# Demonstrating Touch&Fold: A Foldable Haptic Actuator for Rendering Touch in Mixed Reality


Shan-Yuan Teng
University of Chicago, USA
tengshanyuan@uchicago.edu

Pengyu Li
University of Chicago, USA
pengyulee@uchicago.edu

Romain Nith
University of Chicago, USA
rnith@uchicago.edu

Joshua Fonseca
University of Chicago, USA
fonseca@uchicago.edu

Pedro Lopes
University of Chicago, USA
pedrolopes@cs.uchicago.edu



**Figure 1: We engineered a *foldable* haptic device worn on the user's fingernail that renders touch in mixed reality (MR) without preventing users from *also* touching real objects. Here, a user follows MR instructions to repair their bicycle. (a) When the user touches the virtual tire, a cover slides down from our nail-device and pushes against their fingerpad to create the *contact & pressure* with this virtual object. To further increase realism, the cover also includes a linear resonant actuator that renders virtual textures using vibrations. This allows, for instance, to feel the roughness of the virtual mountain tire. Then, (b) 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.**


## ABSTRACT

We propose a nail-mounted *foldable* haptic device that provides tactile feedback to mixed reality (MR) environments by pressing against the user's fingerpad when a user touches a virtual object. What is novel in our device is that it quickly tucks away when the user interacts with real-world objects. Its design allows it to fold back on top of the user's nail when not in use, keeping the user's fingerpad free to, for instance, manipulate handheld tools and other objects while in MR. To achieve this, we engineered a wireless and self-contained haptic device, which measures 24×24×41 mm and weighs 9.5 g. Furthermore, our foldable end-effector also features a linear resonant actuator, allowing it to render not only touch contacts (i.e., pressure) but also textures (i.e., vibrations). We demonstrate how our device renders contacts with MR surfaces, buttons, low- and high-frequency textures.



**ACM Reference Format:**
Shan-Yuan Teng, Pengyu Li, Romain Nith, Joshua Fonseca, and Pedro Lopes. 2021. Demonstrating Touch&Fold: A Foldable Haptic Actuator for Rendering Touch in Mixed Reality. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Emerging Technologies (SIGGRAPH '21 Emerging Technologies), August 09–13, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3450550.3465340


## 1 INTRODUCTION

Mixed Reality (MR) allows overlaying digital content with our real-world surroundings, creating powerful new tools. Many argue that the next challenge of mixed reality is the addition of haptics. Over the last decades, an impressive number of haptic devices have allowed users to feel the forces (e.g., exoskeleton gloves [Choi and Follmer, 2016]) and contacts from interacting with virtual objects (e.g., vibration on the fingerpads [Kim et al., 2016]). However, researchers argue that haptics for MR are inherently different from haptics for virtual reality (VR), as they must leave the user's hands free so that the user can also interact with real objects [Lopes et al., 2018, Withana et al., 2018]. Recently, researchers proposed unencumbered force-feedback in MR by using electrical muscle


Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.


*SIGGRAPH '21 Emerging Technologies, August 09–13, 2021, Virtual Event, USA*


© 2021 Copyright held by the owner/author(s). Publication rights licensed to ACM.


