Shifting & Warping: A Case for the Combined Use of Dynamic Passive Haptics and Haptic Retargeting in VR

André Zenner and Antonio Krüger
German Research Center for Artificial Intelligence (DFKI)
Saarland Informatics Campus
Saarbrücken, Germany
andre.zenner@dfki.de, krueger@dfki.de

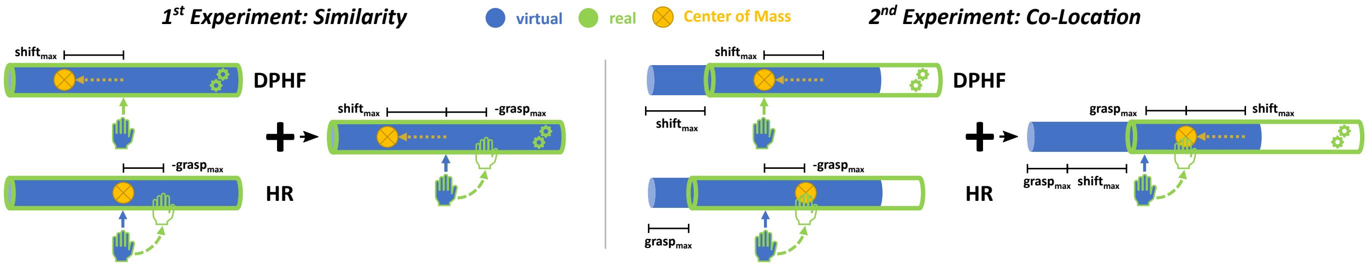

Figure 1. Conceptual sketches of the *DPHF*, *HR*, and combined *DPHF+HR* strategies applied in the two presented thought experiments.

ABSTRACT

Passive haptic feedback for virtual reality can provide immersive sensations but suffers from scalability issues. To tackle these, two independent concepts have been proposed previously: Dynamic Passive Haptic Feedback (DPHF), leveraging actuated props that change their physical state, and Haptic Retargeting, redirecting the user's hand during interaction. While past research on both techniques reported promising results, up to now, these concepts remained isolated. This paper advocates the combined use of DPHF and Haptic Retargeting. We introduce two thought experiments showcasing that the combination of both techniques in an example scenario is beneficial to solve two central challenges of prop-based VR haptics: haptic similarity and co-location of proxies and virtual objects.

Author Keywords

Virtual Reality; Dynamic Passive Haptic Feedback; Haptic Retargeting; Hand Redirection.

CCS Concepts

•**Human-centered computing** → **Virtual reality;** *Haptic devices;* **HCI theory, concepts and models;**

INTRODUCTION

Passive haptic feedback provides highly realistic haptic sensations for virtual reality (VR) by means of physical proxy objects (also called props) [3, 4, 8]. Prop-based techniques have a great potential for many application areas as they can enhance immersion [4], while being low-complexity and low-cost. For their potential to fully realize, however, two central requirements must be fulfilled:

1. **Haptic Similarity:** props need to be sufficiently similar to their virtual counterparts in terms of haptic properties.
2. **Co-Location:** props need to be spatially co-located with their virtual counterparts to enable appropriate interactions.

These requirements lead to scalability issues of passive haptics in many scenarios. To overcome these, two promising techniques have been a focus of past research: *Dynamic Passive Haptic Feedback (DPHF)* [6, 7, 9, 11, 12] and *Haptic Retargeting* [1, 2, 5, 13]. DPHF incorporates actuation into props to change their physical configuration during the experience. An example is the tubular proxy object *Shifty* [11], which shifts an internal mass to adjust its passive haptic (i.e. inertial) feedback. Complementarily, the technique of haptic retargeting introduces small offsets (commonly called warps) between the real and virtual hand as users reach for virtual objects to redirect the real hand to align with a dislocated prop [1].

DPHF and haptic retargeting have both been studied individually in the past. A combination of both concepts, however, has not been proposed until now. This paper advocates the combined use of dynamic proxies and haptic retargeting by introducing two representative thought experiments.

UIST '20 Adjunct, October 20–23, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7515-3/20/10.
http://dx.doi.org/10.1145/3379350.3416166

COMBINING DPHF & HAPTIC RETARGETING

Both thought experiments brought forward in the following involve a theoretical user reaching out to lift up a virtual rod rendered in VR. To provide a realistic haptic sensation for this, our hypothetical system can employ 3 different strategies: (1) Dynamic Passive Haptics (*DPHF*), (2) Haptic Retargeting (*HR*), or (3) the combination of both (*DPHF+HR*).

