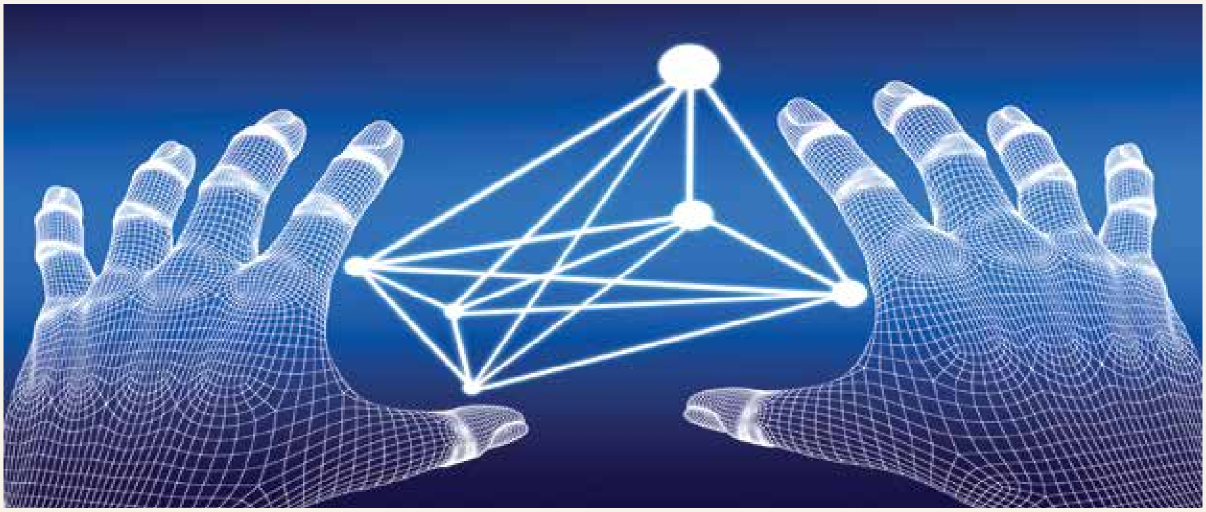

Creating Greater VR Immersion by Emulating Force Feedback with Ungrounded Tactile Feedback

By William R. Provancher

Multisensory Feedback in Virtual Reality

The availability of optical displays from mobile phones and motion tracking from video games and handheld electronics have made it possible to produce head-mounted displays (HMDs) for virtual reality (VR) that are inexpensive, yet of sufficient quality to be viable as consumer products. While these new consumer HMDs may not rival the quality of traditional VR systems, which can cost more than $10,000, they nonetheless provide compelling products that are more than sufficient for consumers to experience VR firsthand for less than $500. This is an impressive accomplishment since not only must the HMD provide sufficient resolution, it must also integrate head tracking so that the displayed scene is updated in a manner that shifts as the user moves his or her head and does so with sufficient accuracy to avoid motion sickness. Additional display features, such as "low display persistence" can also help reduce motion blur in HMDs.[1]

While a human's experience of the world tends to be vision dominant, having a great HMD isn't the alpha and omega of VR. An effective HMD can give a greater sense of immersion than watching a computer monitor, but VR is a unique medium in which providing feedback to all of the senses can actually create a sense of presence. So while having a great HMD is necessary, it isn't sufficient by itself unless one remains a spectator. Most people agree that VR is meant for interaction.

Interaction in VR can come in as many forms as in real life. For example, when walking in a hallway, you expect to hear echoes change as you progress or someone approaches. And you expect to be able to interact physically in the world, especially for simple activities such as turning a doorknob to open a door. However, research to enable this type of physical interaction has lagged behind that of HMDs and 3D audio (taste and smell are also important senses, but vision, audio, and haptic interaction are essential to interactive VR).

Touch Feedback in Virtual Reality

Haptic (touch feedback) interfaces have been commercially available for more than 15 years and vary in form from desktop force feedback devices (e.g., SensAble Phantom or Force Dimension Omega) or hand exoskeletons for portraying grasp forces (e.g., CyberGrasp) to larger devices that are used for welding simulators (e.g., Moog Haptic Master). These devices are sufficient when the virtual task is at a fixed location such as dental or surgery simulation, but these systems can be quite expensive and generally do not allow the user to move over a large workspace, as one might want in a generalized consumer VR system.

