Creating Fully Immersive Virtual and Augmented Reality by Emulating Force Feedback with Reactive Grip™ Touch Feedback

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The availability of low-cost head-mounted displays (HMDs) is making Virtual Reality (VR) and Augmented Reality (AR) affordable to consumers and bringing XR to the mainstream (XR is inclusive of VR, AR, and MR: Mixed Reality). Pairing 3D audio with low-cost HMDs creates immersive XR experiences, but the lack of compelling touch feedback breaks the sense of presence when users interact physically with virtual objects in XR. Traditional force feedback devices limit users to a small motion workspace (e.g., a desktop) and can be very expensive. Vibration feedback (also called "Rumble") is inexpensive, but cannot portray forces. A technology called Reactive Grip™ touch feedback, which mimics the friction forces experienced by a user when interacting with real objects, can emulate force feedback through a handheld controller in XR. This allows users to move their hands naturally while providing compelling touch feedback in response to users' interactions.

1 MULTISENSORY FEEDBACK IN XR

The availability of optical displays from mobile phones and motion tracking and handheld electronics from video games has 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. These new consumer HMDs now rival the quality of traditional VR systems, which cost $10,000 or more, and provide compelling VR experiences for consumers for less than $500. This impressive accomplishment not only requires the HMD to provide sufficient resolution, the HMD must also integrate head-tracking so 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.

While humans tend to be vision dominant, having a great HMD isn't the alpha and omega of XR. An effective HMD can give a greater sense of immersion than watching a computer monitor, but XR is a unique medium in which engaging all of the senses can create a feeling of *presence*. While having a great HMD is necessary, it is not sufficient unless one remains a spectator. Most people agree that XR is meant for interaction.

Interaction in XR can come in as many forms as in real life. When walking in a hallway, you expect to hear echoes change as you progress forward or someone approaches. You also expect to be able to physically interact with the world, especially for simple activities such as turning a doorknob. 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 XR.)

2 STATE OF TOUCH FEEDBACK IN XR

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 / 3D Systems *Phantom* or Force Dimension *Omega*) to hand exoskeletons for portraying grasp forces (e.g., *CyberGrasp* or *Dexmo*) to larger devices that are used for welding simulators (e.g., Moog *Haptic Master*). These devices are sufficient when the virtual task occurs in 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 (a feature one might want for a consumer XR system).

A more affordable alternative to force feedback is vibration feedback, which is ubiquitous in mobile phones and game controllers. In these devices, vibrations are traditionally generated by rotating an eccentric mass (ERM), which has the limitation that the frequency and magnitude of the generated vibrations are coupled. More recently, Linear Resonance Actuators (LRAs) have provided a relatively inexpensive alternative to ERMs. LRAs provide higher bandwidth and shorter latency to the onset of vibratory signal. Thus far, the improved responsiveness has come at the cost of vibration magnitude. The Oculus Touch and HTC Vive controllers both use LRAs to provide responsive, albeit somewhat muted, vibration feedback.

Several next-generation vibration actuators overcome the limitations of the ERMs and LRAs through the use of a piezoelectric (PZT), electroactive polymer (EAP), or voice-coil (VC) actuators to provide a greater range of vibration feedback. All 3 of these actuators have been used for driving audio feedback and far exceed the dynamic range of human tactile sensing (0-1,000 Hz), which allows the actuators to create complex vibration wave forms. Additional drive circuitry is required to provide the wave-form to these actuators. This circuitry is not currently available in an integrated waveform/amplifier IC (in contrast to the simplicity of turning ERMs/LRAs on/off at a given magnitude). While

voice coils (e.g., Lofelt), hybrid voice coil / solenoid (e.g., Nanoport Tachammer) and piezo-electric actuators (e.g., TDK) have existed for quite some time, their commercial use for haptic feedback is relatively new. Voice coils (VCs) can be driven with audio amp circuitry at low voltages, whereas piezo-electric (PZT) and EAPs (e.g., Novasentis) often require hundreds of Volts to drive them. Manufacturers are bringing down the required drive voltages by laminating these materials into many layers. On the other hand, PZT and EAP actuators can be much more compact than VCs.

While these next-generation PZT/EAP/VC actuators can provide wide bandwidth vibration feedback for conveying impact or textures, they still lack 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. An exception is the vibratory inertial feedback devices from the company Miraisens. Their handheld devices use ~40 Hz asymmetric motions of an internal mass using voice coil actuators to create the "Buru-Navi" effect. Their devices provide the sense of force feedback, but their force cues always contain vibratory pulses, which can be distracting and/or numb the fingertips.

