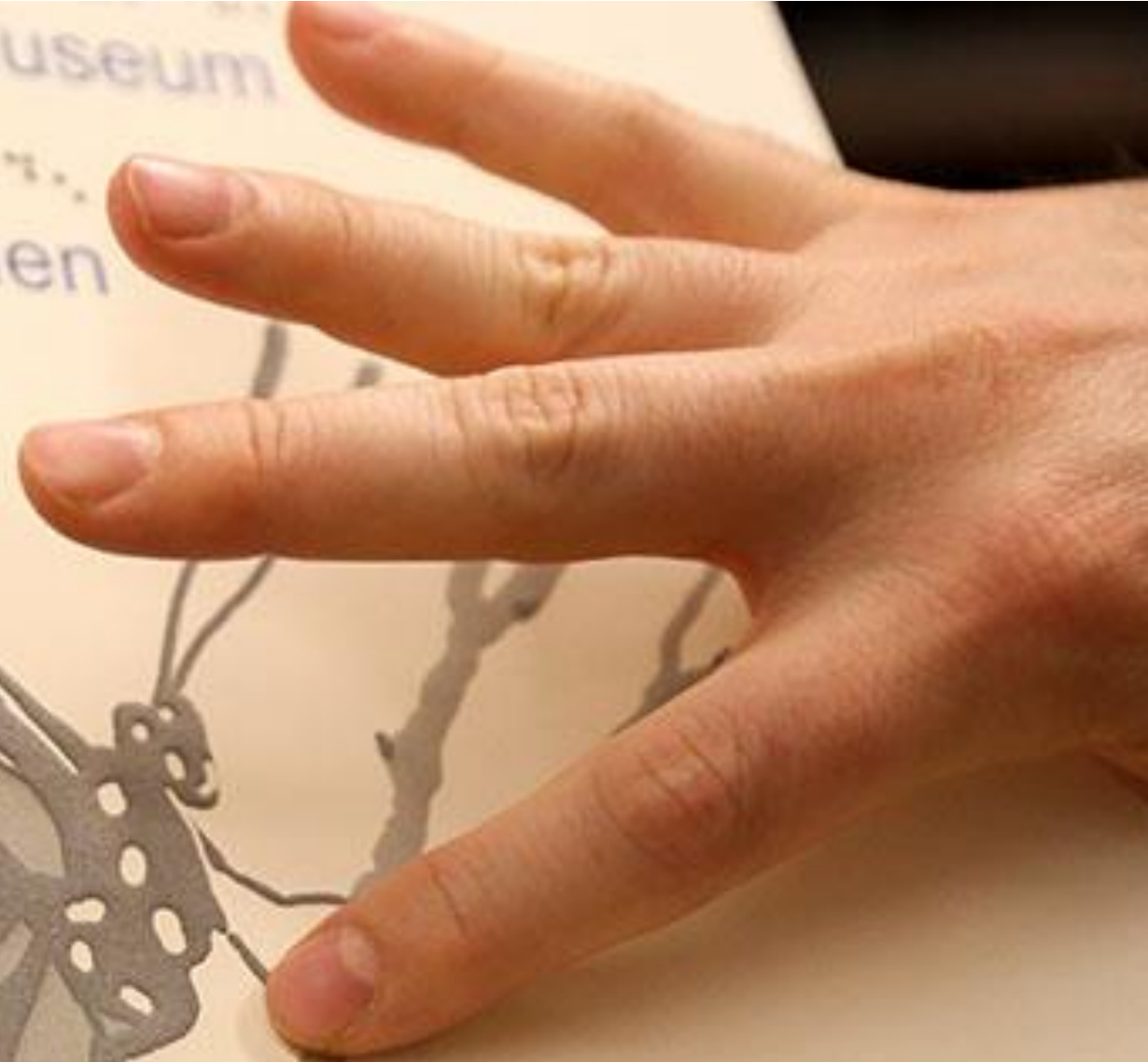


Public Museum  
Butterfly Garden



# Recap

- Haptic concept
- Types of haptic
- Tactile feedback and  
Mechanoreception
- Examples of tactile devices



