# A Wrist-worn Device for Pneumatic Haptic Proxies - Touching Virtual Objects

FRANK WENCHENG LIU* and MASON MANETTA*, Arizona State University, United States
GIDEON KAMAU, Arizona State University, United States
ANDREW OLSON, Arizona State University, United States
AUSTIN JELTES, Arizona State University, United States
JACK HAEHL, Arizona State University, United States
BYRON LAHEY, Arizona State University, United States
ROBERT LIKAMWA, Arizona State University, United States

Touch plays an important role in increasing immersion in virtual reality experiences. We imagine a device that can provide a variety of physical interactions with shapes, textures, and other haptic affordances in a way that is modularly extendable. A multipurpose device like this works towards a sustainable design and use ecosystem. We envision a wrist-worn device with multiple actuated pneumatic haptic proxies that opens up new opportunities of haptic explorations. We present work which allows users to feel virtual objects of varying shapes and textures. The users will also be able to physically feel interactions with these virtual objects when picked up or thrown.

CCS Concepts: • **Hardware** → *Haptic devices*; • **Human-centered computing** → *Virtual reality*.

Additional Key Words and Phrases: HCI, haptics, pneumatics, virtual reality

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## 1 INTRODUCTION

When considering sustainable haptic design, a major challenge is to provide not just one type of physical interaction, but a variety of physical interactions with different shapes, textures, and other haptic affordances. Moreover, our haptic systems ought to be able to modularly extend to support a wide range of emerging haptic interactions. There have been examples of single functionality haptic devices that target shape change [22], texture change [24] and actuation of passive proxies [14]. While these devices are an individual haptic display mode, we are not aware of a device which addresses all three of these functionalities simultaneously. We envision a single device that incorporates all three - providing access to multiple haptic proxies, shape change for the haptic proxies and dynamic forces on the hand when interacting with these physical proxies.

Our device lets developers use one device to curate a large selection of experiences and sensations for a smooth continuous experience, instead of depending on a multitude of single functionality haptic devices. This allows our

*Both authors contributed equally to this research.


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device to create a sustainable design and use ecosystem. How might a device like this one foster haptic development in both industry and academia? What new experiences and stories could be told with this additional level of immersion? In this paper, we showcase our prototype system. We share how our device might open up new opportunities for haptic development, and highlight steps forward to further study our system.

## 2 RELATED WORKS

### 2.1 Passive Haptics

Many works have explored implementations of passive haptic props to improve immersion. iTurk utilizes a prop tethered from the ceiling and utilized tracking to enable users to interact with non-actuated haptic objects in real time [6]. Haptic-go-round introduces a motorized turntable that rotates the correct haptic device to the right direction at the right time to match what users are about to touch [13]. Stair proxies were found to emulate a staircase experience where users feel the illusion of walking up and down stairs [16]. Other works which use moving passive haptic proxies include RoomShift [21], TouchMover [20], and Snake Charmer [2]. Additionally, haptic retargeting can manipulate a user's sense of vision to reduce the spatial mismatches [4] [7].

### 2.2 Pneumatics in HCI

Pneumatic shape changing proxies have great potential in virtual reality use cases. PneUI investigated using pneumatic inflatables as shape changing proxies, where the shapes changed due to variation in pneumatic pressure [25]. PuPoP expanded upon this idea by attaching the shape changing inflatables directly to the user's hand [22]. This allows the object to be deflated out of reach and then inflated on command when the user interacts with a virtual object [22]. Pneu-Multi-Tools introduces an auto-folding interface to expand the shapes possible using inflatable airbags [12]. HaPouch introduces phase change of a volatile liquid to inflate pouches on the fingertips [23].

### 2.3 Wrist-worn and Handheld Haptic Devices

In the field of haptic devices, there are several examples of wrist-worn devices. There have been a variety of wrist-worn devices which provide thermal [5] [17] and vibrotactile [3] sensations on the wrist. There have also been devices which deliver squeeze sensations [18]. Pneufetch uses a wristband with three pneumatically actuated nodes to create different haptic cues[11]. HapWRAP is a pneumatic inflatable device that has tubes which wrap around the wrist that inflate and deflate to provide users with natural cues on their skin [1].

There have also been several handheld haptic devices which can simulate the sensation of grabbing and texture change. Some works such as Grabity [10] and Wolverine [8] use braking mechanisms for grasping that involve mostly the full hand. Other works such as CLAW [9] and CapstanCrunch [19] focus on braking mechanisms for the index and thumb for grasping. These works are not able to render the dynamic forces of objects entering and leaving your hand. Haptic Pivot [14] solves dynamic forces of objects by pivoting a generic haptic proxy into the user's hand with an actuated arm. Torc [15] and Haptic Revolver [24] are devices which provide the feeling of changing textures for the fingertips.

