence the haptic properties the existing device is targeting. As a possible solution, we propose to enhance such haptic devices without compromising their range or quality through the usage of stiffness illusions.

3 STIFFNESS ILLUSIONS

There exists a large body of related work on methods to change the perceived stiffness of materials in HCI. Argelaguet et al. [3] generate an illusion using a cursor on a screen, animating the deformation of a texture when clicking. Kokubun et al. [8] evoke a more direct sensation by using a rear touchscreen and deforming the texture on the front screen based on the contact point of the fingers on the back. Wolf and Bäder [15] present a texture deformation using a projector to elicit the illusion of softer materials while touching a flat rigid surface.

These studies provide evidence that a change in perceived stiffness can be elicited even using two-dimensional visual representations. This shows the feasibility of utilizing stiffness illusions on any touchable surface that is supporting a display, such as touchscreens or projected interfaces. Mixed Reality technologies can extend this concept to apply to any physical device, interface, or even everyday objects. Additionally, the illusion can be applied to representations that are indirectly linked to the interactor, e.g., to a cursor on a screen. This suggests the possibility to enrich haptic experiences also for devices with a separate visual display, such as a computer mouse, hand-held controller, and wearable.

Instead of visual deformation, studies also show the possibility to suggest the sensation of different amounts of stiffness based on sound. Different materials can be simulated by playing deformation or impact sounds synchronously to a virtual object being pressed [9] or walked on [13]. These methods could enrich haptic experiences in many contexts and systems by integrating speakers and headphones or be used to support and extend the effectiveness of visually-induced illusions.

While these existing methods offer new possibilities to simulate softer materials in haptic interfaces, investigations of possible techniques that can cover a broader range of stiffnesses, including the perception of harder materials, have largely been unexplored. To address this gap, we explore a novel concept to alter stiffness perception using Mixed Reality technologies.

4 CONCEPT

Based on an extensive literature analysis and the results of an informal preliminary study, we propose a novel method to induce an altered stiffness perception by adjusting the control-display (C/D) ratio of virtually represented hands of users in Mixed Reality during interaction with surfaces.

C/D ratio refers to the difference in movement gains of a physical interactor and its virtual (mostly visual) representation. Adapting this ratio could cause a small real movement of the interactor to move much further virtually, or vice versa. Adapting the C/D ratio to change the haptic perception has first been explored in classical desktop scenarios. Lécuyer et al. [10] investigated the effect of changing the ratio of computer mouse movement to cursor movement (on-screen) on texture perception by simulating bumps and holes through reducing and increasing movement gains. In Mixed Reality, this concept has primarily been used to subconsciously redirect participants' hands when touching or grasping for objects (e.g., [4]). Adapting the virtual hand's trajectory while a participant is reaching out, will lead to subconscious readjustments that can be used to redirect the touch towards a spatially dislocated physical object.

Samad et al. [11] showed that this phenomenon can alter the perception of objects' weight in virtual environments by manipulating the C/D ratio of the participants' hands during lifting of physical objects, i.e., the visual representation of participants' hands gained less or more vertical distance during lifting tasks than their actual hands.

We propose a similar approach to induce an altered perception of objects' material stiffness by adjusting the C/D ratio of real to virtual hand movements in Mixed Reality when users are exerting force to indent a physical object. Tracking the users' hands and indention distance of an object allows for accurate adjustments of the visual representations. The distance the visual representation is travelling during the indention can then be increased to suggest softer materials. In contrast to other approaches [3, 8, 15], this technique could also enable the simulation of harder materials by decreasing the distance the virtual hand is able to indent the object.

5 FUTURE WORK

Using Mixed Reality technologies, this proposed technique can extend many haptic interfaces, devices, and objects. In this section, we will discuss the impact it may have based on two examples of haptic interface archetypes.

One opportunity it provides is the augmentation of physical props used in virtual environments. The illusion would be able to dynamically adjust the perceived stiffnesses of physical objects provided by the system or found in the real environment. This would result in more variability in virtual materials that can be simulated using the same physical props. For instance, an object made of soft material (such as rubber or cloth) can represent harder and softer materials based on the required context or a physical button could be adapted dynamically to simulate different mechanical behaviours.

Furthermore, this technique could enhance ungrounded encounter-type interfaces, such as drone haptic interfaces (e.g., [1, 7]), which generally suffer from a lack of sufficient force output. Using this method in combination with these systems could improve their ability to simulate less compliant objects, such as walls.

6 CONCLUSION

In this position paper, we outlined the potential of integrating sensory illusions into haptic interfaces to extend the range of haptic experiences that can be provided. In particular, we discussed the existing methods used to alter the stiffness perception of materials and their applicability to existing haptic devices. We then proposed a novel method to elicit a stiffness illusion using Mixed Reality technologies and discussed its possibilities to enhance different haptic interfaces. Conclusively, with our work, we aim to contribute to the design of more sustainable haptic interfaces by integrating haptic illusions, which extend and enhance haptic feedback without compromising the capabilities of the existing devices. Therefore, we envision that such illusions can enable more widely reusable haptic displays in the future, which are suitable for a wide variety of use cases.

ACKNOWLEDGMENTS

This project is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 425869442 and is part of Priority Program SPP2199 Scalable Interaction Paradigms for Pervasive Computing Environments.

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