Explorations of Wrist Haptic Feedback for AR/VR Interactions with Tasbi

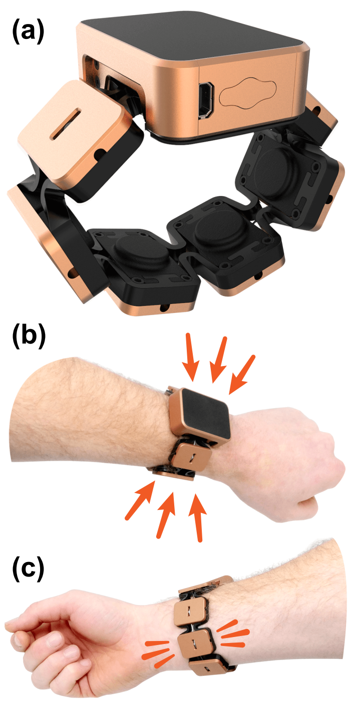

Figure 1: Tasbi **(a)** is a multisensory haptic bracelet that generates powerful and responsive squeeze around the wrist **(b)** as well as vibration at six uniformly spaced radial locations **(c)**. This demonstration explores the combination of Tasbi's wrist-based haptics with visual and audio stimuli for sensory substitution of hand and finger interactions in VR.

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Abstract
Most widespread haptic feedback devices for augmented and virtual reality (AR/VR) fall into one of two categories: simple hand-held controllers with a single vibration actuator, or complex glove systems with several embedded actuators. In this work, we explore haptic feedback on the wrist for interacting with virtual objects. We use Tasbi, a compact bracelet device capable of rendering complex multisensory squeeze and vibrotactile feedback. Leveraging Tasbi's haptic rendering, and using standard visual and audio rendering of a head mounted display, we present several interactions that tightly integrate sensory substitutive haptics with visual and audio cues. Interactions include push/pull buttons, rotary knobs, textures, rigid body weight and inertia, and several custom bimanual manipulations such as shooting an arrow from a bow. These demonstrations suggest that wrist-based haptic feedback substantially improves virtual hand-based interactions in AR/VR compared to no haptic feedback.

Author Keywords
haptics; wearables; multisensory; bracelet; virtual reality

CCS Concepts
•Human-centered computing → Virtual reality; •Hardware → Haptic devices;

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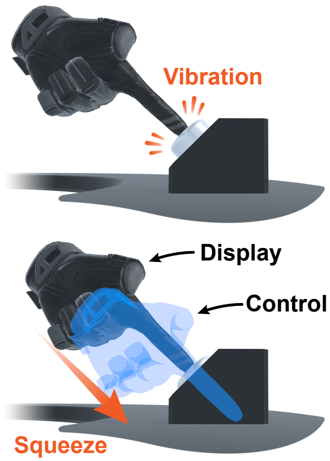

Figure 2: Our general feedback strategy combines wrist vibration for discrete contact and high frequency events, squeeze for continuous forces, and visual pseudo haptic illusions, i.e. control/display manipulation.

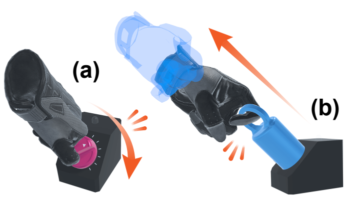

Figure 3: Rotary knobs **(a)** and pull handles **(b)** use an approach similar to the button paradigm in Fig. 2 for twisting and pulling motions, respectively.

Introduction

Augmented and virtual reality interfaces are positioned to revolutionize human-computer interaction by rendering complex three-dimensional visuals and spatialized audio content using portable, all-day-wearable, glasses or head-mounted displays. Stark differences between AR/VR interfaces and conventional two-dimensional screens present problems where interaction devices of the past (e.g. keyboards, mice, and controllers) may no longer be suitable or efficient. Building upon the standard methods of interacting with three-dimensional content [1], we hypothesize that multisensory haptic feedback [2], carefully paired with audio/visual stimuli may improve virtual object interactions. These demonstrations aim to explore and inform this hypothesis using the rich haptic stimuli provided by Tasbi.

Tasbi

Tasbi (Fig. 1) is a multisensory haptic bracelet that incorporates two haptic modalities: vibration and squeeze. Vibration is delivered though six radially and uniformly spaced linear resonant actuators (LRAs), while responsive squeeze is provided by a dorsally located tensioning mechanism. This mechanism features a novel cord winding system that affords Tasbi high force output in a relatively small package size. Design and implementation details can be found in [3]. While Tasbi has a number of potential applications, our primary focus has been on its utility as a haptic feedback device for augmented and virtual reality. Specifically, we are most interested in investigating wrist-based feedback for *sensory substitution* of forces that would otherwise occur at the hands and fingertips. Similar concepts have been explored in the context of prosthetic feedback for amputees, but relatively little work has been done in the context of AR/VR. This abstract and demonstration presents our early explorations across a variety of interactions.

