Haplug: A Haptic Plug for Dynamic VR Interactions

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Abstract. We demonstrate applications of a new actuator, the Haplug, in dynamic virtual environments. The haplug is a linear voice coil motor packaged between springs in a plug-like casing. Response and bandwidth of the haplug are optimized for haptic interactions, and tuned by the motor inertia and spring stiffness. A pair of haplugs is mounted on the hand-tracking controllers of HTC Vive and renders a variety of haptic feedback, such as, feelings to colors, interactions with objects, surface texture and dynamic object behaviors. The Haptic Plug allows rich control of haptic effects in VR and other interactive settings.

Keywords: VR, haptic handhelds, dynamic haptics

1 Introduction

Current Virtual Reality (VR) systems feature a head-mounted display (HMD) to render rich and dynamic virtual environments surrounding a user. These systems are further enhanced by hand-tracking controllers that track users actions, gestures and motion in the environment and provide tactile sensations coupled with the audio-visual content. Due to the low-fidelity nature of the embedded actuator, the haptic feedback is limited to homogenous "buzz-like" vibrations. We present another haptic actuator, the *Haptic Plug* or *Haplug* (Hap-lug), which extends the bandwidth of the haptic actuator and renders high-frequency smooth vibrations, low-frequency motional cues as well as mid-frequency flutter sensations. These sensations are coupled with dynamic VR activities and demonstrated in this submission.

In the following section, we illustrate the design of the Haplug and its implementation with the HTC VIVE controller. This is followed by our framework and introduction to applications. Finally, we illustrate the demonstration layout for Asia Haptics.

2 Haptic Plug

The actuator design of Haplug is shown in Figure 1. On the core of the actuator is a linear voice coil motor (LVCM), whose coil is fastened to a 3D printed casing. A spring of stiffness k_1 is inserted between the coil and the moving mass of inertia M. Another spring of stiffness k_2 is placed before packing the actuator with a cap.

adfa, p. 1, 2011.

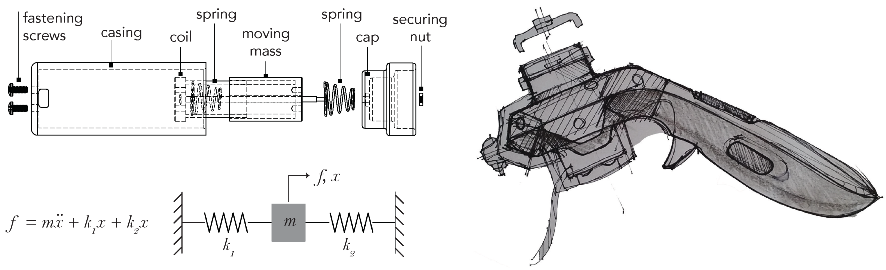

Fig. 1. Dynamical modeling of Haplug and its use with a Vive Controller

The spring stiffness, casing dimensions, and the moving inertia are optimized for low- to mid- frequency response (resonance peak at ~20 Hz). The actuator can play periodic waveforms, pulses and filtered noise, and time controlled patterns. The actuator design is simple, versatile and can be scaled to wide variety of off-the-shelf motors. A 3D adapter is printed to house the actuator and mounts through the center slot of the Vive controllers, as shown in Figure 1.

The frequency response of the Haplug is adjusted to match with that of the human detection threshold curve, as shown in Figure 2. This way, the control features of the Haplug are naturally optimized in the dynamic range of haptic perception. Figure 2b shows measured frequency response of the Haplug with preferred spring stiffness. It is observed that the first order approximation of the Haplug follows the human detection threshold curve determined in [1]. However, for accurate modeling, weights of the casing and the moving mass, the orientation as well as the compliance of the hold must be considered in the model.

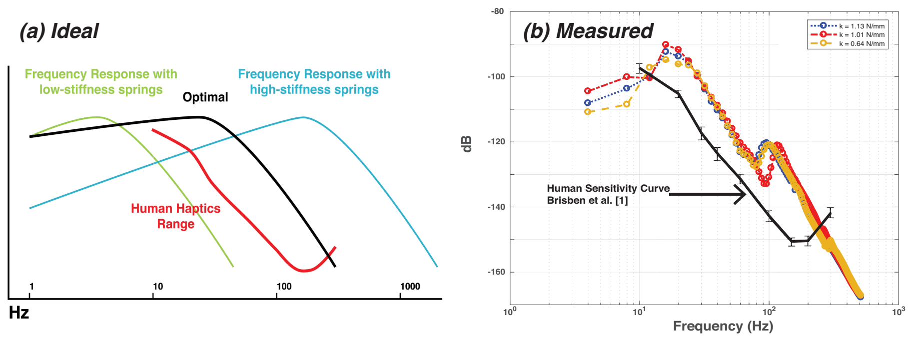

Fig. 2. Frequency response matching of Haplug, and the measured frequency response of the mockup prototype using preferred spring stiffness.

