[DC] Enhancing Proxy-Based Haptics in Virtual Reality

André Zenner*
German Research Center for Artificial Intelligence (DFKI)
Saarland Informatics Campus, Saarbrücken, Germany

ABSTRACT

Rich haptic sensations in interactive virtual reality (VR) applications support immersive experiences. This position paper outlines my research efforts aiming to bring enhanced haptic interactions to VR users. Leveraging the highly realistic haptic feedback provided by real, physical proxy objects, I present two orthogonal research directions attempting to overcome the central drawbacks of conventional passive haptics. The first research direction leverages physical manipulations to enhance scalability through reusable yet low-complexity dynamic passive haptic proxy objects. Orthogonal to this, I explore hand redirection techniques in a second, more software-focused research direction based on virtual manipulations. In a concluding section, this position paper outlines how both approaches could be combined to further enhance haptics in VR.

Index Terms: Human-centered computing—Virtual reality; Human-centered computing—Haptic devices; Human-centered computing—Interaction techniques;

1 Introduction & Research Motivation

As the visual and auditory quality of virtual reality (VR) systems improved significantly, the importance of providing likewise realistic haptic sensations for virtual environments (VEs) is steadily gaining importance. From the real world, users are used to interpreting haptic sensations from muscles and tendons (i.e. kinesthetic cues), as well as the skin (i.e. tactile cues). Consequently, an integration of such perceptions in realistic virtual simulations and scenes promises to enhance the realism of virtual experiences. Current consumer interaction devices, however, still primarily rely on simple vibration feedback which is unable to provide appropriate sensations.

To bring immersive haptics to VR interactions, researchers explored a wide variety of techniques ranging from active to passive haptics, and mixed approaches [7] (see Fig. 1). While active techniques provide a dynamic range of sensations leveraging system-controlled actuation (e.g. motors) to actively exert forces on the user, they usually require complex devices and sophisticated software control to provide realistic feedback [5]. Passive haptic approaches, in contrast, do not involve any computer-controlled actuation but still achieve rich and highly realistic haptics in VR. This is accomplished by letting users interact with real physical objects, called proxies or props, that represent virtual objects [3]. Touching real surfaces, shapes and materials, the feedback is profoundly realistic and passive haptics has been found to enhance immersion in VR [3]. The concept, however, requires exhaustive co-location of proxies and virtual objects, as well as sufficient similarity in terms of perceivable haptic properties. As a result, conventional passive haptic approaches for VR do not scale well when it comes to representing different or dynamic VEs.

The goal of my PhD research is to enhance haptic perception in VR by **exploring techniques that promise to alleviate or even eliminate these drawbacks of conventional passive haptics.**

*e-mail: andre.zenner@dfki.de

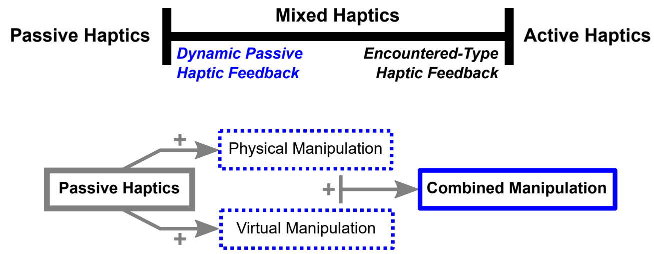

Figure 1: Haptics Continuum [7] and Research Approach

2 Overcoming the Drawbacks of Passive Haptics

To enhance proxy-based haptic perception in VR, I investigate the two orthogonal paths of (1) leveraging physical manipulation of the real environment and (2) leveraging virtual manipulation of user interactions, with the ultimate goal to (3) combine both approaches (see research concept in Fig. 1). The following sections briefly outline my previous and proposed work in these contexts:

1. **Physical Manipulation:** We introduced the concept of *Dynamic Passive Haptic Feedback* [7], in line with two handheld haptic VR controllers that represent this category of dynamic props, known as *Shifty* [7] and *Drag:on* [8] (shown in Fig. 2).
2. **Virtual Manipulation:** We investigated the detection thresholds for VR hand redirection [9] (used for redirected touching [4] and haptic retargeting [1]) – techniques that can enhance the scalability of passive haptic feedback.
3. **Combined Manipulation (Proposed Work):** We plan to explore solutions that combine physical and virtual manipulation, aiming to enhance the haptic perception of VEs, e.g. by combining haptic retargeting and dynamic passive haptic props.