# Haptics for VR

CMSC730 | Huaishu Peng | Spring 2026



Small taste of VR  
Haptics Research



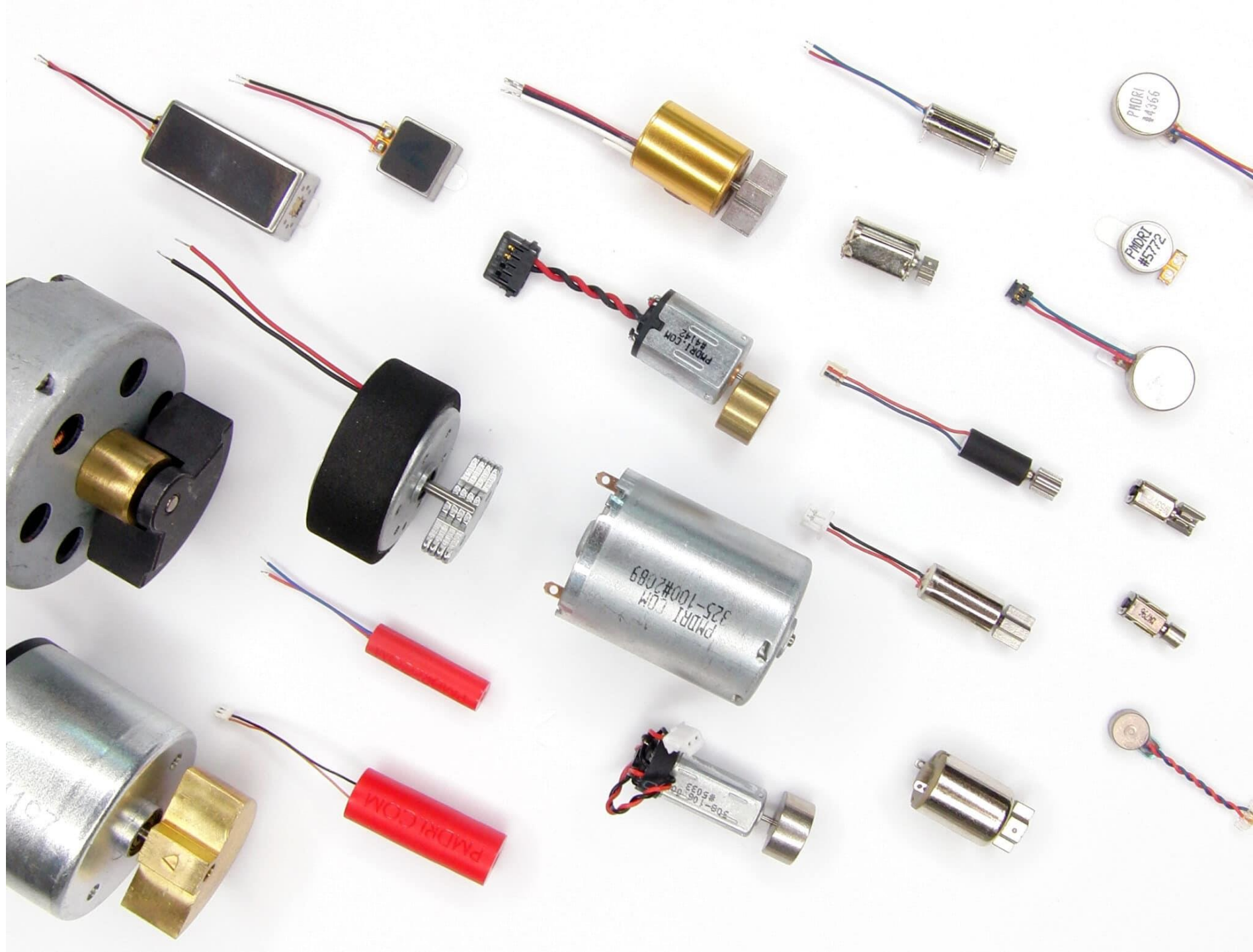
**Visual rendering is not enough to offer immersive experience**



# Current VR Controllers

Vibration

# Vibration feedback





## How to add haptic feedback to VR systems

If you are going to design a system **to offer full body physical feedback**, how will you do it?



**Pure vibrotactile stimulation** ignores the role of sustained or distributed force in conveying realism.

In the real world, very few experiences are conveyed by vibration alone.

**Hardlight VR Suit**  
Failed Kickstarter Campaign

**Pressure and Force Feedback**

**Shape and Curvature**

**Texture**

**Temperature**

**Shear Forces**

**...**



An alternative idea?

An alternative idea?