Previous Demonstration

Tasbi was previously demonstrated at the 2019 World Haptics Conference. This demo featured *unimanual* feedback for stiffness rendering via virtual push buttons and a separate bow and arrow interaction. Since then, *bimanual* feedback has been enabled through the introduction of a second bracelet on the opposite wrist. A number of new compelling two-handed interactions have been developed to explore this space. In addition, we have designed feedback for interactions involving twisting and pulling motions, as well surface and object weight and inertia rendering.

Multisensory Feedback Paradigm

We adhere to a simple three-part "formula" for most interactions. First, haptic vibration renders *discrete* events such as hand collisions, impacts, and high frequency content, often in concert with audio effects. Usually, all six vibrotactors in Tasbi are simultaneously actuated for a stronger stimulus, but when appropriate we use a subset to convey directionality (see *Force Fields*). The second part leverages proportional squeeze for *continuous* interaction forces. For example, increasing squeeze as a virtual button is pressed to render its stiffness, or squeezing when objects are picked up to convey their mass. The third and final element is visual. Like many of the latest VR games, we employ the "god-object" principle [4] to both prevent virtual hands from penetrating objects, and to compute interaction forces. We extend this idea through a concept known as *psuedo-haptics*, where artificial discrepancies between the real (control) hand, and the virtual (display) hand are added to suggest that certain actions require more physical effort. We have previously shown that manipulating the control-to-display (C/D) ratio congruently with squeeze improves users' perception of virtual "stiffness" [3]. Combining all three sensory stimuli can lead to more compelling interactions than would be possible with a unisensory approach.

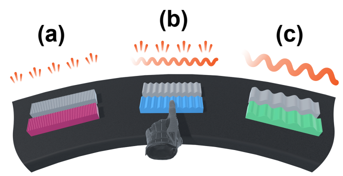

Figure 4: Vibration is used to render fine detail textures **(a)**, while squeeze offers the ability to render course, geometry-based surfaces **(c)**. Both can be combined **(b)**.

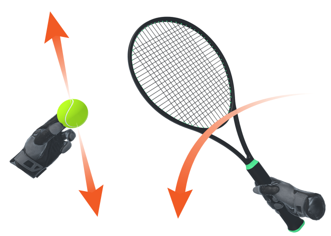

Figure 5: The weight and inertia of rigid-body objects can be rendered through fluctuations in squeeze.

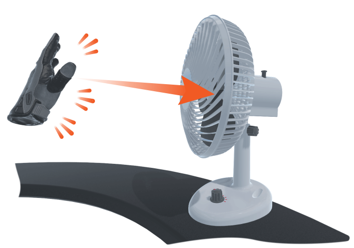

Figure 6: Forces not associated with physical contact, such as the airflow from this fan, are rendered with squeeze and vibration.

Primitive Interactions

Our multisensory approach is easily understood through the example of a virtual push button (Fig. 2). When the user's virtual finger first makes contact with its surface, a low amplitude vibration is rendered. As the button is pressed, squeeze increases proportional to its displacement. Changing the C/D ratio to increase the amount users must extend for a given button displacement gives the impression that the button is harder to press, or "stiffer". Additional vibrations can be played along the button's range of motion and end of travel for heightened realism. We consider the button an example for the primitive interaction of *pushing* objects. We have also explored other primitive motions, such as *twisting* in the form of knobs, and *pulling* in the form of pull handles (Fig. 3). Although the haptic feedback for each of these is exactly the same, we have found that users generally interpret each primitive interaction differently given the context of the associated visuals. As such, Tasbi is flexible enough to accommodate many types of interactions.

Surfaces and Textures

Rendering virtual surfaces and textures through vibrating actuators is a thoroughly explored area. Because Tasbi is equipped with six LRAs, it could implement many existing texture rendering algorithms. Vibration in general, however, is mostly confined to rendering *fine* surface details – bumps, cracks, ridges, etc. Rendering surfaces with *coarse* details related to geometry is typically reserved to grounded kinesthetic-type devices that physically restrict or guide hand motion. Tasbi, as an ungrounded wearable, cannot exert net forces/torques, yet, we find squeeze provides a surprisingly compelling way to render surface normals.