ACM ISBN 978-1-4503-8364-6/21/08…$15.00
https://doi.org/10.1145/3450550.3465340

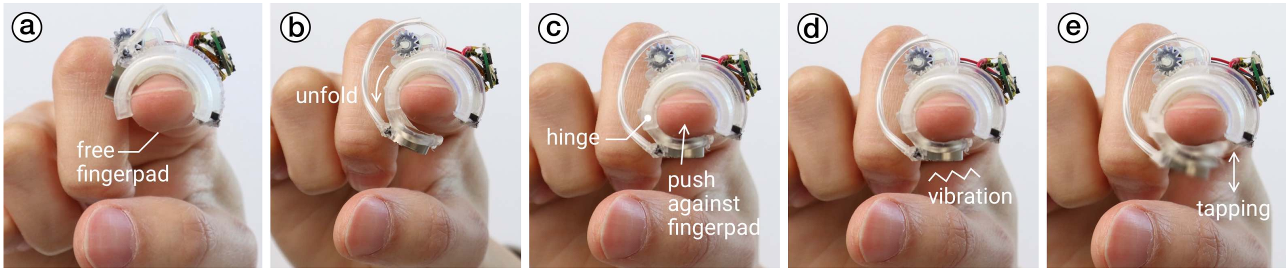


**Figure 2: (a) When not in use our device keeps the fingerpad free for feeling the haptics of real-world objects. When activated, it unfolds (b) via a rack and pinion, and (c) a hinge redirects the force against the user's fingerpad, which allows it to create three types of haptic effects: contact (pressure of the cover), (d) high-frequency textures (using an LRA embedded in its cover), and (e) low-frequency textures (by rocking the cover back and forth).**

stimulation instead of the traditional exoskeletons [Lopes et al., 2018]. However, this only provides the sense of pushing against an object and does not stimulate the sense of touching an object. As of now, there is no device that provides users with a sense of contact at the fingerpad in MR without covering up their fingerpads. Existing approaches involve applying actuators on the fingerpads, such as thin electrodes [Kajimoto, 2012, Withana et al., 2018] or soft actuators [Han et al., 2018]. While some of these are also driven by the goal of minimal interference with the user's tactile sensation, adding these thin patches decreases one's ability to perform discriminate textured surfaces because these patches impair the tactile acuity of our fingerpads [Nittala et al., 2019]. When it comes to rendering touch in MR without covering up the fingerpads, the most promising solution remains placing a vibration motor on the user's fingernail [Ando et al., 2007]. While this leaves the fingerpad free, it has two main disadvantages: it does not create pressure, and its feedback is unrealistic, as it occurs on the fingernail rather than on the fingerpad.

We tackle this challenge by engineering a foldable haptic device that provides virtual objects with haptic feedback by pressing against the user's fingerpad, yet, quickly tucking away when the user grasps real objects. Our device, depicted in Figure 1, works by unfolding a cover that wraps around and presses against the user's fingerpad. The key to its compact form factor is that the unfolding cover can be retracted and stored on top of the fingernail via a motor-driven rail. Furthermore, besides rendering the sense of touch, it also renders textures by means of a linear resonant actuator (LRA) embedded in its cover, as depicted in Figure 2

Besides being a one-of-a-kind device for MR haptics, it is also completely *untethered* and *self-contained,* a feature not seen in any existing haptic device of this kind. In its small footprint (24×24×41 mm and 9.5 g), it includes actuators, electronics, battery, and wireless communication through Bluetooth. We demonstrate how our device renders haptic sensations such as taps, button presses, and low- or high- frequency textures.

## 2 IMPLEMENTATION

Figure 3 depicts our self-contained prototype[1], which was 3D printed using a Form Labs 3 with clear resin to minimize visual interference with the real world. It attaches to the user's fingernail using double-sided tape.

At the core of our contribution is our folding mechanism, depicted in Figure 4. Its key design feature is a hemispheric rail from which our "cover" unfolds. The cover is comprised of two segments connected via a thin plastic sheet. To fold or unfold, we actuate the cover using a rack and pinion drive. Figure 4a depicts the initial configuration, in which the cover's front segment stays in the case. Figure 4b depicts the cover's front segment is pushed as it is driven by the pinion to the point where the front segment is fully extended and hits a hinge stopper at the end of the rail. Figure 4c depicts the last stage in which a wedge in the cover pushes and causes the front segment to pivot around the hinge and land flush against the fingerpad. The shape of our casing, cover and its hemispherical rail are all conical in order to ergonomically follow the finger's shape, allowing the cover to fully contact with the fingerpad.