## 3 DESIGN SECTION

We focused on the following design objectives when considering sustainable haptic design and developing a multitool for haptic interaction:

*Interactivity.* Our device should be able to render force feedback for acquiring, grasping, and releasing virtual objects. Our device should also actuate shape change through inflation/deflation for these shaped-proxies. When the user's hand moves towards a virtual object, the shaped-proxy should synchronously move into the user's hand. These shaped-proxies should be out of hand when unneeded.

*Adaptability.* Our device should provide haptic sensations for a variety of differently shaped virtual objects in virtual reality scenes. Multiple shaped-proxies should be readily available to enter the user's hands. Additionally, these shaped-proxies should be able to be easily swapped to fit the use case of different VR scenes.

*Wearability.* Our device should be light-weight and comfortable. Our device should be able to deliver the physical shaped-proxies comfortably into the user's hand when needed.

Our prototype is an ungrounded, untethered wrist-worn device that is able to present up to three inflatable proxy shapes (currently shown are sphere, cube, and rod). These inflatable shaped-proxies can be swapped and modified based on the use case and are connected to two pneumatic motors which provide the inflation and deflation. The shaped-proxies are connected to three servo actuated arms. These arms can pivot the three inflatables into and out of the user's grasping field, rendering dynamic forces and preventing accidental grasps.

Our system interfaces with the Unity game engine and Oculus Quest. When the user's hand is within a certain distance relative to the virtual object, the corresponding physical shaped-proxy begins to inflate/deflate and the object goes into/out of the user's hand by pivot movement of the arms. The Unity application sends commands to the microcontroller (ESP32) through the REST API Server, and the microcontroller generates the hardware signals for the pneumatic motors and servo motors.

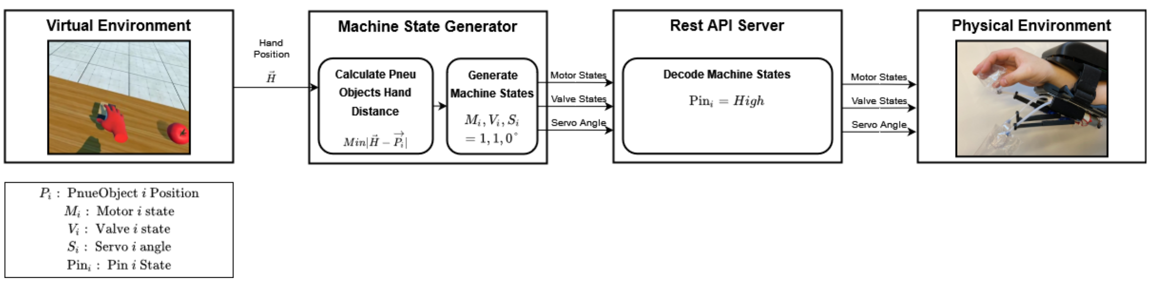


Fig. 1. High Level System Diagram

## 4 PLANNED EVALUATION

From a system perspective, we want to evaluate how well we can make the shaped-inflatables readily available and physically available when the user reaches out to grab the corresponding virtual object. We break down our system evaluation into inflation/deflation times of the shaped-proxies, speed and force of servo arm actuation, the latency from the virtual object grabbing to when the haptic proxy actuates into the user's hand.

From a human-centered interaction perspective, we plan to explore how our system impacts users' experience in VR and examine how they interact with the virtual objects via physical shaped-proxies. We want to 1) study how multiple inflatable shaped-proxies can enhance the virtual experience when performing advanced tasks that require multiple virtual objects; 2) explore how stiffness of the object impacts the immersion and believability of the haptic proxy; 3) evaluate the perception of dynamic forces on the user's hand.

## 5 FUTURE WORK

The ability to physically feel virtual objects offers a range of new research and training opportunities. We envision the future of touch in the metaverse through networked haptics - users could throw a virtual object to another user in an entirely different country, and both users could feel the forces of throwing and catching a physical object. We envision the future of touch in the metaverse to feel real - virtual objects and physical shaped-proxies interactions are 1:1 mapped and modifications to the inflatable shaped-proxies could provide varying textures. We envision the future of touch in the metaverse for proxies to feel dynamic - alternating inflation and deflation of the proxies could mimic for example the breathing of a live animal or the changing ripeness of a fruit.