DPHF in this scenario is realized by a weight-shifting prop (e.g. *Shifty* [11]) with a shape identical to the virtual rod. We assume that the prop can relocate its center of mass (CM) within a range $[+shift_{max}, ..., -shift_{max}]$, where 0 represents the CM location in the balanced state. *HR* is realized through a balanced, passive prop, in combination with a hand warping technique (e.g. body warping [1, 2, 13]). We assume that the user's real hand can unnoticeably be redirected along the main axis of the prop in a range of $[+grasp_{max}, ..., -grasp_{max}]$ [13]. When applying *DPHF+HR*, hand redirection is combined with the dynamic prop and the VR system first shifts the prop's CM to a location $cm \in [+shift_{max}, ..., -shift_{max}]$ (i.e. $|cm|$ away from the center 0), followed by redirecting the real hand of the user to $grasp \in [+grasp_{max}, ..., -grasp_{max}]$ (i.e. $|grasp|$ away from the center 0). In the following, we examine the effects of these 3 strategies on *Haptic Similarity* and *Co-Location*.

1st Thought Experiment: Haptic Similarity

The first experiment assumes the user to lift the virtual rod while grasping it at its geometric center. Simulating a virtual object that is heavy to one end (e.g. a hammer), the 3 strategies are applied to haptically render a weight shift inside the rod. As a measure for this (and thereby for *Haptic Similarity*), we analyze the *maximum weight-shifting effect* achievable with the 3 different strategies and assuming a perfectly co-located prop, given by the respective maximum lever distance $lever_{max}$ (i.e. distance between *cm* and *grasp*). We regard techniques yielding greater $lever_{max}$ as superior, since larger effect ranges can simulate more virtual objects.

The left side of Figure 1 compares how the 3 different strategies can produce their respective maximum shifting effect. Using only a weight-shifting dynamic prop (*DPHF*), the maximum achievable lever distance is: $lever_{max} = |shift_{max}|$, since the hand will grasp at the geometric center ($grasp = 0$) while the CM of the prop relocates maximally ($cm = shift_{max}$). For *HR*, the user will lift a balanced, passive prop identical in shape and co-location with a fixed CM at the geometric center ($cm = 0$). In this case, the maximum achievable shift effect is constraint by the maximum unnoticeable grasping offset towards the end that is supposed to feel more lightweight ($grasp = -grasp_{max}$). Thus $lever_{max} = |grasp_{max}|$ for *HR*.

To achieve greater shifting effects using *DPHF* or *HR* individually would require either an increase of the weight inside the prop, its shifting range, or hand redirection beyond thresholds [13]. In contrast, the combined use of *DPHF+HR* enables rendering of increased effect ranges without modifying the prop, nor redirecting beyond thresholds. Instead, the weight of the prop can be shifted maximally ($cm = shift_{max}$), while the user's hand can be redirected towards the opposite end of the prop ($grasp = -grasp_{max}$), effectively yielding $lever_{max} = |shift_{max}| + |grasp_{max}|$.

This thought experiment shows for our example scenario that the effect ranges achievable with *DPHF+HR* are greater than the ranges achievable with *DPHF* and *HR* alone (in fact, they sum up). Consequently, *DPHF+HR* allows props to represent more virtual objects – showcasing the benefit of combining both techniques to solve the challenge of *Haptic Similarity*.

2nd Thought Experiment: Co-Location

The user in our second experiment again lifts a virtual rod at its geometric center, but this time expects it to feel balanced. The system employs the 3 strategies to prevent any noticeable weight shift, compensating for spatial offsets of the prop along the main axis of the virtual object (assuming correct orientation; see Figure 1 right). We define as our measure for *Co-Location* the *maximum dislocation* $offset_{max}$ of the prop along this axis, which still allows the user to perceive the virtual object as balanced. We regard techniques that yield larger $offset_{max}$ as superior, since larger compensation ranges better solve the challenge of *Co-Location*.

The right of Figure 1 illustrates for each technique the maximum unnoticeable dislocation along the considered axis. When only *DPHF* is used, the weight-shifting prop can be dislocated only by up to $offset_{max} = |shift_{max}|$, as the prop cannot align its physical CM with the geometric center of the virtual rod for dislocations beyond $|shift_{max}|$. Employing only *HR* with an identical, passive prop with fixed CM at its center, the maximum displacement that can be compensated for is constrained by $|grasp_{max}|$. If displaced further, the user's hand cannot unnoticeably be redirected to the displaced physical CM, yielding a corresponding $offset_{max} = |grasp_{max}|$.

As before, prop modifications or redirection beyond thresholds would be required to increase the range of displacement that the individual techniques can compensate for, unless they are combined. To compensate for larger displacements, the combined technique can first shift the physical CM by $|shift_{max}|$ towards the virtual CM, and secondly bridge the remaining spatial distance of up to $|grasp_{max}|$ leveraging *HR*. The maximum unnoticeable displacement for *DPHF+HR* is consequently $offset_{max} = |shift_{max}| + |grasp_{max}|$ in this scenario.

