Haptic Interaction Techniques for Dexterous Manipulation in Metaverses

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ABSTRACT

Metaverses have been used for social VR since around 2017, and the number of users continuously increases. However, current manipulation by hand in metaverses is not dexterous. Grasping force is not considered in virtual grasping; objects released suddenly fall or stand still in the air. Many natural and dextrous operations in physically simulated virtual worlds can not be done in the metaverse: games such as Jenga, which require tactile sensation and dexterity, evaluation of real-world assembly tasks, and reproduction and practices of manual techniques.

Precision grasping is a typical dexterous operation using fingers, and more than a dozen patterns are known. To reproduce this in VR, it is necessary to accurately measure the postures of the fingers and control the avatar's fingers based on them. It is known that the haptic sense of the fingers contributes to dexterous grasping, and it is desirable to indicate the contact of each finger and contact force strength. Such haptic display devices have already been proposed. But they are not necessarily suitable for use in the metaverse.

In this presentation, we will introduce two haptic display devices designed regarding new metaverse requirements. One is a wearable display device that presents pressure and vibration to the fingertips without covering the finger-balls. The other is a small and lightweight 3-degree-of-freedom force feedback device capable of displaying external forces but is self-propelled, eliminating limitations on its range of motion.

1 Introduction

Metaverses have been used for social VR since around 2017, and the number of users continuously increases. In such usage, many people wear HMD for longer than two hours and stand, sit, move, and even lie in the room. It may be time to consider haptic interfaces for such long-time casual and active use of VR with headsets. In addition to buttons and throttles, hand controllers for VR headsets use capacitive sensing to measure the finger openings [15]. However, such measurements are limited to flexion-extension, and abduction-adduction is not supported. Some headsets, like the Quest series[13], and hand trackers, like Leap Motion Controller[9], use multiple cameras and track hand shapes, including abduction-adduction. In current social VRs, the main activity is embodied communication, and hand gestures are important. Social VRs also require navigation, GUI menu operation, and some text inputs, which are not well covered by camera-based hand-tracking yet, which may hinder its widespread.

In addition to these currently obvious issues, manipulation by hand in metaverses is not dexterous. Grasping force is not considered in virtual grasping; objects released suddenly fall or stand still in the air.

The current metaverse also has three-dimensional spatiality, but interactions with manipulation targets are partially symbolized, and free interactions based on physics have not been realized [6, 3]. So, just like in a video game, the interactions and worlds are designed so that this symbolization isn't an issue. On the other hand, many natural and dextrous operations in physically simulated virtual worlds can not be done in the metaverse: games such as Jenga, which require tactile sensation and dexterity, evaluation of real-world assembly tasks, and reproduction and practices of manual techniques. Precision grasping is a typical dexterous operation using fingers, and more than a dozen types of patterns are known[8]. To reproduce this in VR, it is necessary to accurately measure the postures of the fingers and control the avatar's fingers based on them. Accurate real-time simulation of the movement and interaction between objects and fingers is essential, and it has been pointed out that the haptic sense of the fingers contributes to dexterous grasping. Many VR controllers also have a built-in vibrator that vibrates the entire controller, and contacts are expressed through vibrotactile sensations. However, for dexterous finger operations, it is desirable to indicate the contact of each finger and contact force strength. There had been proposals for haptic display devices [14], which present tactile sensations to each finger for dexterous manipulation. But they are not necessarily suitable for use in the Metaverse.

Hands and fingers are also used for communication, such as gestures in metaverses that include social aspects. In addition, there is a demand for long usage times and the desire to avoid leaving the metaverse while communicating with other users, so users need to perform real-world tasks while wearing the device: Switching between standing/sitting positions, typing keyboards, eating and drinking, etc. They must also make large body movements, such as walking around the room, waving their hands loudly, and dancing. In this way, when considering dexterous operations in the metaverse, including Social VR, it becomes clear that there are demands on hand controllers that did not exist before, and the need for haptic display devices will also change.