Our device can bring an added dimension of richness and interactivity into VR content. For example, an experienced gardener could teach a student on the other side of the world how to grow tomato plants using our device in VR. The gardener could hand the student different virtual garden tools (mapped to different shaped-proxies) to work the garden. The student would gain muscle memory working with these tools in VR. Once the tomato plant bore fruit (mapped to one shaped-proxy), the student would be able to pick it from the plant. The device's servo arms could provide the resistance in pulling the virtual fruit from the virtual branch. The ripeness of the fruit could be conveyed through the shaped-proxy's stiffness.

We recognize the physical fabrication of the inflatable structures as a fundamental challenge for the widespread adoption of this haptic technology and see this as an opportunity to tap into commercial manufacturing and product resources rather than reinventing processes that likely already exist.

Looking forward, we envision our prototype system to provide a platform for continued development in haptic experiences allowing us to touch the virtual world.

## 6 CONCLUSION

Touch plays an important role in increasing our immersion and practical capabilities in virtual experiences. We tackle the challenge of providing a variety of physical interactions with shapes, textures, and dynamic forces that are modularly extendable. Our system combines interactivity of physical haptic proxies, the adaptability of multiple readily available proxies, and a wearability of a wrist-worn form factor. Developers can use our device to curate a large selection of haptic sensations and experiences in virtual and mixed reality applications. We hope this system can democratize the development of haptic experiences and make such explorations accessible to the community at large.

## REFERENCES


[1] Nathaniel Agharese, Tyler Cloyd, Laura H. Blumenschein, Michael Raitor, Elliot W. Hawkes, Heather Culbertson, and Allison M. Okamura. 2018. HapWRAP: Soft Growing Wearable Haptic Device. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*. 5466–5472. https://doi.org/10.1109/ICRA.2018.8460891

[2] Bruno Araujo, Ricardo Jota, Varun Perumal, Jia Xian Yao, Karan Singh, and Daniel Wigdor. 2016. Snake Charmer: Physically Enabling Virtual Objects. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction* (Eindhoven, Netherlands) *(TEI '16)*. Association for Computing Machinery, New York, NY, USA, 218–226. https://doi.org/10.1145/2839462.2839484

[3] Ruben Azevedo, Nell Bennett, Andreas Bilicki, Jack Hooper, Fotini Markopoulou, and Manos Tsakiris. 2017. The calming effect of a new wearable device during the anticipation of public speech. *Scientific Reports* 7 (05 2017). https://doi.org/10.1038/s41598-017-02274-2

[4] Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson. 2016. Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1968–1979. https://doi.org/10.1145/2858036.2858226

[5] F. Bolton, Shahram Jalaliniya, and Thomas Pederson. 2015. A Wrist-Worn Thermohaptic Device for Graceful Interruption. *Interaction Design and Architecture(s)* 26 (10 2015), 39–54.

[6] Lung-Pan Cheng, Li Chang, Sebastian Marwecki, and Patrick Baudisch. 2018. *ITurk: Turning Passive Haptics into Active Haptics by Making Users Reconfigure Props in Virtual Reality*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3173574.3173663

[7] Lung-Pan Cheng, Eyal Ofek, Christian Holz, Hrvoje Benko, and Andrew D. Wilson. 2017. Sparse Haptic Proxy: Touch Feedback in Virtual Environments Using a General Passive Prop. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 3718–3728. https://doi.org/10.1145/3025453.3025753

[8] Inrak Choi, Elliot W. Hawkes, David L. Christensen, Christopher J. Ploch, and Sean Follmer. 2016. Wolverine: A wearable haptic interface for grasping in virtual reality. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 986–993. https://doi.org/10.1109/IROS.2016.7759169

[9] Inrak Choi, Eyal Ofek, Hrvoje Benko, Mike Sinclair, and Christian Holz. 2018. *CLAW: A Multifunctional Handheld Haptic Controller for Grasping, Touching, and Triggering in Virtual Reality*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3174228

[10] Eisuke Fujinawa, Shigeo Yoshida, Yuki Koyama, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2017. Computational Design of Hand-Held VR Controllers Using Haptic Shape Illusion. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (Gothenburg, Sweden) *(VRST '17)*. Association for Computing Machinery, New York, NY, USA, Article 28, 10 pages. https://doi.org/10.1145/3139131.3139160

[11] Liang He, Ruolin Wang, and Xuhai Xu. 2020. PneuFetch: Supporting Blind and Visually Impaired People to Fetch Nearby Objects via Light Haptic Cues. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3334480.3383095

