Crossing the Chasm: Linking with the Virtual World through a Compact Haptic Actuator

Pornthep Preechayasomboon
University of Washington
Seattle, WA, USA
prnthp@uw.edu

Ali Israr
Facebook Reality Labs,
Redmond, WA, USA
aliisrar@fb.com

Figure 1: (top) Chasm along with a scale is shown for size. (bottom) Chasm is embedded in a handheld marker prototype. An Oculus Touch controller is also strapped to the back of the hand for tracking. The outline in the inset shows where Chasm is embedded in the prototype.

CHI 2020 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA.

ACM ISBN 978-1-4503-6819-3/20/04.
https://doi.org/10.1145/3334480.3383137

Abstract

We present a demonstration of Chasm, a broadband screw-based linear actuator that renders rich and expressive haptic feedback on wearable and handheld devices. Chasm renders low-frequency skin-stretch and high-frequency vibrations, both simultaneously and independently, through a single tactor and thereby augmenting user interactions with multidimensional haptic feedback in a light and compact form factor. We embody Chasm in a marker-shaped prototype and integrate it with a virtual reality headset through a robust software framework for real-time control of haptic features. We develop a set of VR scenarios to demonstrate rich tactile feedback rendered with the handheld marker and augment the user experience with feeling of impacts, textures, object stiffness and weight on the hand.

Author Keywords

Haptic device; Virtual reality; User interaction

CCS Concepts

• **Human-centered computing~Human computer interaction (HCI)**; *Haptic devices*; User studies;

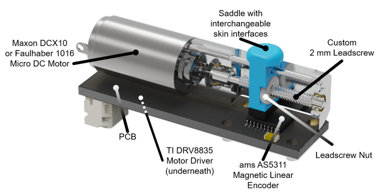

Figure 2: A cutaway section showing Chasm's internal components

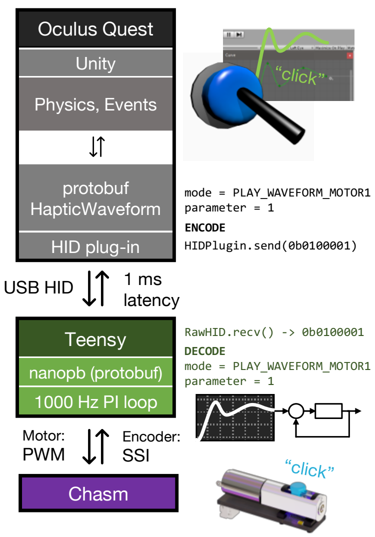

Figure 3: Chasm's software framework.

Introduction

Human touch is critical for users' engagement with the surrounding environment and enables physical interactions with objects around them. We introduce Chasm: a Compact Haptic Actuator with a Screw Mechanism. We optimize the design of a leadscrew mechanism and embed it in a handheld pointer to interact with broadband dynamic behaviors of virtual objects. We demonstrate Chasm's high bandwidth and high-fidelity features and its capacity to augment user interactions with multisensory experiences.

Design

Chasm's primary design element is a 2 mm leadscrew coupled to a direct current (DC) motor (Faulhaber 1016 with a 10 mm diameter) with no integrated gearhead. The leadscrew drives a leadscrew nut with a skin interface (or tactor), which directly contacts and moves the user's skin. To achieve high fidelity haptic rendering, the leadscrew nut is tracked with a high-resolution magnetic encoder (ams AS5311) for closed-loop control. The design and evaluation of an exemplary Chasm actuator is presented in [1]. In the current configuration, the leadscrew and leadscrew nut are housed in a custom aluminum housing and screws onto the motor and assembled inside a 3D-printed thin stylus shell that a user holds during interactions.