As this experiment makes apparent, combined use of *DPHF+HR* can also allow for larger prop displacements to go unnoticed than when applying only *DPHF* or *HR* alone – demonstrating the potential of the combined techniques to solve the challenge of *Co-Location* in prop-based VR haptics.

CONCLUSION & FUTURE WORK

This paper is the first to advocate the combined use of *DPHF* and *HR*. We show that *DPHF+HR* can increase flexibility and design freedom by allowing props to represent more virtual objects, and compensating for larger dislocations than *DPHF* and *HR* individually can. In future work, we will conduct user experiments to gather practical insights and aim to formulate requirements for successful combined feedback, studying *HR* in combination with different *DPHF* props [6, 7, 9, 10, 12].

ACKNOWLEDGMENTS

This research was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 425868555.

REFERENCES

[1] Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson. 2016. Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences. In *Proc. CHI*. ACM, New York, NY, USA, 1968–1979. DOI: `http://dx.doi.org/10.1145/2858036.2858226`

[2] Lung-Pan Cheng, Eyal Ofek, Christian Holz, Hrvoje Benko, and Andrew D. Wilson. 2017. Sparse Haptic Proxy: Touch Feedback in Virtual Environments Using a General Passive Prop. In *Proc. CHI*. ACM, New York, NY, USA, 3718–3728. DOI: `http://dx.doi.org/10.1145/3025453.3025753`

[3] Ken Hinckley, Randy Pausch, John C. Goble, and Neal F. Kassell. 1994. Passive Real-world Interface Props for Neurosurgical Visualization. In *Proc. CHI*. ACM, New York, NY, USA, 452–458. DOI: `http://dx.doi.org/10.1145/191666.191821`

[4] Brent Edward Insko. 2001. *Passive Haptics Significantly Enhances Virtual Environments*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, USA. `http://www.cs.unc.edu/techreports/01-017.pdf`

[5] Luv Kohli. 2013. *Redirected Touching*. Ph.D. Dissertation. University of North Carolina at Chapel Hill, USA. `http://www.cs.unc.edu/techreports/13-002.pdf`

[6] Benjamin C. Mac Murray, Bryan N. Peele, Patricia Xu, Josef Spjut, Omer Shapira, David Luebke, and Robert F. Shepherd. 2018. A Variable Shape and Variable Stiffness Controller for Haptic Virtual Interactions. In *Proc. RoboSoft*. IEEE, 264–269. DOI: `http://dx.doi.org/10.1109/ROBOSOFT.2018.8404930`

[7] Jotaro Shigeyama, Takeru Hashimoto, Shigeo Yoshida, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2019. Transcalibur: A Weight Shifting Virtual Reality Controller for 2D Shape Rendering Based on Computational Perception Model. In *Proc. CHI*. ACM, New York, NY, USA, 1–11. DOI: `http://dx.doi.org/10.1145/3290605.3300241`

[8] Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. 2015. Substitutional Reality: Using the Physical Environment to Design Virtual Reality Experiences. In *Proc. CHI*. ACM, New York, NY, USA, 3307–3316. DOI: `http://dx.doi.org/10.1145/2702123.2702389`

[9] Hsin-Ruey Tsai, Ching-Wen Hung, Tzu-Chun Wu, and Bing-Yu Chen. 2020. ElastOscillation: 3D Multilevel Force Feedback for Damped Oscillation on VR Controllers. In *Proc. CHI*. ACM, New York, NY, USA, 1–12. DOI:`http://dx.doi.org/10.1145/3313831.3376408`

[10] Eric Whitmire, Hrvoje Benko, Christian Holz, Eyal Ofek, and Mike Sinclair. 2018. Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller. In *Proc. CHI*. ACM, New York, NY, USA, 1–12. DOI: `http://dx.doi.org/10.1145/3173574.3173660`

[11] André Zenner and Antonio Krüger. 2017. Shifty: A Weight-Shifting Dynamic Passive Haptic Proxy to Enhance Object Perception in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics* 23, 4 (2017), 1285–1294. DOI: `http://dx.doi.org/10.1109/TVCG.2017.2656978`

[12] André Zenner and Antonio Krüger. 2019a. Drag:on: A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift. In *Proc. CHI*. ACM, New York, NY, USA, Article 211, 12 pages. DOI: `http://dx.doi.org/10.1145/3290605.3300441`

[13] André Zenner and Antonio Krüger. 2019b. Estimating Detection Thresholds for Desktop-Scale Hand Redirection in Virtual Reality. In *Proc. VR*. IEEE, 47–55. DOI:`http://dx.doi.org/10.1109/VR.2019.8798143`