Consider the blocks in Fig. 4. All blocks employ the previously mentioned visual and haptic "god-object" rendering technique, where squeeze is proportional to the proxy hand penetration depth. As the user sweeps their hand across the surface, penetration depth and thus squeeze force change. For the larger amplitude blocks, this change in squeeze conveys surface height reasonably well. For the smaller amplitude blocks, typical vibration effects are employed at each peak. The middle block represents a balance of both squeeze and vibration based surface rendering, and is arguably the most compelling of all three.

Object Weight and Inertia

A challenge for all ungrounded haptic devices is realistically conveying the sense of object weight and inertia. Of course, it is impossible to render the downward force of weight, or the forces/torques of linear/angular inertia, without being connected to the physical world. Some glove-type devices may attempt rendering a type of psuedo-weight by applying forces to the fingers in the direction of gravity or in the opposite direction of acceleration. The challenge here is that the applied forces/torques must be grounded to other parts of the hand, where undesired reaction forces may result in perceptual discontinuities. In contrast, radial squeeze offers an interesting approach because it is *self grounding*, and forces are only felt as localized inward pressure. A simple approach would map a range of object weight and intertia to a range of squeeze levels. We have found this *static* approach to be rather ineffective. Instead, rendering *dynamic* effects result in a much more compelling interaction. In Fig. 5, a base amount of squeeze is applied when the tennis ball or racket is picked up, but additionally, the inertia of these objects is rendered through small fluctuations in squeeze as the user waves them in mid-air. For the tennis racket, we also increase squeeze proportional to the tilt angle, conveying a sense of the moment arm torque it would impart to the wrist. One challenge, however, is appropriately scaling each phenomenon's contribution to total squeeze since only on degree of freedom is available.

Figure 7: The ladder interaction, where squeeze increases as users lift themselves, explores movement and enhancing proprioception.

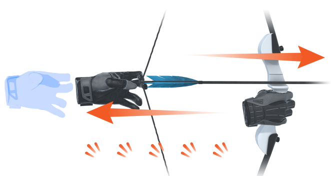

Figure 8: One bimanual interaction is demonstrated using a bow and arrow. Both wrists experience increasing squeeze as the bow is drawn. Subtle vibrations while drawing increase realism.

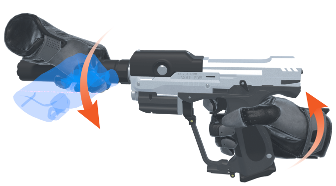

Figure 9: The pistol demonstrates a more complex two handed object with multiple points of interaction, such as twisting off the silencer or cocking the slide.

Force Fields

We have also explored rendering force fields for phenomena that have no physical points of interaction. The fan in Fig. 6 demonstrates this. When the users' hand moves in front of the air stream, squeeze increases to convey air pressure, and changes proportional to the distance between the fan and hand. Light vibrations are rendered on vibrotactors facing the fan to convey localized wind effects.

User Movement and Proprioception

Many VR games solve the locomotion problem by allowing players to grab nearby surroundings and pull themselves in a desired direction. However, if the player is not fixated on their target, or is also focused on other tasks, proprioception can break down and the sense of locality will be lost. Squeeze can mitigate this by conveying distance traveled along a path. In the ladder example of Fig. 7, vibrations are rendered with each grab, and squeeze increases as users pull themselves up each rung, resetting on release, and thereby giving a sensual presentation of climbing.

Bimanual Interactions

The most compelling Tasbi interactions are those that render feedback on *both wrists*. This is most apparent when the interaction simulates reactive forces between hands. For example, using a bow and arrow (Fig. 8): squeeze is rendered on the bow hand to simulate stabilizing forces, while increasing squeeze on the string hand simulates the build-up of bow tension. As in most examples, the experience is substantially enhanced with subtle vibration and C/D manipulation. Even more complex interactions are possible, as shown in the pistol demonstration (Fig. 9). It features unimanual haptic effects, such as squeeze for trigger pull and vibration for firing, and bimanual effects such as squeeze forces when the player uses the opposite hand to cock the slide or twist off the silencer.

Demonstration Format

Each of the interactions discussed here are available to demo. The interactions are organized and contained on separate virtual islands which users can move between depending on their interests. Two separate demo stations are available. Demo participants are expected to wear a commercial VR headset. Since we currently rely on VR controllers for hand and finger tracking, users should ideally have some familiarity with basic controller-based grab and gesture mechanics. A short calibration is required during the Tasbi donning process.

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