3 Framework and Applications

A pair of Haptic Plugs is mounted on two Vive hand-tracking controllers. VR environments are developed in Unity 3D using a SteamVR Plugin and haptic effects are channeled through stereo audio channels [2]. The tracked location of the end-effector, **X**, is compared to the virtual environment, **Y**. Based on user interactions, a haptic function $\mathbf{H} = f(\mathbf{X}, \mathbf{Y})$ is defined. In this section, we explore a library of rendered haptic effects and demonstrate in use cases.

3.1 Haptic Effects

The Haptic Plug plays a set of haptic effects. It plays low- to mid- frequency flutter sensations, and high-frequency (> 80 Hz) smooth vibrations. Moreover, it plays pull and push sensations as a consequence of pulse inputs. The response time of the actuator is fast (< 10 ms) and the feedback is perceivable in the 2 Hz to 200 Hz range. A set of expressive effects is shown in Figure 3.

3.2 Use cases

Following are some use cases and applications designed and implemented for this demonstration. With these cases, we highlight rich interactions with the Haptic Plug.

Surface Textures
The haplug can render wide variety of surface textures by periodically turning the haptic feedback on and off and/or modulating the perceived intensity of stimulations. A VR experience is designed that consists of three touch surfaces the user interacts with. In one surface, black and white stripes are associated with OFF and ON state of stimulations. By varying hand movements and spatial layout of patterns, attendees will feel varying feedback caused by rapid transitions of the haptic signal. In the second surface, texture of surfaces varied from fine to coarse, therefore rendering smooth to rough textures. In the third surface, users feel textural features of various pavements, landmarks, and regions in the pictures or they interact with an viscoelastic surface.

Feelings to Colors
In another installation, users produce colorful strokes in the surrounding free space. We associate vibration frequency and amplitude to the color's Hue, Chroma and Lightness according the vibration to color mapping in the CIELAB model. The color to vibration mapping is determined using a subjective evaluation study to be published.

Object Manipulation
In this installation, users interact with objects in the environment. In one case attendees handle and drag objects. A "snap" action is highlighted by a brief pulse pushing or pulling the hand, and drag forces are represented by vibration amplitude coupled to the hand motion. Heavier objects render high resistance and therefore higher amplitude, whereas, lighter objects render low resistance and therefore lower amplitude.

Dynamic Object Behaviors

The haplug cannot render static forces, such as the weight of an object. However, transient forces as a result of dynamic interactions with the objects and spaces can be presented with high fidelity. We modulate and perceptually synchronize the parameters of vibrations with activities and dynamic behaviors of object interactions, where a user interacts with springy, viscous and inertial objects. In one case, the user bounces, throws and juggles balloons in the environments, and in another case, the user switches tools to pop them.

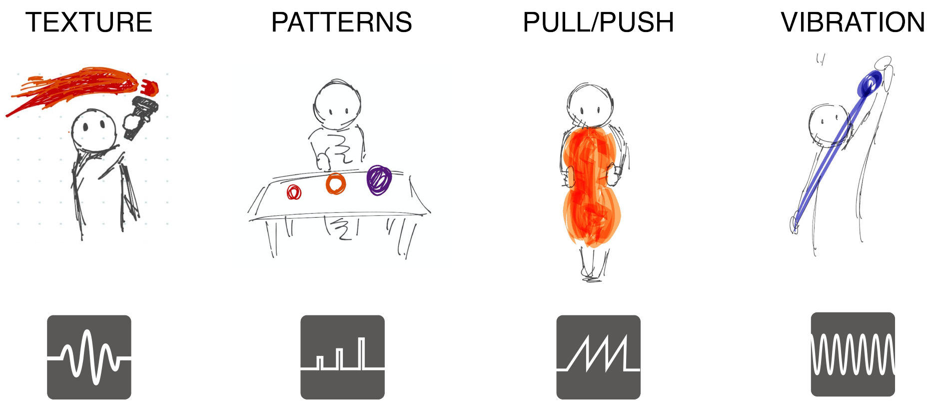

Fig. 3. Applied effects using the Haptic Plugs in VR settings.

Illusory Movements
We also developed an interactive scenario, where a user balances rolling objects on a wooden slab and feel moving and floating objects between the hands. In another case, the user has super-power capabilities. The effects are made using well-known sensory illusions in touch, such as apparent tactile motion, in which phantom motion and content is produced between the two hands holding Haptic Plugs [3].

4 Demonstration Layout and Presentation

In AsiaHaptics 2016, we will offer a wide variety of applications to highlight use of the Haptic Plug. Attendees will experience virtual environments using HTC VIVE VR system, and coherent haptic feedback will be rendered through instrumented hand tracking controllers. Attendees will go over the list of experiences and provide feedback to the authors for future use and research.

The demo will be accommodated in a typical 2m by 2m demonstration space. Only one attendee will go through the VR demonstration that lasts no more than 3 minutes, however, other attendees can visualize the experience while standing and waiting for their turn. Putting on and taking off the systems are minimized and take roughly 1 minute including instructions and introduction. Two organizers will man the booth and participants will receive gifts and postcards reminding them of the project after the conference.

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