XR Needs "Mixed Feelings"

Engineering haptic devices that work in both virtual and physical realities

Haptic devices allow us to feel virtual worlds through touch and forces; yet they are incompatible with haptics present in our everyday life. This urges us to re-think how to engineer a wave of new haptic devices for extended reality.

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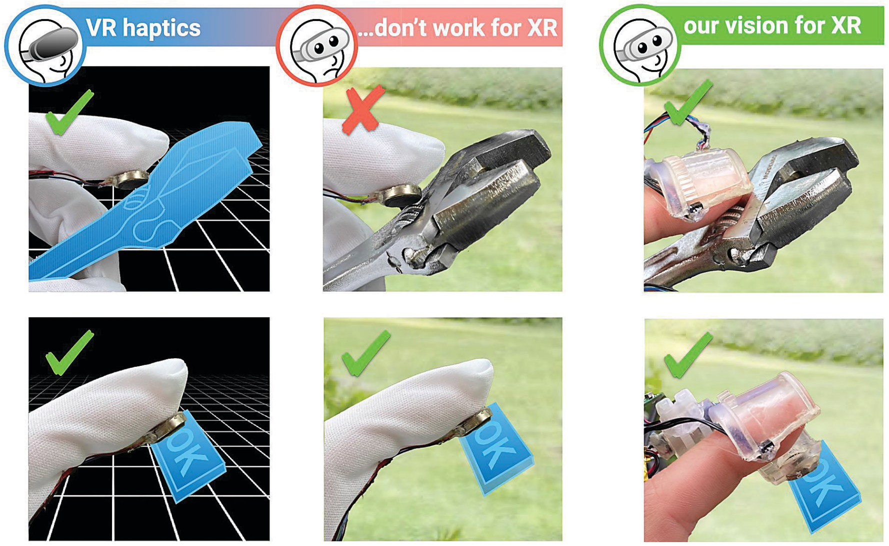
With advancements in haptic technologies, virtual reality (VR) headsets are starting to go far beyond just depicting realistic representations of what it looks like to be in another place. Today, VR headsets are increasingly coupled with haptic devices that can also represent how it feels like to interact in another place. These haptic devices allow VR users to experience "virtual feelings" that originate from the simulated environment, like touching a virtual object and feeling its weight [1], textures [2], temperature [3], or even impact [4]. To generate such realistic feedback onto various haptic receptors in our skin, haptic devices are typically engineered as gloves or suits—in other words, these devices are designed to wrap around our body as much as possible, which is what allows them to send haptic signals to our skin. For instance, vibration gloves [5] are very much like ordinary gloves, except they also have vibration motors in contact with the user's finger pads and palm. Therefore, a user wearing such gloves can touch a virtual object and feel the corresponding motor under their finger pad vibrate. The gloves wrap these motors around the user's skin to ensure that the motors stimulate the right locations.

However, our current approach (of wrapping the actuators directly around the user's skin) sets a hard boundary between VR and the rest of the world. If you have an actuator on top of your skin, you can feel "virtual sensations," but your skin cannot feel anything else, including sensations originating from the real world. In other words, a user wearing a vibration glove will need to take the gloves off to grab a pen, type on their phone, or to open the door of their house. The consequence of developing virtual reality haptics in this way is that it ends up isolating us from the richness of

Figure 1. (a) Traditional haptic gloves for VR cover the user's hands to provide a sense of touch when interacting with virtual objects (here, a virtual wrench or a virtual button). However, despite the fact this is a time-tested and common approach to haptics, it is not compatible with XR—in XR users also interact with physical objects besides virtual ones. (b) As such, adopting haptics for VR to XR experiences fails—for example, here, the haptic gloves block sensations from the physical wrench. We argue we need a paradigm shift in our way of thinking about haptics. (c) Our vision for XR haptics is that the haptic devices "respect" the physical objects by keeping user's fingerpads free to manipulate physical objects, and only cover up the fingerpads to stimulate the skin when the user touches the virtual button.



the real world—the feeling of touch in crafts, food, nature, and people, just to name a few.

For a long time, augmented reality or mixed reality (AR/MR) stood as a solution to this question as it enables us to "augment" or "mix" our real world with virtual overlays. With advanced tracking and see-through optical displays, users can experience virtual content projected on top of their surroundings. These virtual overlays have become very realistic, seeming as if they were part of the physical world. Much like in VR, researchers, industry, and consumers also feel the need to add haptics to the virtual content projected in extended reality (XR) a term that encompasses all variations of this interactive concept such as VR, AR, or MR.

But here lies a paradox: A haptic device for mixed reality needs to render the physicality of virtual content while respecting the user's physical reality. Imagine wearing our aforementioned vibration glove while interacting with a user interface (UI) in mixed reality, this UI floats in mid-air and allows you to interact with a real-time data plot. The vibration gloves will prove extremely useful in interacting with this virtual UI. Every time you touch a slider to configure the plot, you can feel that you touched it, which speeds up your interaction and makes it feel more familiar. This is similar to how typing on a physical keyboard is faster than a mid-air keyboard with no haptic feedback. Remember however that you are in mixed reality, not in a fully simulated virtual world. As such, your next interaction might not be virtual, instead, you might reach out to shake hands with a colleague or grab a pen to take notes. Unfortunately, the first thing you need to do is to remove your vibration gloves. The gloves were useful for interacting with the virtual UI but they are preventing you from the sensations innate to the physical world. Here lies our conundrum. We moved away from VR to MR to promote a mixed reality that did not prioritize the virtual over the real, but the addition of haptics on top of MR, pushed us back into prioritizing the virtual.