2.1 Physical Manipulation: Dynamic Passive Haptics

The advantages and drawbacks of passive and active haptics are largely complementary. As a consequence, mixed approaches that combine both concepts promise enhanced feedback. Based on this idea, past research already introduced mixed haptic feedback strategies such as encountered-type haptic systems [6]. Relying on sophisticated robotic actuation to relocate haptic proxies in a just-in-time manner when users reach out to touch virtual objects, they can be placed close to the active end of the continuum in Fig. 1, leaving a conceptual gap closer to the passive end of the continuum. To fill this gap, we introduced the notion of *Dynamic Passive Haptic Feedback (DPHF)* in our previous work [7], proposing proxy objects *"that use actuators to change their passive haptic properties (e.g. size, shape, weight, weight distribution, texture, temperature, position, orientation, function, etc.), without exerting noticeable active forces on the user"* [7]. Being more flexible than conventional passive props, DPHF proxies adapt their passive haptic response to the virtual objects they represent, increasing the haptic realism of VR interactions. DPHF thereby enables the reuse of props and handheld controllers, which serve as proxies for many different virtual objects.

In my past research, we introduced two examples of DPHF proxy objects, both of which come in the form factor of a handheld VR controller. *Shifty* [7] uses a single stepper motor to adjust the inertial properties of the proxy by shifting an internal 3D-printed weight. Leveraging the dominant impact of vision on perception in VR, we could show experimentally that the adaptation of the controller's moment of inertia can enhance the perception of the weight, length and thickness of virtual objects. We also introduced *Drag:on* [8], a second DPHF proxy in a handheld controller format which uses actuators to change its shape. By adapting its surface area, Drag:on changes its air resistance (drag) and weight distribution to create a range of different haptic sensations when moved during interaction with virtual objects and the VE. In a user study, we could show that in comparison to standard VR controllers, Drag:on improves the perception of virtual resistance, increasing the haptic realism during swing and rotational movements. Drag:on requires actuation only when changing state, but still can haptically render the feeling of different virtual mechanical resistances, virtual gas streams, and virtual objects differing in scale, material and fill state [8].

2.2 Virtual Manipulation: Hand Redirection

Since users cannot see the real environment while wearing an HMD, it is theoretically possible to improve the scalability of passive haptics by letting a few props represent a larger set of virtual objects. In our previous work, for example, we found great potential for 3D-printed hair of different lengths to serve as proxy surfaces, as it can be used to simulate a variety of virtual materials differing in hardness and roughness when overlaid with varying virtual textures [2]. These findings suggest that proxies could be designed to carry patches of different physical surface samples, each used to simulate a range of different virtual materials.

To realize this, VR systems need to guide the user to the best-matching stimuli. This can be achieved through redirected touching or haptic retargeting, leveraging the visual dominance in VR. Using hand redirection, i.e. virtual manipulations of hand trajectories, such systems can redirect the user's real hands when reaching for a virtual object to the appropriate haptic sample or prop. I contributed to this line of research by deriving estimates for the amount of hand redirection that can go unnoticed by immersed users [9]. In a psychophysical experiment, we found that for desktop-scale vertical and horizontal redirection, users cannot reliably detect hand redirection in a range of ca. 9°. Moreover, our results showed that unnoticeable gain-based hand redirection allows for redirected reach up to 13.75% further or up to 6.18% less far than in virtual space.

2.3 Combined Manipulation: Proposed Research

Being conceptually orthogonal to each other, physical and virtual manipulation techniques can be combined. In my future PhD research, I aim to explore this combination to enhance the perception of virtual objects, environments and interactions in VR. In this context, I plan, for example, to investigate how DPHF and hand redirection can act in concert to create more expressive haptic sensations. Considering *Shifty*, for example, combining both techniques could potentially enlarge the range of inertial sensations that the prop can provide when orchestrating both the physical transformation of the prop (e.g. shifting the weight to one side) and the virtual manipulation of the user's reach (e.g. redirecting the hand to pick up the prop at the other side). Similarly, by virtually manipulating (e.g. scaling) swing or rotation motions when interacting with a device like the Drag:on, haptic sensations of resistance could be intensified or attenuated.

3 Research Implications & Conclusion

My PhD research aims to explore techniques that could be an integral part of future VR interaction devices and systems. While vibrotactile feedback has become standard, consumer systems still completely lack kinesthetic sensations, such as those provided by my VR controller prototypes Shifty and Drag:on. By exploring the concept of DPHF, my research tries to demonstrate and validate that easy-to-build and mechanically simple concepts can significantly enrich haptic interaction in VR. Promoting reusable yet low-complexity interaction devices, DPHF enables the immersive perception of haptic properties that the consumer sector still completely lacks, and which would involve complicated actuation and control when provided by active haptic solutions. To complement the hardware-focused approach of DPHF, I further aim to study a software-focused approach to tackle aforementioned drawbacks of proxy interaction by studying how virtual manipulation can exploit limitations of the human perceptual system to enrich VR interaction. The ultimate goal of my research approach is to combine hardware- and software-based techniques, and a discussion of the following questions promises to further guide upcoming research:

1. How can particularities of human perception (e.g. visual suppression) be leveraged to enhance DPHF and hand redirection?
2. How might further DPHF proxies work and what could they look like?
3. In which ways could DPHF proxies and hand redirection techniques be combined to enhance haptic interactions in VR?

Figure 2: The DPHF controllers *Shifty* [7] (left) and *Drag:on* [8] (right).

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