A more affordable alternative to force feedback is vibration feedback, which most of us are familiar with in mobile phones and game controllers. In these applications, vibrations are traditionally generated by rotating an eccentric mass, which has the limitation that the frequency and magnitude of the generated vibrations are coupled. A next generation of "HD haptic" vibration actuators overcame this limitation through the use of a piezoelectric or electroactive polymer actuator to provide a greater range of vibration feedback. While this form of feedback is great for portraying the vibration experienced through contact or from textures, it lacks the ability to convey the sense of interaction forces, which is essential for manipulation. Researchers have also developed inertial feedback systems that use spinning or sliding masses to provide haptic feedback, but these systems tend to have large power and space requirements and typically cannot portray sustained interaction forces.

Conveying interaction forces is essential for almost any form of manipulation in VR (or teleoperation). This is true whether providing training through a surgery simulator or picking a lock in a puzzle game. However, no current haptic interface appears to be capable of providing the fidelity available through traditional force feedback devices combined with a large workspace that allows VR users to move their hands naturally.

This issue is also observed with motion interfaces for gaming such as the Microsoft Kinect or Leap Motion hand gesture sensor. Tracking the user's hand motions and representing them in VR (e.g., the hand motions used to interact with computer menus in the movie *Minority Report*) is insufficient. Without physical confirmation of an action, these motion interfaces leave the user with a clumsy, tentative interaction, since they often need to make gross gestures and linger until an entry or action is registered on the computer. Physical feedback provides confirmation that is familiar and intuitive to users.

However, it is a challenge to provide suitable feedback for a range of VR interactions at a price that is appropriate for consumer VR — to be combined with the many HMDs that will become available in the coming year.

Reactive Grip Feedback

Tactical Haptics has developed a new form of haptic feedback called Reactive Grip™ that fits this middle ground between force and vibration feedback. That is, it can mimic force feedback, but with a large workspace, at a lower cost, and without connectivity to a desktop through a robotic arm.

Reactive Grip feedback works by mimicking the friction forces experienced by users as if they were actually holding the object. These friction forces are applied through the motion of actuated sliding plate contactors (also called tactors) that move on the surface of the device's handle (see Figure 1). When grasped, the sliding contactor plates induce in-hand shear forces and skin stretch that mimic the friction and shear forces experienced when holding the handle of a device, tool, or other equipment. Through the coordinated motion of these distributed, sliding contactor plates, this device is capable of providing force and torque cues to a user.

When the sliding tactor plates are actuated in unison in the same direction, the controller communicates a force cue in the corresponding direction along the length of the handle to the user (Figure 2b). When the

Figure 1 | Tactile feedback device with sliding contactor plates placed around the handle. The contactor plates are independently actuated and slide vertically.

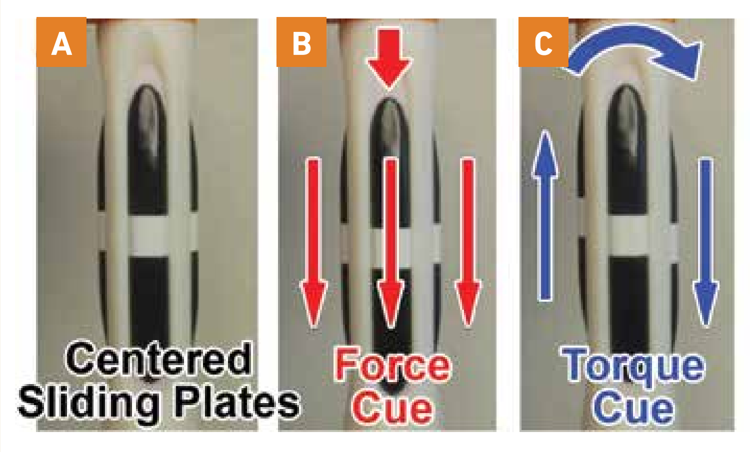

Figure 2 | Sliding contactor plates in their (A) centered, (B) down, and (C) differential positions. A downward force is portrayed in (B), and (C) portrays a torque.

sliding plate tactors are moved in opposite directions, the controller portrays a torque to a user (Figure 2c). The speed and magnitude of the tactor motions can be altered to create varying force/torque cues, which can also be superimposed to layer simulated feedback with different tactile effects.

The device has been refined over time to utilize three sliding plate tactors, instead of four sliding plate tactors used previously.[2] With three sliding plate tactors, the device has a smaller handle diameter, making it easier to grip. Force cues are still portrayed by moving sliding contactor bars together along the length of the handle, while torque cues are communicated by moving combinations of contactor plates in opposite directions.

The Reactive Grip controller is integrated with a Razer Hydra 6DoF (six degrees of freedom) motion tracker, which is used to measure the hand/device position and orientation and provide this information within virtual environments. However, Reactive Grip feedback will work in combination with any type of motion tracking.