Chasm can render shear forces up to 4.8 N with a 3.4 mm stroke and perceivable vibrations up to 170 Hz. In this demonstration, we embed Chasm in a marker-like prototype – approximately the size of a whiteboard marker. The user holds on to the marker as shown in Figure 1 and lays their thumb on the tactor. The user's hand and the marker together are tracked using an Oculus Touch controller that is strapped to the hand using a custom-made hook-and-loop strap.

Control & Software Framework

We developed a feedback controller and software framework for Chasm that integrates with most existing consumer hardware such as a personal computer (PC) running macOS or Windows, or a standalone virtual reality headset such as the Oculus Quest. Chasm is controlled with a Teensy 4.0 microcontroller in the universal serial bus human interface device (USB HID) class mode. USB HID enables plug-and-play with most devices without the need of drivers. Aside from plug-and-play, USB HID also provides low-latency communication, ideally a 1 millisecond delay between the user's device and the microcontroller.

Chasm's microcontroller runs an interrupt-driven 1 kHz PI (proportional-integral) control loop to update the position of the leadscrew nut whilst waiting for incoming commands from the host (the computer or VR device). Commands sent to the microcontroller are serialized using protocol buffers (protobuf[1]). Such commands include: move the nut to a set position with a defined rate (velocity), upload and store a host-created waveform, playback the stored waveforms, or send diagnostic data back to the host. The waveforms are a time series of positions for the leadscrew nut. Since the waveforms can be arbitrary in position, they can be as complex as the developer desires. For example, the waveform shown in Fig. 3, shows a sharp increase in displacement along with an oscillation, creating a "click" effect. Lastly, due to our multiplatform systems

[1] https://developers.google.com/protocol-buffers

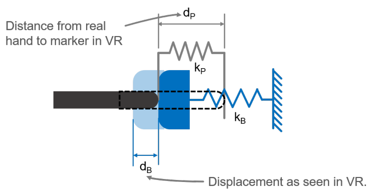

Figure 4: Our simulation model for interactions within the demonstration

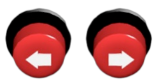

Figure 5: Left and Right Buttons used to scroll between the demonstration boards

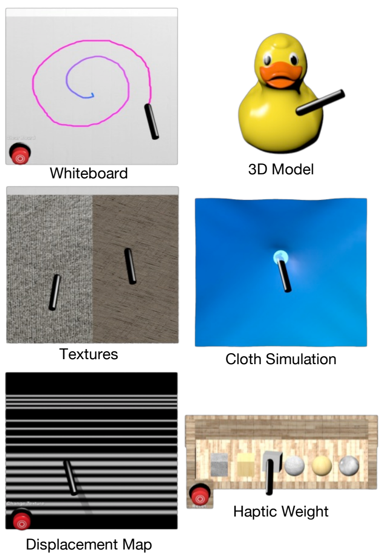

Figure 6: Six demonstrations showcasing Chasm's usability in various scenarios

integration and the Unity game engine, we can rapidly prototype these haptic effects on one system (a PC) and deploy it to any other system (an Oculus Quest).

Simulation Model for Interaction

Our demonstrations involve several different scenarios where the user can feel the stiffness or weight of different objects. Aside from providing haptics in the form of shear forces and vibrations, we also employ the pseudo-haptic weight illusion, specifically the "control display ratio" [2], to help strengthen the experience.

To achieve this in Unity, our virtual marker has a Configurable Joint with a virtual spring that is anchored to the actual marker's location and can only translate along its lengthwise axis, as shown in Figure 4. The spring would then extend at different rates for objects with different weights and stiffnesses and thus creating a different control display ratio for each. If the spring barely extends, then the object is light-weight or has low stiffness, conversely, if the spring extends a large amount, the object is heavier or has high stiffness – requiring more "effort" to move. The length that the spring extends is then also used for translating Chasm's end effector, thus heavier objects will render a higher displacement leading to higher shear force. In our concurrent work [1], we demonstrate that the model renders tactile illusions of force and is useful for stiffness discrimination of virtual buttons and weight of virtual objects.

