Demonstration of Visuo-Haptic Redirection in Above-surface Drawing with an Extendable Pen

Fumihiko Nakamura*
Ritsumeikan University

Hinata Miyauchi
Ritsumeikan University

Asako Kimura†
Ritsumeikan University

Yuta Kataoka
Ritsumeikan University

Shohei Mori†
University of Stuttgart

Fumihisa Shibata
Ritsumeikan University

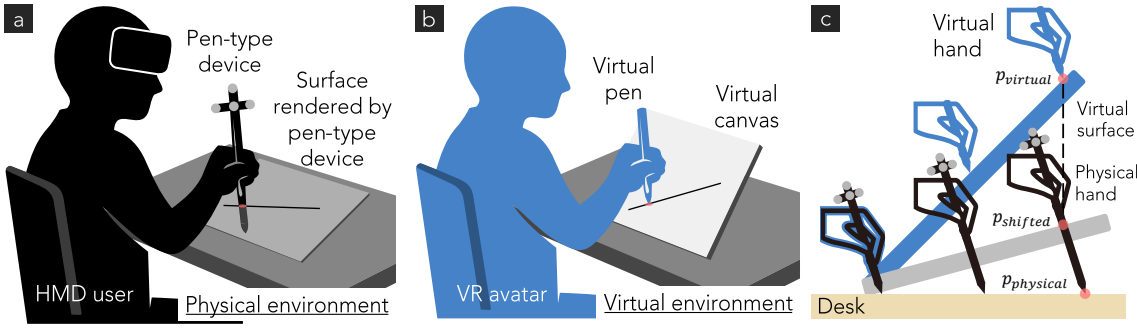

Figure 1: Above-surface drawing through the combination of handheld tool-driven encountered haptics and redirection technique. (a) In a physical environment, a user draws illustrations on a gently sloped canvas rendered using a physically extendable pen. (b) In the virtual environment, the virtual canvas has a steeper slope than the physical one, and the virtual hand is redirected from the physical hand position, allowing the user to draw on a canvas that is steeper than the physical one. (c) By visually shifting the virtual pen position based on the contact point, redirection is achieved, thereby expanding the drawable space in which the user can draw with encountered haptics.

Abstract

Virtual reality (VR) enables drawing with fewer constraints than conventional media. However, the absence of physical drawing surfaces results in a lack of haptic feedback and physical support, which are essential for drawing. To address this limitation, we present an above-surface drawing technique that integrates visuo-haptic redirection with an encountered haptic feedback via an extendable pen. Our approach physically renders contact by extending the pen tip to a physical desk surface while visually redirecting the virtual pen position, thereby shifting the perceived contact point along the height direction. By leveraging visuo-haptic illusion, this technique expands the drawable interaction space beyond the mechanical limits of the device while preserving the sensation of physical contact. We demonstrate our system through a VR drawing scenario involving both linearly and non-linearly varying surface geometries, allowing users to experience above-surface drawing with encountered haptics under different redirection conditions.

Index Terms: Visuo-haptic redirection, drawing, encountered haptics.

1 Introduction

Drawing is an essential activity for communication through illustrations in both physical and virtual environments. Virtual reality (VR) enables drawing without physical constraints imposed by apparatus such as papers and displays. However, the absence of physical drawing surfaces also eliminates natural haptic feedback, which plays a critical role in drawing. To address this issue, many VR styluses provide active haptic feedback, allowing users to perceive the virtual contact with virtual objects. Nevertheless, the lack of physical support leads to increased fatigue over time.

To provide physical support in VR, prior studies have explored passive haptics by aligning virtual surfaces with physical ones [3]. Although this approach can offer stable haptic feedback, it depends on the surrounding physical environment, which limits its applicability. To overcome this limitation, encountered haptics approaches dynamically move physical proxies to match virtual surfaces, thereby reducing dependency on stationary environmental setups. However, such approaches may introduce safety concerns, including the risk of collisions between users and moving devices.

To address the limitations of both passive haptics and encountered haptics approaches, we previously proposed the concept "Pen Meets Desk," which lies between these two approaches [4]. In this concept, haptic feedback is generated by extending a handheld pen itself and physically contacting a physical surface such as desks. This approach offers encountered haptic feedback in a safe, portable, and low-cost manner. However, mechanical constraints of the hardware, such as limited extension length and actuation latency, restrict the available interaction space and potential use cases.

To overcome these mechanical limitations, previous studies have leveraged human perceptual characteristics, such as illusions. One notable technique is redirection, which subtly modifies the virtual hand or tool position relative to the physical one. Previous work has demonstrated that redirection can effectively expand the interaction space without users perceiving modification [2]. Moreover, tool-mediated interactions have been shown to further increase the redirection detection threshold [5]. Inspired by these findings, we introduce redirection techniques into our encountered haptic feedback concept.

This paper proposes a drawing system that integrates redirection with handheld tool-driven encountered haptic feedback (Figure 1

*e-mail: f-naka@fc.ritsumei.ac.jp
†These authors contributed equally as last authors.

