

Displaying Realistic Contact Accelerations Via a Dedicated Vibration Actuator

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ABSTRACT

During real physical interactions, contact between a hand-held tool and an object causes high-frequency tool accelerations that are detected by mechanoreceptors in the human hand. These haptic signals provide salient cues about changes in tool-surface contact state and enable effortless identification of material and surface properties. Unfortunately, these rich contact sensations are often absent from haptic renderings of virtual and remote objects. This demonstration features a classic implementation of bilateral teleoperation with two augmented SensAble Omni haptic interfaces. By using this system to touch a variety of remote objects, users will have an opportunity to experience first-hand the remarkable improvements in haptic realism that can be achieved through the use of a dedicated high-frequency vibration actuator driven by contact accelerations.

KEYWORDS: Haptic rendering, hard contact, texture.

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O.

1 INTRODUCTION

When touching objects in your surroundings, you can feel a rich array of haptic cues that reveal each item’s geometry, material, and surface properties. For example, the vibrations and forces experienced by your hand as you stroke a piece of cardboard with a pen are distinct and different from those generated by touching a paintbrush to a curved foam surface or using a scalpel to make a surgical incision. The human talent for discerning haptic surface properties such as stiffness and texture through an intermediate tool stems partly from the phenomenon of *distal attribution*, in which a hand-held tool comes to feel like an extension of one’s own body because its dynamics are simple to understand [6]. Humans are amazingly adept at eliciting and interpreting haptic feedback during tool-based interactions with physical objects, naturally leveraging this wealth of information to guide both exploratory and dexterous manipulation.

Touching a real physical object with a hand-held tool causes the tool to experience high-frequency accelerations that reflect the mechanical characteristics of the contact. These accelerations are easily sensed by the Pacinian corpuscles in the glabrous skin of the human hand [1], and they enable easy identification of the surface’s key properties. Unfortunately, current haptic interfaces cannot display objects that feel as crisp and distinctive as real objects; instead, the standard position-based control algorithm and base-mounted actuators doom most virtual surfaces to feel soft and undefined, significantly limiting the usefulness and

applicability of such systems. For example, the human subject study in [4] demonstrated that typical virtual surfaces seeking to emulate *wood* are actually indistinguishable from *soft foam*, earning a mere 2 out of 7 for realism during unsighted tapping.

It is our belief that the haptic realism of virtual and remote objects can be dramatically improved by augmenting low-frequency position feedback with high-frequency vibrations that are matched to the accelerations that occur during real contact.

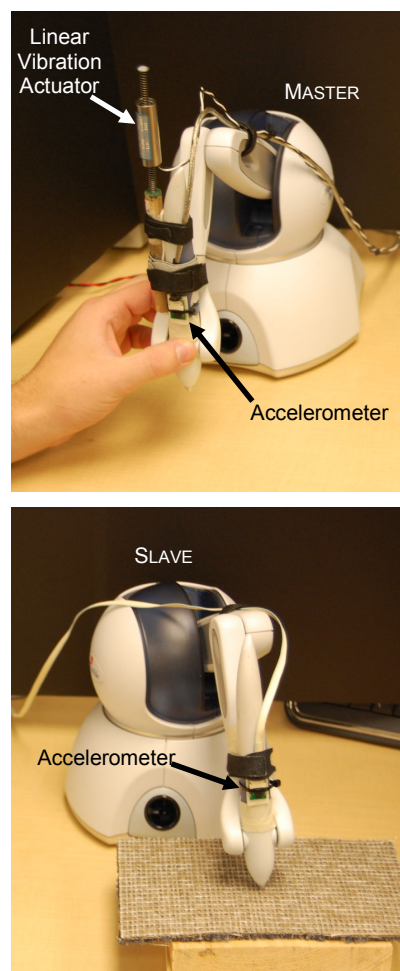


Figure 1. Demonstration Setup. The master device (top) is a SensAble Omni augmented with a linear vibration actuator and an accelerometer. It allows a human operator to interact with the environment of the slave device (bottom), which is a second Omni augmented with an accelerometer. The master Omni’s motors provide the user with low-frequency position feedback, while the dedicated vibration actuator provides contact acceleration feedback, driven by the accelerations sensed at the slave tip.