For example, many conventional wearable haptic display devices cover the finger balls, hindering the manipulation of objects in the real world [4, 7, 16]. On the other hand, wearable haptic display devices that do not cover the finger balls are limited to presenting vibrations from the back of the finger (from the nail side). So, while presenting the amount of penetration of the finger into the object in an easy-to-understand manner, they are not good at reproducing the vibrations that occur in the real world due to contact or sliding, [2, 12]. Also, when considering home use, it is not desirable to use a large device to increase the range of motion[11, 10].

In this presentation, we will introduce two haptic display devices designed regarding these new requirements. One is a wearable presentation device[1] that presents pressure and vibration to the fingertips without covering the finger balls. The other is a small and lightweight 3-degree-of-freedom force feedback device capable of displaying external forces but is self-propelled, eliminating limitations on its range of motion[5].

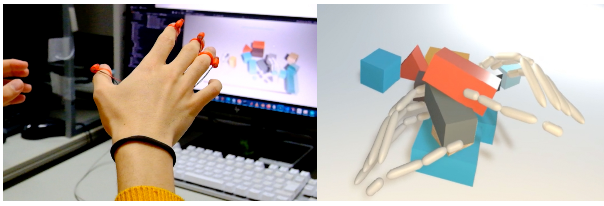


Figure 1. The finger-ring-type haptic interface

2 Direct manipulation virtual environment with tension-based finger-ring-type haptic interface for dexterous manipulation

This direct manipulation virtual environment comprises two key components. One is a physics-based manipulation system with a virtual-coupling-based virtual both hands that closely mimics the arrangement of human hand bones, thereby allowing for realistic physical manipulation. The user's hand poses are measured by the Leap motion controller and applied to virtual hands through the virtual couplings.

The other is a haptic rendering and display system. To generate haptic signals, we utilized information obtained from the physics engine. When the virtual hand skeleton comes into contact with an object, a sudden change in the contact force value generates a collision signal. By setting material properties, our method can generate collide, frictional, and stick-slip signals for different materials.

Regarding actuators, we used small-sized coreless motors driven by motor controllers with current control functions. This provides a more realistic haptic experience, mimicking the feeling of touching and manipulating objects with your hands. Our system combines physics-based manipulation with haptic rendering to realize dexterous manipulation.

3 Portable self-propelled force feedback device

This device has an infinite workspace horizontally by employing the driving unit and is highly portable due to its simple and lightweight mechanism. The mechanism provides the horizontal two DoF forces and omits the vertical force to reduce the weight and provide a torque instead.

Since the force in the rear direction is the force to prevent penetration of the hand to the object by locomotion, it should be designed to present a larger force than in the right/left direction. Therefore, two

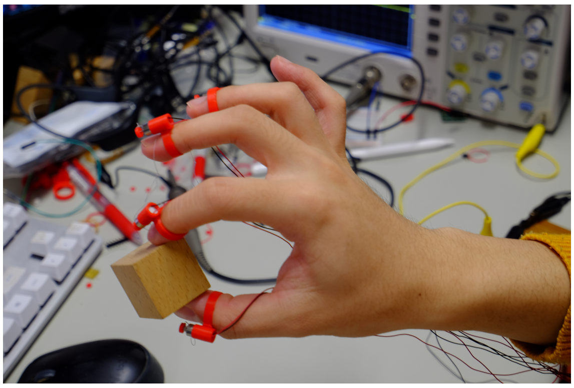


Figure 2. Illustration of the proposed haptic device. The design ensures users can also interact with physical objects in the real world.

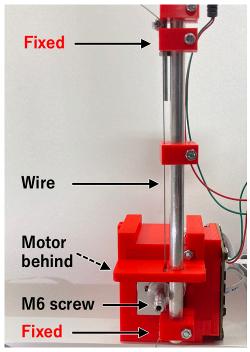
tires are grounded, forces in the front/rear direction are presented by translational forces driven in the same direction, and forces in the right/left direction are presented by torques generated by driving in the opposite direction. Although the vertical force and torque can be presented independently if the driving unit generates a torque in the pitch direction, for example, by using four wheels[10], this device avoids making the driving unit larger and accepts side effects by pitch axis torque when presenting the vertical force.