Stryker VR uses another form of inertial feedback which excels at providing impact effects and gun recoil feedback. They move a mass along the rail of a linear motor and collide the mass with an end-stop to generate very large force impulses. Stryker VR's gun controllers are expensive, have a large power draw, and are limited to providing gun feedback. In contrast, Nanoport's Tachammer actuators provide similar, but scaled down (& less expensive) inertial feedback that has started appearing in VR gun controllers for emulating gun kick-back. Both

Stryker VR and Nanoport's solutions are limited to providing vibrations and impulses.

3 REQUIREMENTS FOR INTERACTION IN XR

Conveying contact and interaction forces is essential for almost any form of manipulation (in XR or teleoperation). This is true whether providing training through a surgery simulator or picking a lock in a puzzle game. No current haptic interface can provide the fidelity of a traditional force feedback devices combined with a large workspace that allows users in XR to move their hands naturally.

This issue is also true of gaming motion capture systems such as the Microsoft Kinect or Leap Motion hand gesture sensor. Tracking the motions of users' hands and representing these hand motions in XR (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 touch feedback provides confirmation that is familiar and intuitive to users. It is a challenge to provide suitable feedback for a range of XR interactions that has the potential to be inexpensive enough for consumer XR.

Tactical Haptics has developed a new form of haptic feedback called shear feedback (also called skin stretch feedback in the literature) that spans the middle ground between force and vibration feedback. Shear feedback can mimic force feedback with a large workspace and at a lower cost than traditional force feedback devices. This form of haptic feedback applies shear forces to users' hands which mimic the friction forces that users would experience if they were touching the simulated object with their own hands. This form of feedback can emulate force feedback yet does not require the device or user to be connected to a
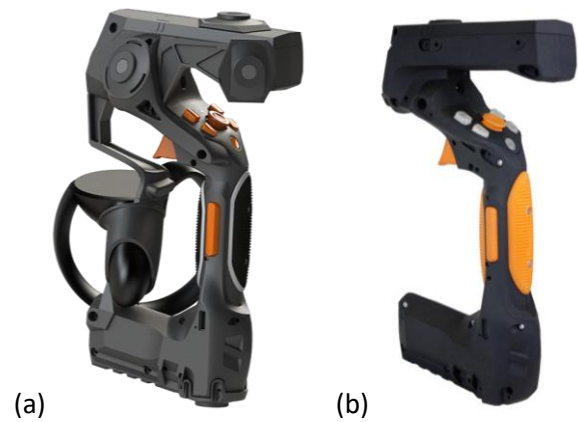

Fig. 1: (a) Render of Reactive Grip™ touch feedback device redesigned for modularity and manufacturability with two sliding contactor plates on the surface of the handle (shown with Oculus Touch tracker bracket and Multi-Pose™ Magnet Sockets). The contactor plates are actuated to slide in the vertical direction. (b) Reactive Grip™ controller prototype.

desktop through a robotic arm. The tradename for this haptic feedback is Reactive Grip™ touch feedback.

4 HOW REACTIVE GRIP™ SHEAR FEEDBACK WORKS

Reactive Grip™ touch feedback works by mimicking the friction forces experienced by users as if they were actually grasping the object in the virtual environment with which they are interacting. 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 Figs. 1 & 2). When grasped, the actuated sliding contactor plates induce in-hand shear forces and skin

Fig. 2: Force/Torque illusions are created by actuating the sliding contactor plates in response to the user's hand motions.

stretch that mimic the friction and shear forces experienced when holding the handle of a device, tool, or other equipment and interacting with objects in the environment. This device is capable of providing force/torque cues to users, in response to their actions, through the actuation of its sliding plates (see Fig. 2).

The speed and magnitude of the tactor motions can be varied to create varying force/torque cues; these cues can also be superimposed to layer simulated feedback with different tactile effects.

The device has been refined to utilize two sliding plate tactors (Figs. 1 & 2), instead of three or four sliding plates used previously.[1] With two sliding plates, the device has a smaller handle diameter, making it easier to grip and permitting fewer, more robust actuators to be incorporated into the device for improved performance and reliability.