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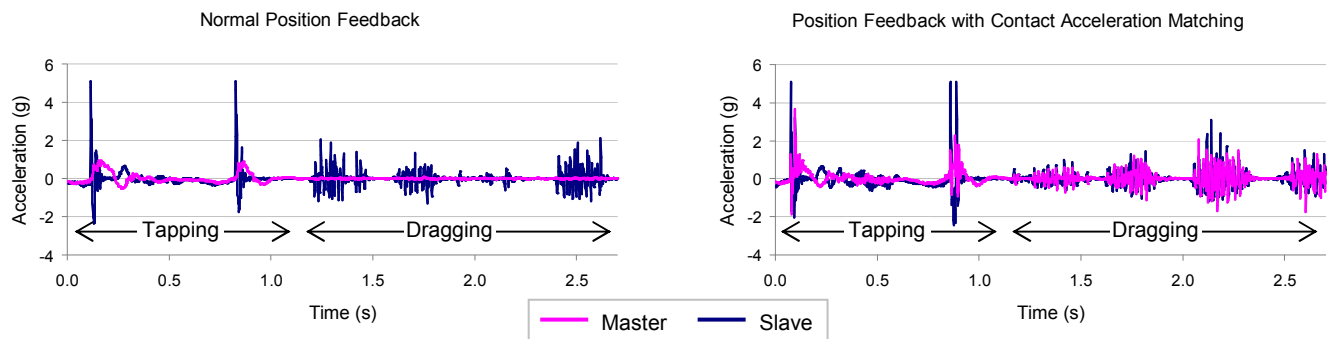


Figure 2. Sample readings from the accelerometers attached to both the master stylus (user-interface) and slave robot during interaction with a textured rubber surface. The left graph shows data from a standard position-position controller; notice that the master accelerations are smooth. The right graph demonstrates the effect of a dedicated high-frequency vibration actuator driven with the accelerations measured at the slave tool; notice that the master accelerations are qualitatively well matched to those of the slave.

2 PREVIOUS WORK

In some prior work [4, 5, 7], measurement-based contact vibrations were added to traditionally rendered surfaces using the haptic interface’s native DC motors. This technique is attractive because it provides higher bandwidth stimulation for the user without requiring any additional hardware, but it is highly susceptible to configuration-based variations in the device’s high-frequency dynamics. A viable alternative can be found in the older teleoperation work of Howe and colleagues, where high-frequency slave fingertip accelerations were relayed to the user (along with low-frequency force feedback) via a pair of supplementary voice coil actuators [2, 3]. The measured acceleration was multiplied by an empirically determined constant to drive the actuator, and the authors reported that its output varied by a factor of 2.24 across the frequency range of interest. Despite the simplicity of the approach, human subject tests indicated that this hybrid feedback strategy increased user performance in inspection, puncturing and peg-in-slot tasks; furthermore, users commented that the vibrations improved the “feel” of the interface. Despite the encouraging open-loop output results of Howe and colleagues, few researchers and no haptic device companies have chosen to use a supplementary vibration actuator for high-fidelity haptic rendering; this is the design approach we want to improve on and demonstrate.

3 DEMONSTRATION

Our active stylus (shown in Figure 1) features a dedicated linear vibration actuator purchased from H2W Technologies. It consists of an electromagnetic coil around a movable permanent magnet core; the magnet is rigidly connected to the stylus, and a pair of compression springs centers the movable coil in the actuator’s workspace. Driven by a linear current amplifier, this vibration actuator has both the bandwidth and force capability to recreate the contact accelerations from light taps and dragging.

We will demonstrate our active stylus through a teleoperation exercise with an augmented master-slave system. Visitors will use the active stylus, attached to a SensAble Omni, to control the position of a second Omni. As the user explores a number of remote samples that vary in texture and stiffness, the encoders and DC motors of the two Omnis will measure and convey traditional haptic position feedback to the user. On top of this standard feedback, the accelerometers and the vibration actuator will be used to display matched contact accelerations on the master. Our present approach drives the vibration actuator with a current that is proportional to the vertical acceleration sensed at the slave. Individuals testing our demonstration will have the opportunity to

teleoperate both with and without the added acceleration feedback, so they can directly compare the two experiences.

Positive user responses and preliminary data (a sample of which is shown in Figure 2) suggest that the addition of the contact acceleration-matching feedback strongly improves the realism of the remote user experience with respect to the acceleration felt through the stylus. From this demonstration, users will have an opportunity to feel first-hand the improvements in haptic realism that can be realized through the use of a dedicated high-frequency vibration actuator.

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