Offer both **vibration** and **variable force feedback**  
with pneumatic haptic wearable system



# Force Jacket: Pneumatically-Actuated Jacket for Embodied Haptic Experiences



CHI 2018 Paper

CHI 2018, April 21–26, 2018, Montréal, QC, Canada

## Force Jacket: Pneumatically-Actuated Jacket for Embodied Haptic Experiences

Alexandra Delazio\*    Ken Nakagaki\*\*    Roberta L. Klatzky†\*    Scott E. Hudson†\*  
Jill Fain Lehman\*    Alanson P. Sample\*  
\*Disney Research Pittsburgh, PA    †MIT Media Lab Cambridge, MA    ‡Carnegie Mellon University Pittsburgh, PA  
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### ABSTRACT

Immersive experiences seek to engage the full sensory system in ways that words, pictures, or touch alone cannot. With respect to the haptic system, however, physical feedback has been provided primarily with handheld tactile experiences or vibration-based designs, largely ignoring both pressure receptors and the full upper-body area as conduits for expressing meaning that is consistent with sight and sound. We extend the potential for immersion along these dimensions with the Force Jacket, a novel array of pneumatically-actuated airbags and force sensors that provide precisely directed force and high frequency vibrations to the upper body. We describe the pneumatic hardware and force control algorithms, user studies to verify perception of airbag location and pressure magnitude, and subsequent studies to define full-torso, pressure and vibration-based feel effects such as punch, hug, and snake moving across the body. We also discuss the use of those effects in prototype virtual reality applications.

### ACM Classification Keywords

H.5.2 User Interfaces: Haptic I/O, Interaction Styles

### Author Keywords

Haptics; Pneumatic Actuation; Force Feedback; Vibrotactile; Wearable; Virtual Reality

### INTRODUCTION

The creation of immersive virtual and augmented realities relies on engaging all of the senses. Although the fields of visual effects and sound effects have long histories and a wide variety of technologies to contribute, the inclusion of haptic feedback in such experiences is an area of recent growth. Many of the new haptic technologies being explored focus on feedback to the hand [4], fingertip[3], and hand-held tools[19]. However, as VR and AR applications increasingly expand to full-body



Figure 1. Force Jacket - A: Appearance of Force Jacket; B: Individual airbag with force sensitive resistor; C: User study set-up.

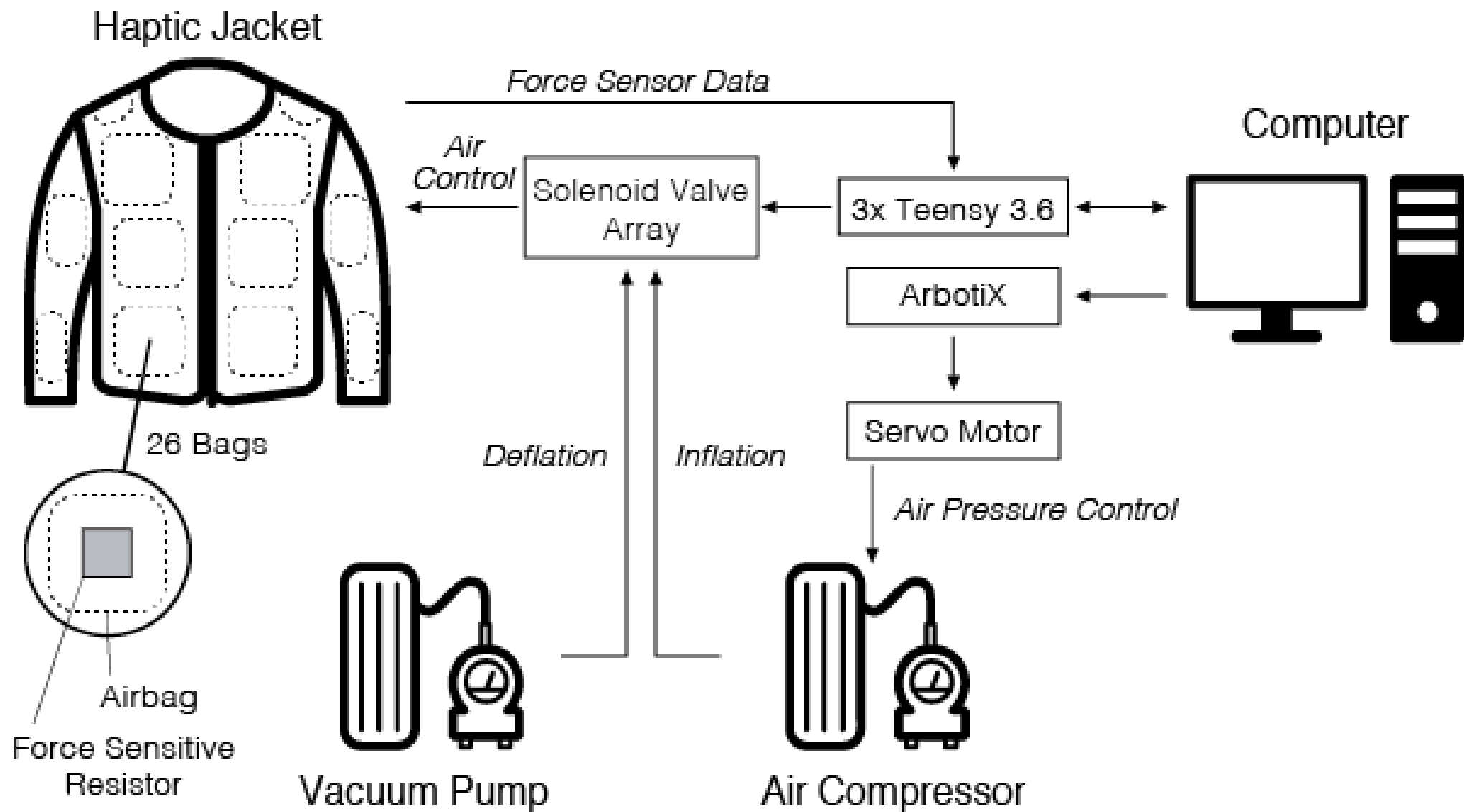
spatial experiences, tactile sensation must expand with them. Similarly, most current approaches are limited to expressing motion and vibrational feedback through vibrotactile stimulation [11, 12, 13], ignoring the role of sustained or distributed force in conveying realism. Even in the real world, very few experiences are conveyed by vibration alone.