Interactive Scenarios

We describe the following scenarios to demonstrate the usage of Chasm and its framework in a virtual reality setting. Users don an Oculus Quest headset and hold the marker prototype to interact with various objects and interfaces in the virtual environment. The user would place their thumb pad on Chasm's end effector and apply light pressure, similar to holding a marker or a laser pointer.

Buttons

There are two virtual buttons, a left and a right button, that are persistent across all demos, as shown in Figure 5. They allow the user to scroll to different demos. Some demonstrations also include a reset button to restart each individual demonstration.

Whiteboard

The whiteboard allows users to use the virtual marker to draw. Upon contact with the board, Chasm's end effector will snap to a set position creating an impact effect and pressure while pressing into the board. While the user draws, Chasm renders a 75 Hz sine wave with an amplitude of 0.68 mm, creating the illusion of texture and friction. When the user removes the marker from the board, Chasm's end effector moves back to its original position, similar to releasing pressure when moving a pen off the board.

Textures

The textures demonstration is similar to the whiteboard, except the user does not draw, but feel different textures represented by different frequencies and amplitude of displacement. The left, rough texture resembling concrete, has a 25 Hz frequency at 1.2 mm amplitude and the right, smoother texture resembling carpet has a 40 Hz frequency at 0.8 mm amplitude. Chasm's ability to rapidly switch between modalities are highlighted here when the user switches back-and-forth between the two textures.

Displacement Map

Textures that are irregular or have sparse asperities cannot be simply rendered by vibrations. In this demonstration, the marker samples the brightness of the underlying texture map that it is directly touching and the sampled value then drives Chasm's end effector. Brighter areas of the texture would render higher displacements. Users can switch between a number of textures with the reset button.

Cloth Simulation

A stretchable cloth is presented to the user to demonstrate the use of arbitrary haptic effects. When the marker is brought into the proximity of the cloth, an orb snaps to the marker along with a sudden haptic jolt. The cloth can now be stretched inwards and outwards using the marker. While stretching, Chasm varies the amount of displacement to simulate an opposing force from stretching. After reaching a certain limit of stretch, the cloth snaps away from the marker and another haptic snap effect is played.

3D Model

In this demonstration, the presence of a 3D object in virtual space is presented. A large 3D model of a rubber ducky is shown. The user can then use the marker to touch and feel the model. Chasm renders a shear force to oppose the hand from penetrating the model.

Haptic Weight

Six objects are presented to the user on a shelf: 3 cubes and 3 spheres. Each object is approximately the same size but has varying weight ranging from a very lightweight foam cube to a heavy metallic cube. Chasm renders shear force along with the control display ratio visual effect creating a convincing simulation of weight.

Conclusion

Chasm is a compact and broadband haptic actuator that renders expressive and high-fidelity tactile feedback. We prepare a set of VR scenarios where effectiveness of Chasm is highlighted while a user interacts with virtual objects. In the Interactivity session, audience will scroll through these scenarios and experience dynamic behaviors of virtual objects (such as click, texture, weight and stiffness) We demonstrate: (i) high-fidelity multidimension haptic cues (such as low-frequency skin-stretch and high-frequency vibrations) rendered with a compact actuator, (ii) multidimensional tactile cues combined with visual cues and user's motor actions render realistic and expressive behaviors, (iii) a robust software framework to control the haptic actuator and for prototyping haptic experiences, and iv) a set of rendering methods and associated scenarios to augment sensory experience in virtual environments.

References

[1] Pornthep Preechayasomboon, Ali Israr, Majed Samad. 2020. Chasm: A Screw Based Expressive Compact Haptic Actuator. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. ACM.

[2] Majed Samad, Elia Gatti, Anne Hermes, Hrvoje Benko, and Cesare Parise. 2019. Pseudo-Haptic Weight: Changing the Perceived Weight of Virtual Objects By Manipulating Control-Display Ratio. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. ACM.