Realistic Dexterous Manipulation of Virtual Objects with Physics-Based Haptic Rendering

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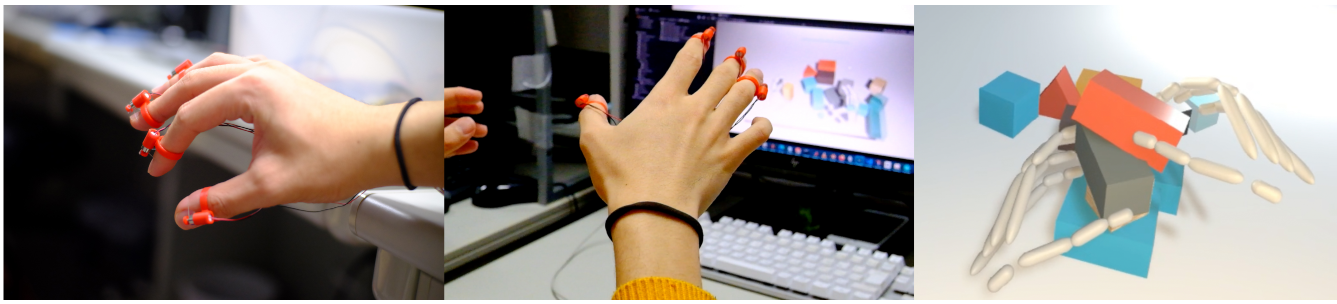

Figure 1: (Left) The user is wearing our haptic device. (Middle) The user manipulates virtual objects under a VR headset, and the virtual scene is projected on the display. (Right) the scene in the virtual environment when the user is manipulating.

ABSTRACT

This paper introduces a system that focuses on physics-based manipulation and haptic rendering to achieve realistic dexterous manipulation of virtual objects in VR environments. The system uses a coreless motor with wire as the haptic actuator and physics engine in the software to create a virtual hand that provides haptic feedback through multi-channel audio signals. The device simulates contact collision, pressure, and friction, including stick-slip, to provide users with a realistic and immersive experience. Our device is lightweight and does not interfere with real-world operations or the performance of vision-based hand-tracking technology.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction(HCI)**; • **Interaction devices**; • **Haptic devices**;

KEYWORDS

Haptic Devices, Dexterous Manipulation

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1 INTRODUCTION

Dexterous manipulation of virtual objects in VR environments is a crucial topic for achieving realistic user experiences. However, achieving this level of realism is challenging due to the neglect of important factors such as realistic physics-based effects and haptic feedback in current manipulation methods. While some research has implemented physics-based hand-object interaction, the lack of haptic feedback compromises the user experience, leading to lower manipulation efficiency and convenience. In addition, current devices suffer from issues such as visual interference between the hand and virtual objects, a lack of friction between them, and the inadequate accuracy of hand gesture recognition and calibration, all of which hinder fine manipulation experiences.

To address these issues, we have developed a system that focuses on physics-based manipulation and haptic rendering. Our approach involves using a coreless motor as the haptic actuator and creating a virtual hand with a physics engine in the software to achieve a haptic interface. By simulating contact collision, pressure, and friction, including stick-slip, our device can provide users with haptic feedback that is essential for achieving fine manipulation experiences.

Our system is designed to provide haptic feedback to the user through multi-channel audio signals (with a sampling rate of over 5kHz) and audio power amplifiers. This design allows us to create collide, frictional, and stick-slip signals for different materials. Additionally, our device is lightweight(40g) and does not interfere with real-world operations, nor does it affect the performance of vision-based hand-tracking technology.

2 RELATED WORKS

The objective of our physics-based manipulation approach is to achieve dexterous manipulation. As noted by Han et al. [Han and Trinkle 1998], dexterous manipulation involves using multiple agents to control objects while maintaining a fixed contact location between these agents and the objects. Okumura et al. [Okamura et al. 1998] conducted experiments to measure haptic waveforms for different materials and used formulas to fit the data and provide numerical values for different materials. This research is inspired by the following. Aoki et al.[Aoki et al. 2009] proposes a lightweight wire-based fingertip-mounted haptic device to provide contact sensation for mixed reality environments, allowing users to feel virtual objects and forces without discomfort or obstruction. Liu et al. [Liu et al. 2013] describe the design and functionality of a new haptic interface called SPIDARMF, which uses four strings attached to each fingertip to provide 3-degree-of-freedom spatial force feedback for each finger in a virtual reality environment. Another important work[Hasegawa et al. 2014] proposed a simulation model for tapping, leading to realistic event-based forces, including impact impulse, decayed waves, and subsequent collisions.