4 Conclusion and Future Directions

In this presentation, we focused on haptic display devices. We introduced a finger ring-shaped haptic display device that allows for dexterous operation and a small self-propelled force feedback device that realizes external force presentation, both considered for use in the Metaverse. However, to enjoy the metaverses while experiencing dexterous manipulation with fingers and external forces, software issues such as the physical simulation and haptic rendering also need to be resolved. In particular, the synchronization of physical simulation and haptic rendering is an essential issue for realization in a metaverse where many people participate. Haptic rendering is strongly affected by network delay. Although it is possible to create a system that accepts delays by devising software, this will also be affected by future trends in network technology, such as optical switches. In addition, stick operations are mainly used for navigation operations in the Metaverse. Achieving stable free-hand navigation operations will also be essential for the spread of free-hand control. Wearable haptic display devices may offer

(a) Overall View

(b) Grip



(c) Reduction Mechanism

Figure 3. The portable self-propelled force feedback device

another solution by assisting with free-hand navigational dexterity.

References

[1] *SIGGRAPH '23: ACM SIGGRAPH 2023 Emerging Technologies*, New York, NY, USA, 2023. Association for Computing Machinery.

[2] H. Ando, E. Kusachi, and J. Watanabe. Nail-mounted tactile display for boundary/texture augmentation. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology*, ACE '07, page 292–293, New York, NY, USA, 2007. Association for Computing Machinery.

[3] Cluster Inc. cluster, 2017. `https://vrchat.com/`, 2023.9.

[4] CyberGlove Systems Inc. CyberGrasp. `https://www.cyberglovesystems.com/cybergrasp`, 2023.9, 2001.

[5] A. Fukasawa, R. Taniguchi, T. Sato, and S. Hasegawa. Portable self-propelled force feedback device. In *IEEE World Haptics Conference, WHC 2023, Delft, Netherlands, July 10-13, 2023*, pages 382–388. IEEE, 2023.

[6] G. Gaylor, J. Joudrey, and VRChat Inc. VRChat, 2017. `https://vrchat.com/`, 2023.9.

[7] HaptX Inc. HaptX Gloves G1. https://haptx.com/, 2023.9, 2023.

[8] N. Kamakura, M. Matsuo, H. Ishii, F. Mitsuboshi, and Y. Miura. Patterns of static prehension in normal hands. *The American journal of occupational therapy*, 34(7):437–445, 1980.

[9] Leap Motion Inc. Leap Motion Controller, 2014. https://en.wikipedia.org/wiki/Leap_Motion, 2023.9.

[10] N. Nitzsche, U. D. Hanebeck, and G. Schmidt. Mobile haptic interaction with extended real or virtual environments. In *Proceedings 10th IEEE International Workshop on Robot and Human Interactive Communication. ROMAN 2001 (Cat. No. 01TH8591)*, pages 313–318. IEEE, 2001.

[11] Q. Parent and J. Perret. Usability of a large-scale force-feedback device in different immersive environments. In *EuroVR Conference*, 2016.

[12] P. Preechayasomboon and E. Rombokas. Haplets: Finger-worn wireless and low-encumbrance vibrotactile haptic feedback for virtual and augmented reality. *Frontiers in Virtual Reality*, 2:738613, 2021.

[13] Reality Labs, Meta Platforms Inc. Meta Quest 3, 2023. https://en.wikipedia.org/wiki/Meta_Quest_3, 2023.9.

[14] W. Somsak. 4+ 4 fingers direct manipulation with force feedback. *ACM SIGGRAPH 2000 Emerging Technologies Project*.

[15] Valve Corporation. Valve Index Controller, 2017. https://en.wikipedia.org/wiki/Valve_Index, 2023.9.

[16] Weart S.r.l. TouchDIVER. https://weart.it/haptic-vr-products/touchdiver, 2023.9, 2021.