979-8-3195-0529-3/26/$31.00 ©2026 IEEE
DOI 10.1109/VRW70859.2026.00387

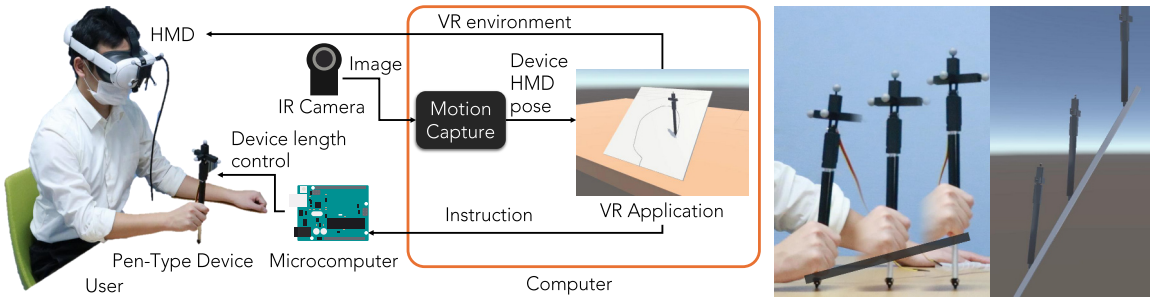

Figure 2: System configuration and demonstration. Participants draw illustrations on slanted virtual canvases, which differ from the physical ones rendered by the extendable pen.

a, b). By combining redirection with extendable pen-based haptics, our approach has the potential to augment interactable drawing space beyond the limitations of either technique alone. We demonstrate that our method induces illusions that effectively expand the drawing space, particularly along the height direction, while maintaining the sensation of physical contact.

2 System

Our system consists of a computer, an HMD (head-mounted display), and a pen-type device (Figure 2). On the computer, we ran a VR application and a motion capture system. The VR application was built with Unity ver. 2022.3.43f1. The motion capture system (Motive 3.1.4) tracked the HMD and the pen-type device and sent the tracked object's position and posture to the VR application via inter-process communication. We used Meta Quest 3 as the HMD and attached retro-reflective markers for the motion capture system to the front side of the HMD.

We created a pen-type device that enabled controlling the length. The pen-type device was composed of a linear actuator (L16-140-35-6-R, Actuonix), a microcomputer (Arduino Uno R3, Arduino LCC.) with a motor shield (Arduino Motor Shield Rev3, Arduino LCC.), and four retro-reflective markers for the motion capture system. The entire device length was 288.8 mm, and the extendable length of our device was 140.0 mm. The linear actuator's maximum speed of travel was 32.0 mm/s. The microcomputer was connected to the computer with a USB cable and received instructions to control the pen length from the computer via serial communication. The device weighed about 114 g.

To provide haptic feedback, we combined a pen-type device with a redirection technique that shifted the virtual pen tip position from the physical pen tip position (Figure 1 c). When the virtual pen made contact with the virtual surface, we first computed the intersection $p_{virtual}$. We then derived a shifted point $p_{shifted}$ as the intersection between the virtual contact surface presented by the pen-type device and a line perpendicular to the desk surface that passes through $p_{virtual}$. We computed the distance d between $p_{shifted}$ and $p_{physical}$, and mechanically extended the pen-type device by this distance with the linear actuator, thereby physically changing the length of the pen so that its tip contacts the physical desk surface. Through this mechanism, the pen-surface contact position was redirected along the desk-vertical direction, enabling interaction beyond the intrinsic mechanical range of the device.

3 Demonstration

In our demonstration, we showcase our technology under several configurations, including tilted canvases with linearly varying heights and mountain-shaped geometries with non-linearly varying heights. Participants wear an HMD and our device, and draw illustrations on these geometries while different redirection gains (x1.0, x1.5, x2.0) are applied. The gain values are determined based on the previous visuo-haptic illusion study [1]. For comparison, participants can also perform the same tasks without encountered haptics, allowing them to contrast visuo-haptic illusions with purely visual illusions. Through our demonstrations, participants experience the impact of visuo-haptic illusion on perception and interaction along the height direction.

4 Conclusion

This work presents an above-surface drawing technique that augments the drawable space by integrating a redirection technique with an extendable pen-based encountered haptic feedback. We developed an extendable pen-type device using a linear actuator to render encountered haptic feedback. Also, we developed a redirection method that shifts the contact point along the height direction, thereby expanding the drawable space. In the demonstration, we showcase our method under multiple scenarios involving linearly or non-linearly varying heights. Through these demonstrations, participants experience how the visuo-haptic illusion induced by encountered haptics affects the drawing sensation.

Acknowledgments

This work was supported by Ritsumeikan University's Support Program for Female Researchers for International Collaborative Research and the Alexander von Humboldt Foundation funded by the German Federal Ministry of Research, Technology and Space.

References

[1] P. Abtahi and S. Follmer. Visuo-haptic illusions for improving the perceived performance of shape displays. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, p. 1–13. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3173574.3173724 2

[2] E. J. Gonzalez, P. Abtahi, and S. Follmer. Reach+: Extending the reachability of encountered-type haptics devices through dynamic redirection in vr. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, UIST '20, p. 236–248. Association for Computing Machinery, New York, NY, USA, 2020. doi: 10.1145/3379337.3415870 1

[3] F. Kern, P. Kullmann, E. Ganal, K. Korwisi, R. Stingl, F. Niebling, and M. E. Latoschik. Off-the-shelf stylus: Using xr devices for handwriting and sketching on physically aligned virtual surfaces. *Frontiers in Virtual Reality*, 2:1–20, 2021. doi: 10.3389/frvir.2021.684498 1

[4] F. Nakamura, Y. Takanaga, H. Miyauchi, Y. Kataoka, S. Mori, F. Shibata, and A. Kimura. Pen meets desk: Above-surface drawing with encountered-type haptics using an extendable pen. *Journal of Information Processing*, 34:29–38, 2026. doi: 10.2197/ipsjjip.34.29 1

[5] Y. Zhou and V. Popescu. Tapping with a handheld stick in vr: Redirection detection thresholds for passive haptic feedback. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 83–92. IEEE, 2022. doi: 10.1109/VR51125.2022.00026 1