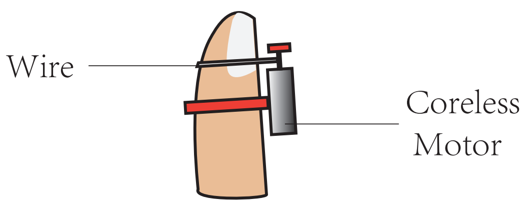

Figure 2: Fabrication of finger haptic actuator

3 DESIGN AND IMPLEMENTATION

Our system is made up of two key components, the first of which is a physics-based manipulation system. We used the virtual coupling technique to construct a virtual hand that closely mimics the arrangement of human hand bones, thereby allowing for realistic physical manipulation.

The second key component of our system 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. We were able to generate collide, frictional, and stick-slip signals for different materials by setting material properties. These signals are transmitted to haptic devices through the sound card. We designed our haptic display system according to figure 2.

Regarding actuators, we used small-sized coreless motors that are driven by audio power amplifiers. Additionally, we used a DC bias circuit to increase the amplitude of the audio signal. This allows the motor to apply varying pull forces to the fingers, as opposed to just vibrations. This provides a more realistic haptic experience, as it mimics the feeling of actually touching and manipulating objects with your hands. Overall, our system combines physics-based manipulation with haptic rendering to create a more immersive and realistic virtual environment.

4 CONCLUSIONS AND FUTURE WORKS

We have created a virtual manipulation and haptic system based on physics. This system enables users to interact with objects in a virtual environment and feel high-quality vibration feedback through their fingertips at a high definition. The physical hand was designed using Virtual Coupling and leverages a physics engine to collect information on contact force, relative velocity, and friction state. This system allows users to perform various manipulation tasks with dexterity and can be used with a visual-based hand-tracking system. It weighs around 40g and does not interfere with real-world activities. The device also eliminates the need for hard attachments or components at the fingertips, allowing the user to touch real-world objects without removing the device, shown as figure 3. With this system, users can easily manipulate objects and accomplish challenging tasks.

In the future, we will attempt to add more motors into the system without increasing the user's workload in order to provide a more diverse haptic experience at the fingertips.

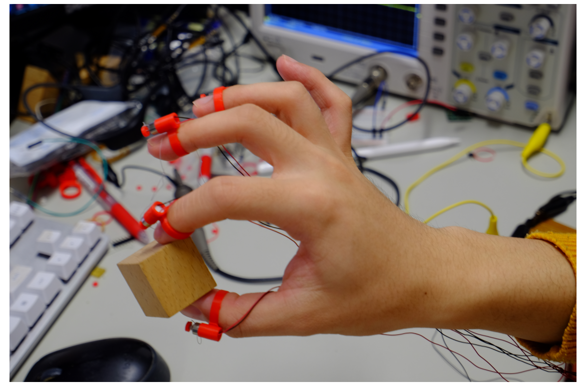

Figure 3: Illustration of the proposed haptic device. The design ensures users can also interact with physical objects in the real world.

REFERENCES

Takafumi Aoki, Hironori Mitake, Danial Keoki, Shoichi Hasegawa, and Makoto Sato. 2009. Wearable haptic device to present contact sensation based on cutaneous sensation using thin wire. In *Proceedings of the International Conference on Advances in Computer Entertainment Technology*. 115–122.

Li Han and Jeffrey C Trinkle. 1998. Dextrous manipulation by rolling and finger gaiting. In *Proceedings. 1998 IEEE International Conference on Robotics and Automation (Cat. No. 98CH36146)*, Vol. 1. IEEE, 730–735.

Shoichi Hasegawa, Yukinobu Takehana, Alfonso Balandra, Hironori Mitake, Katsuhito Akahane, and Makoto Sato. 2014. Vibration and subsequent collision simulation of finger and object for haptic rendering. In *Haptics: Neuroscience, Devices, Modeling, and Applications: 9th International Conference, EuroHaptics 2014, Versailles, France, June 24-26, 2014, Proceedings, Part II 9*. Springer, 352–359.

Lanhai Liu, Satoshi Miyake, Katsuhito Akahane, and Makoto Sato. 2013. Development of string-based multi-finger haptic interface SPIDAR-MF. In *2013 23rd International Conference on Artificial Reality and Telexistence (ICAT)*. IEEE, 67–71.

Allison M Okamura, Jack T Dennerlein, and Robert D Howe. 1998. Vibration feedback models for virtual environments. In *Proceedings. 1998 IEEE International Conference on Robotics and Automation (Cat. No. 98CH36146)*, Vol. 1. IEEE, 674–679.