The Reactive Grip™ controller has been integrated with several different tracking options, including Oculus (see Fig. 1), HTC, and Windows MR. The controller design was developed to be tracker agnostic and could be paired with Optitrak, Vicon, PhaseSpace, Polhemus, Ascension, or other tracking systems.

In addition to its novel touch feedback, Tactical Haptics has also created a new way to form game peripherals in-game using magnet sockets positioned on the exterior of the controllers. These reconfigurable magnet sockets allow the controllers to transform on-the-fly from being used independently to being combined into a machine-gun or gamepad / steering wheel configuration (see Fig. 3). We call these Multi-Pose™ Magnet Sockets. Other configurations are also supported via magnetic sockets at the top and bottom of the controller (such as a bike handle-bar-like configuration, 2-handed sword, etc.). In addition, the magnet sockets permit relative motion after joined, which users can utilize as a natural input (e.g., reloading a gun or as a throttle to control the magnitude of output).

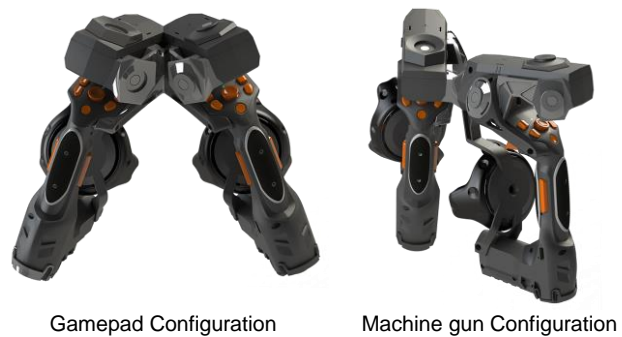Gamepad Configuration   Machine gun Configuration

Fig. 3: Reconfigurable magnet sockets for on-the-fly peripherals. The company's haptic controllers include reconfigurable magnet sockets that allow the controllers to transform on-the-fly from being used independently to being combined into the (left) machine-gun configuration, or (right) gamepad / steering wheel configuration. Other configurations are also supported with additional magnetic sockets at the top and bottom of the controller.

Tactical Haptics has developed a software development kit (SDK) with software plugins that integrate with the Unity and Unreal game engines. The company's haptic plug-ins work in conjunction with the physics engines native to each of these game engines in order to calculate virtual force and torque vectors based on users' interactions with objects in XR. These calculated forces and torques are then portrayed to a user through the motion of the sliding contactor plates via the company's proprietary software. The calculated forces are combined for portraying complex load cases, which often occur during virtual interactions.

Several tech demos and games have been created to highlight the different types of physical interaction that are possible with this device, including a bow & arrow, slingshot, sword and shield, shooting gallery, physics/gravity gun (tractor beam), flail, ball maze, deformable elastic object, box manipulation, throwing/catching, virtual painting/sculpting, dune buggy driving, and fishing, among others. These scenarios highlight the system's ability to simulate interaction forces with the environment and between the user's hands to portray virtual inertia (continuous and impulsive), compliance, and friction. Videos showing possible

interactions with this device can be found at
http://tacticalhaptics.com/media/ or
https://tacticalhaptics.com/demo-user-feedback-from-gdc-2019-tactical-haptics/ .

5 SUMMARY

The availability of low-cost head-mounted displays (HMDs) is bringing XR into the mainstream. While low-cost HMDs and 3D audio create immersive XR experiences, the lack of compelling touch feedback breaks the sense of presence when users try to interact physically with virtual worlds. Reactive Grip™ touch feedback provides a solution that allows users to move their hands naturally while receiving compelling touch feedback.

ACKNOWLEDGMENTS

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AUTHOR BIO

William R. Provancher received B.S. and M.S. degrees in Engineering from the University of Michigan. Before returning to graduate school, he worked for 5 years at Lockheed Martin Missiles and Space. His Ph.D. from Stanford University in Mechanical Engineering focused on haptics, tactile sensing and feedback. His postdoctoral research involved the design of bioinspired climbing robots. As a tenured Associate Professor in the Department of Mechanical Engineering at the University of Utah he taught courses in the areas of mechanical design, mechatronics, and haptics. He received an NSF CAREER award in 2008 and has won Best Paper, Demo, and Poster Awards for his work on tactile feedback in 2009, 2011, and 2014. He is currently president and CEO of Tactical Haptics, which is focused on applying his prior tactile feedback research to create more immersive haptic feedback to virtual reality.