The current device system development kit (SDK) supports development in both Unity and C++, and examples of several demo scenarios have been developed as shown in Figure 3. Developers can utilize their own physics models or any physics engine (including Unity's internal PhysX physics engine) to calculate the virtual forces and torques applied to virtual objects. These calculated forces and torques are then portrayed to a user through the motion of the sliding contactor plates. Virtual forces are portrayed by moving the sliding plates in the same direction, and virtual torques are portrayed by moving the sliding plates in opposite directions (Figure 2). These sliding contactor motions are superimposed for portraying combined loading cases that would be common during virtual interactions.

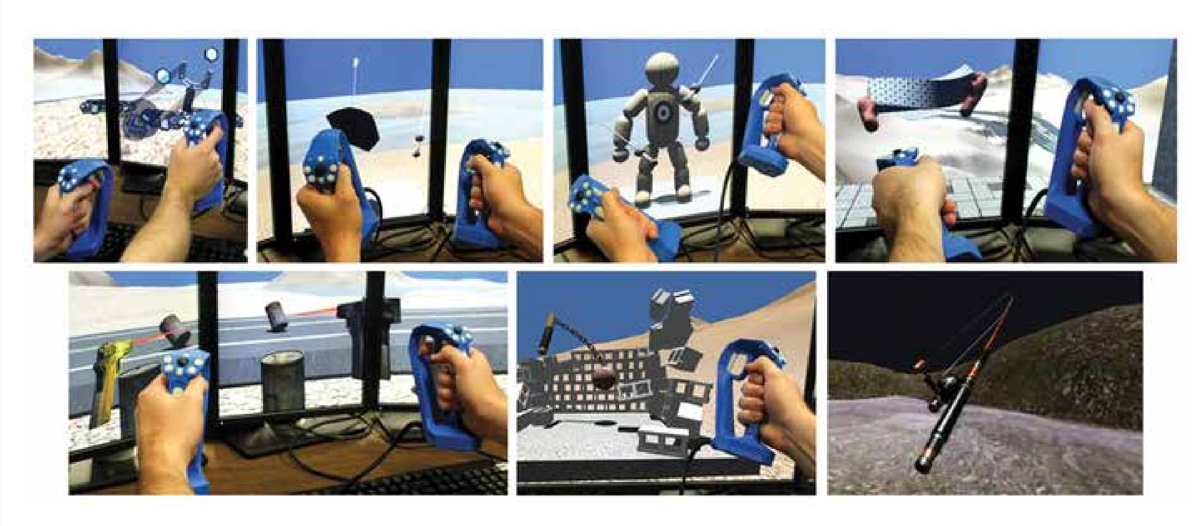

Figure 3 | Examples of the physical interaction possible with dual-handed Reactive Grip haptic motion controllers.

Reactive Grip feedback works by mimicking the friction forces experienced by users as if they were actually holding the object.

Forces and torques can also be measured with a load cell and portrayed with the Reactive Grip controllers for teleoperation applications. Support for additional development environments such as CHAI 3D, WorldViz's Vizard, Unreal Engine, and others are anticipated in the future.

As shown in Figure 3, the two tactile devices allow for independent motion of the user's hands. Because of this, it is possible to demonstrate a wide variety of interactions. Several demonstrations have been created to highlight different types of interaction with this device, including a slingshot, sword and shield, shooting gallery, medieval flail, stretching of a deformable object, dune buggy driving, and fishing, among others. These scenarios highlight the system's ability to simulate coupled interaction forces between the user's hands and portray virtual inertia (continuous and impulsive), compliance, and friction.[3]

Conclusion

The availability of low-cost head-mounted displays will bring virtual reality into the mainstream and make VR affordable to consumers. While low-cost HMDs and 3D audio will create an immersive VR experience, the lack of a solution to provide compelling touch feedback will break the sense of presence when users try to interact physically with the virtual world. One possible solution is Reactive Grip touch feedback, which will allow users to move their hands naturally while providing compelling touch feedback.

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REFERENCES AND FURTHER INFORMATION

[1] For further information on design requirements for HMDs, see Michael Abrash's presentation on the future of VR from Valve's Steam Dev Days (Jan. 2014): http://media.steampowered.com/apps/abrashblog/Abrash%20Dev%20Days%202014.pdf.

[2] A. L. Guinan, M. N. Montandon, A. J. Doxon, and W. R. Provancher. Discrimination thresholds for communicating rotational inertia and torque using differential skin stretch feedback in virtual environments. Proc. of the 2014 Haptics Symposium, Houston, Texas, USA, Feb. 23-26, 2014.

[3] A video showing interactions that are possible with Reactive Grip can be found at http://youtu.be/uD3hhIYr1f4.