[12] Sheng-Pei Hu and June-Hao Hou. 2019. Pneu-Multi-Tools: Auto-Folding and Multi-Shapes Interface by Pneumatics in Virtual Reality. In *The Adjunct Publication of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 36–38. https://doi.org/10.1145/3332167.3357107

[13] Hsin-Yu Huang, Chih-Wei Ning, Po-Yao Wang, Jen-Hao Cheng, and Lung-Pan Cheng. 2020. *Haptic-Go-Round: A Surrounding Platform for Encounter-Type Haptics in Virtual Reality Experiences*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3313831.3376476

[14] Robert Kovacs, Eyal Ofek, Mar Gonzalez Franco, Alexa Fay Siu, Sebastian Marwecki, Christian Holz, and Mike Sinclair. 2020. *Haptic PIVOT: On-Demand Handhelds in VR*. Association for Computing Machinery, New York, NY, USA, 1046–1059. https://doi.org/10.1145/3379337.3415854

[15] Jaeyeon Lee, Mike Sinclair, Mar Gonzalez Franco, Eyal Ofek, and Christian Holz. 2019. TORC: A virtual reality controller for in-hand high-dexterity finger interaction. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)*. ACM. https://www.microsoft.com/en-us/research/publication/torc-a-virtual-reality-controller-for-in-hand-high-dexterity-finger-interaction-3/

[16] Ryohei Nagao, Keigo Matsumoto, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. 2018. Ascending and Descending in Virtual Reality: Simple and Safe System Using Passive Haptics. *IEEE Transactions on Visualization and Computer Graphics* 24, 4 (2018), 1584–1593. https://doi.org/10.1109/TVCG.2018.2793038

[17] Roshan Lalitha Peiris, Yuan-Ling Feng, Liwei Chan, and Kouta Minamizawa. 2019. *ThermalBracelet: Exploring Thermal Haptic Feedback Around the Wrist*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3290605.3300400

[18] Evan Pezent, Ali Israr, Majed Samad, Shea Robinson, Priyanshu Agarwal, Hrvoje Benko, and Nick Colonnese. 2019. Tasbi: Multisensory Squeeze and Vibrotactile Wrist Haptics for Augmented and Virtual Reality. In *2019 IEEE World Haptics Conference (WHC)*. 1–6. https://doi.org/10.1109/WHC.2019.8816098

[19] Mike Sinclair, Eyal Ofek, Mar Gonzalez-Franco, and Christian Holz. 2019. CapstanCrunch: A Haptic VR Controller with User-Supplied Force Feedback. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 815–829. https://doi.org/10.1145/3332165.3347891

[20] Mike Sinclair, Michel Pahud, and Hrvoje Benko. 2013. TouchMover: Actuated 3D Touchscreen with Haptic Feedback. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces* (St. Andrews, Scotland, United Kingdom) *(ITS '13)*. Association for Computing Machinery, New York, NY, USA, 287–296. https://doi.org/10.1145/2512349.2512805

[21] Ryo Suzuki, Hooman Hedayati, Clement Zheng, James L. Bohn, Daniel Szafir, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2020. *RoomShift: Room-Scale Dynamic Haptics for VR with Furniture-Moving Swarm Robots*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3313831.3376523

[22] Shan-Yuan Teng, Tzu-Sheng Kuo, Chi Wang, Chi-huan Chiang, Da-Yuan Huang, Liwei Chan, and Bing-Yu Chen. 2018. PuPoP: Pop-up Prop on Palm for Virtual Reality. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) *(UIST '18)*. Association for Computing Machinery, New York, NY, USA, 5–17. https://doi.org/10.1145/3242587.3242628

[23] Ryusei Uramune, Hiroki Ishizuka, Takefumi Hiraki, Yoshihiro Kawahara, Sei Ikeda, and Osamu Oshiro. 2022. HaPouch: A Miniaturized, Soft, and Wearable Haptic Display Device Using a Liquid-to-gas Phase Change Actuator. *IEEE Access* (2022), 1–1. https://doi.org/10.1109/ACCESS.2022.3141385

[24] Eric Whitmire, Hrvoje Benko, Christian Holz, Eyal Ofek, and Mike Sinclair. 2018. *Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173660

[25] Lining Yao, Ryuma Niiyama, Jifei Ou, Sean Follmer, Clark Della Silva, and Hiroshi Ishii. 2013. PneUI: Pneumatically Actuated Soft Composite Materials for Shape Changing Interfaces. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology* (St. Andrews, Scotland, United Kingdom) *(UIST '13)*. Association for Computing Machinery, New York, NY, USA, 13–22. https://doi.org/10.1145/2501988.2502037