Spinning up a new wave of haptic devices that integrate well with our lives will enable us to operate in a richer, more stimulating, and more efficient interface reality.

Currently, our research field and the future of XR consumer products stand at a crossroads: Where we enjoy realistic haptic feedback in VR but stay isolated from the rest of the physical world; or, one where we stay in the physical world augmented with XR interfaces that, sadly, provide no physical sensations. We ask ourselves and our research community—is there a better vision for XR where we can enjoy both realistic virtual touch and the richness of the real world without having to decide between incompatible technologies? Can we have "mixed feelings" in XR?

To this end, we have been rethinking how to integrate haptics into our lives. We realized haptic fidelity is not the only goal to optimize for. In fact, if we understand how people live their lives, use their body, perceive, and situate themselves in diverse environments, we can design a new generation of haptic devices that can support and enrich lives accordingly.

Our first approach to tackle this proposition was Touch&Fold, a new type of haptic device that allows users to feel haptics as they interact with mixed reality user interfaces, but also leaves the user's finger pads free to interact with physical tools and objects. Touch&Fold is unlike typical vibration gloves and other haptic devices; it does not cover the user's skin when the user needs their skin to manipulate a tool, for example, to use a screwdriver. Instead, Touch&Fold leaves the user's finger pads free by default and only covers them with haptic actuators on demand, in other words, when the user touches a virtual interface. When this happens, our device unfolds from the user's fingernail to the finger pad and contacts the finger pad, creating the sense of virtual touch and textures with variable pressure and vibration. Once the fingers let go of the virtual interface, the device folds away, collapsing back onto the nail. Now the user can touch and manipulate other physical objects with their naturally bare hands. As shown in Figure 2, the user can feel the texture of a virtual tire when fixing their bike and can feel the real tire too. Using Touch&Fold, users can switch from a physical piano to a virtual piano (providing them infinite keys) seamlessly. In our user studies [6], participants wearing the devices could skillfully manipulate screws and perceive fine textures, while still feeling haptics anytime they touched virtual UIs in mixed reality.

Touch&Fold is an example of a step toward our larger vision for the future of wearable haptic devices. First, it marks a departure from our previous model of haptic actuators in the form of gloves or suits that wrap around the user's body. Instead, it is a haptic actuator that is only active when needed and tucks away when not. Second, it demonstrates a road map for a new generation of haptic devices that: (1) ensure the palmar side of the hands, with which we often interact with objects, are left undisturbed, thus allowing the hand to perform a wide range of essential manual activities that few of us would be willing to do without; (2) are designed mindfully of their shapes, sizes, mechanisms to minimize interference with the user's body; and (3) are designed for real environments—taking haptics outside of labs and VR, including the outdoors.

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Luckily, we do not feel intellectually lonely in this quest, in recent years of haptic research other approaches have resonated constructively with our vision. These include an on-demand actuator for the palm [7], relocated haptic feedback to another part of body [8], or using thin actuators [9]. We believe if this vision is successful, it will have substantial commercial and societal impact. Spinning up a new wave of haptic devices that integrate well with our lives will enable us to operate in a richer, more stimulating, and more efficient interface reality, in which we do not need to choose between being isolated in super-realistic VR or stuck in unrealistic XR. Instead we can enjoy haptics wherever we are.

Figure 2. An example scenario where bicycle repair instructions are provided via mixed reality.

When the user touches the virtual tire, a cover slides down from our nail device and pushes against their fingerpad to create contact and pressure with the virtual object. (a) This allows the user to, for instance, feel the roughness of the virtual bike tire. (b) Then, when the user turns to interact with real objects, the cover folds back, leaving their fingerpads free to feel the texture of their real tire or operate physical tools.

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Biographies

Shan-Yuan Teng is a Ph.D. student in computer science at the University of Chicago advised by Prof. Pedro Lopes. Teng's research aims at advancing a new generation of haptic devices that exhibit properties we have come to expect from our mobile phones and wearables, such as extreme mobility and always-on availability. One instance of this is Touch&Fold, a custom-engineered device that allows users to feel touch in mixed reality without encumbering their finger pads. This work was published at ACM CHI and nominated for the Best Paper Award. His works have been demonstrated at ACM CHI, UIST, and SIGGRAPH Emerging Technologies.

Pedro Lopes is an assistant professor in computer science at the University of Chicago. Lopes focuses on integrating computer interfaces with the human body. Some of these new integrated devices include a muscle stimulation wearable that allows users to manipulate tools they have never seen before or that accelerate their reaction time and a device that leverages the sense of smell to create the illusion of temperature. His work has received a number of academic awards, such as four ACM CHI/UIST Best Paper Awards, the Sloan Fellowship, and the NSF CAREER Award. His research also captured the interest of the public and media, was covered by the *New York Times*, and was exhibited at the Ars Electronica & World Economic Forum.

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