Our device unfolds using a DC motor (26:1 Sub-Micro Planetary Gearmotor 0.1 kg-cm, Pololu) mounted on our 3D printed rail drive (rack with 26 teeth and pinion with 12 teeth). We embedded a linear resonant actuator (LRA C10-100, Precision Micro Drives) in the cover that touches the user's finger, allowing our device to render a wider range of textures (between 150-190 Hz). The force sensor (FSR 400, Interlink Electronics) attached inside the cover serves as a feedback signal for fine-tuning the amount of pressure applied on the fingerpad. Finally, a photo interrupter (SG-105F, Kodenshi) is used to sense whenever the cover is fully retracted, which serves as the signal to stop actuating our DC motor. Our 16.8x10.3 mm PCB houses at its core a microcontroller with Bluetooth Low Energy (nRF52811, Nordic Semiconductor) with a ceramic chip antenna (W3008C, Pulse Larsen). We power our device using a 40 mAh LiPo battery. We measured a current of 200 mA when it unfolds, which takes 184 ms per interaction. As such, our device can be used for 12 min of continuous tactile feedback. It is worth noting that in typical interactions with MR interfaces one just expects to feel a few hundred milliseconds of contact (e.g., tapping a button), thus our device's battery tends to last for many hours of on-demand use. To display the graphics to the user, we used a HoloLens 2. Built-in depth cameras on the headset are used to track their hands. To trigger our device when the user touches an MR object, we expand the finger's collision box in Unity3D to the radius of our device, which further compensates for its aforementioned latency.

[1]More details can be found in our paper [Teng et al., 2021]. We also provide all the source code, firmware and schematics at http://lab.plopes.org/#touchfold

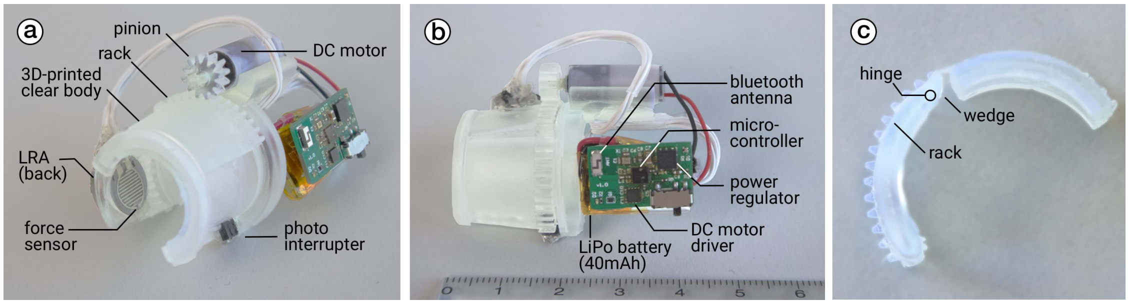


**Figure 3: (a) Our self-contained haptic device; (b) detail of its cover; (c) top view of our device with ruler unit in cm.**

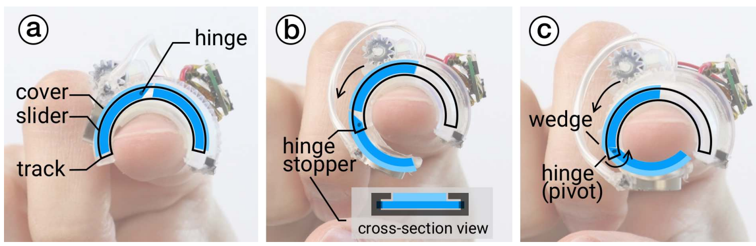


**Figure 4: The key to our mechanism's unfolding is that (a) its cover is comprised of two segments; (b) our hinge is based on two detents that create a stopper and (c) force the cover to pivot and be pushed by the wedge against the fingerpad.**

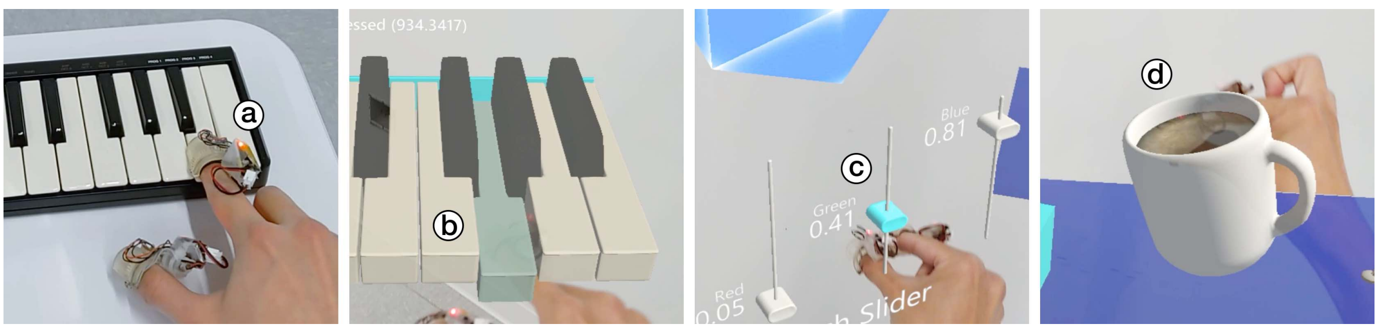


**Figure 5: Adding contact haptic feedback to GUI widgets in existing Microsoft HoloLens Mixed Reality Toolkit (MRTK) while preserving the ability to feel physical objects: (a) pressing a physical piano key (b) pressing a virtual piano key (c) pinching a slider, (d) grabbing objects, a coffee mug in this case.**

## 3 DEMONSTRATING FOLDABLE ACTUATORS

We demonstrate our foldable actuators by integrating with an existing MR toolkits (HoloLens MRTK [Microsoft, 2020]). We add the missing haptics to MR widgets (buttons, sliders, etc.), while preserving the haptic feedback from physical objects when the user interacts with them. As depicted in Figure 5, the user presses the key on a physical piano keyboard with their bare fingerpad (Figure 5a); yet when the user presses the key on a virtual piano, our device unfolds and renders touch contact haptic feedback (Figure 5b). Furthermore, by wearing two of our devices, we also render contact haptic feedback for pinching (Figure 5c) or grabbing virtual objects (Figure 5d). Coarse and fine textures of the virtual object can be simulated as well.

## REFERENCES

Hideyuki Ando, Eisuke Kusachi, and Junji Watanabe. 2007. Nail-mounted Tactile Display for Boundary/Texture Augmentation. In Proceedings of the International Conference on Advances in Computer Entertainment Technology (ACE '07), 292–293. https://doi.org/10.1145/1255047.1255131

Inrak Choi and Sean Follmer. 2016. Wolverine: A Wearable Haptic Interface for Grasping in VR. In Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16 Adjunct), 117–119. https://doi.org/10.1145/2984751.2985725

Teng Han, Fraser Anderson, Pourang Irani, and Tovi Grossman. 2018. HydroRing: Supporting Mixed Reality Haptics Using Liquid Flow. In Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18), 913–925. https://doi.org/10.1145/3242587.3242667

Hiroyuki Kajimoto. 2012. Electrotactile Display with Real-Time Impedance Feedback Using Pulse Width Modulation. IEEE Transactions on Haptics 5, 2: 184–188. https://doi.org/10.1109/TOH.2011.39

Hwan Kim, Minhwan Kim, and Woohun Lee. 2016. HapThimble: A Wearable Haptic Device Towards Usable Virtual Touch Screen. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 3694–3705. https://doi.org/10.1145/2858036.2858196

Pedro Lopes, Sijing You, Alexandra Ion, and Patrick Baudisch. 2018. Adding Force

Feedback to Mixed Reality Experiences and Games Using Electrical Muscle Stimulation. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18), 446:1-446:13. https://doi.org/10.1145/3173574.3174020

Aditya Shekhar Nittala, Klaus Kruttwig, Jaeyeon Lee, Roland Bennewitz, Eduard Arzt, and Jürgen Steimle. 2019. Like A Second Skin: Understanding How Epidermal Devices Affect Human Tactile Perception. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19), 380:1-380:16. https://doi.org/10.1145/3290605.3300610

Shan-Yuan Teng, Pengyu Li, Romain Nith, Jersey Fonseca, and Pedro Lopes. 2021. Touch&Fold: A Foldable Haptic Actuator for Rendering Touch in Mixed Reality. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21). https://doi.org/10.1145/3411764.3445099

Anusha Withana, Daniel Groeger, and Jürgen Steimle. 2018. Tacttoo: A Thin and Feel-Through Tattoo for On-Skin Tactile Output. In Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18), 365–378. https://doi.org/10.1145/3242587.3242645

Microsoft. 2020. Hand interaction examples scene | Mixed Reality Toolkit Documentation. Retrieved September 16, 2020 from https://microsoft.github.io/MixedRealityToolkit-Unity/Documentation/README_HandInteractionExamples.html