To move toward more expressive technology, a wearable haptic interface, the Force Jacket, that has both vibrotactile and variable force feedback for the upper body and arms was introduced (Figure 1A). A software-controlled valve system inflates and deflates each of 26 bags independently to provide targeted forces and vibrotactile stimulation against each part of the upper body relative to force sensitive resistors on each bag (Figure 1B). An initial user study evaluated users' perception of airbag localization and magnitude where users experienced seven levels of pressure (1.6 - 8.5 N) on 26 upper body locations, generating a perceptually reliable range of values (Figure 1C). The values formed the basis for a second study in which users authored *feel effects* such as punch, hug, and a snake moving across the body, based on the paradigm in [12]. Finally, we derive canonical values from the user-authored data for a subset of the feel effects to demonstrate the capability of the Force Jacket in several applications.

CHI 2018

Delazio et.al.

How are you going to build such system? What are the possible hardware components?

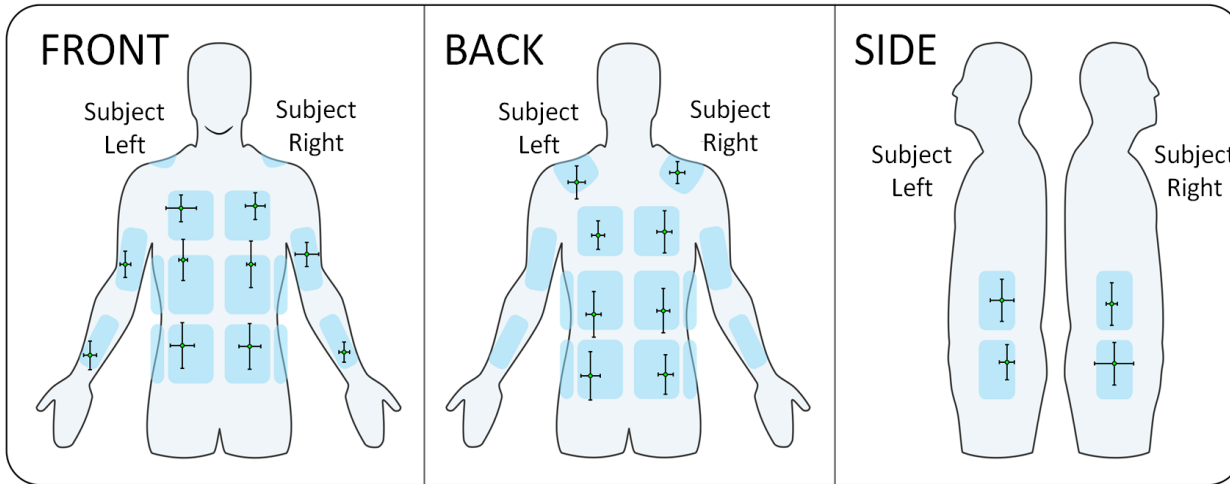




**Will it work? What would be the next step with the initial prototype?**

## Localization User Study

to determine users' ability to perceive the location of the various inflatable compartments in the haptic pneumatic wearable.



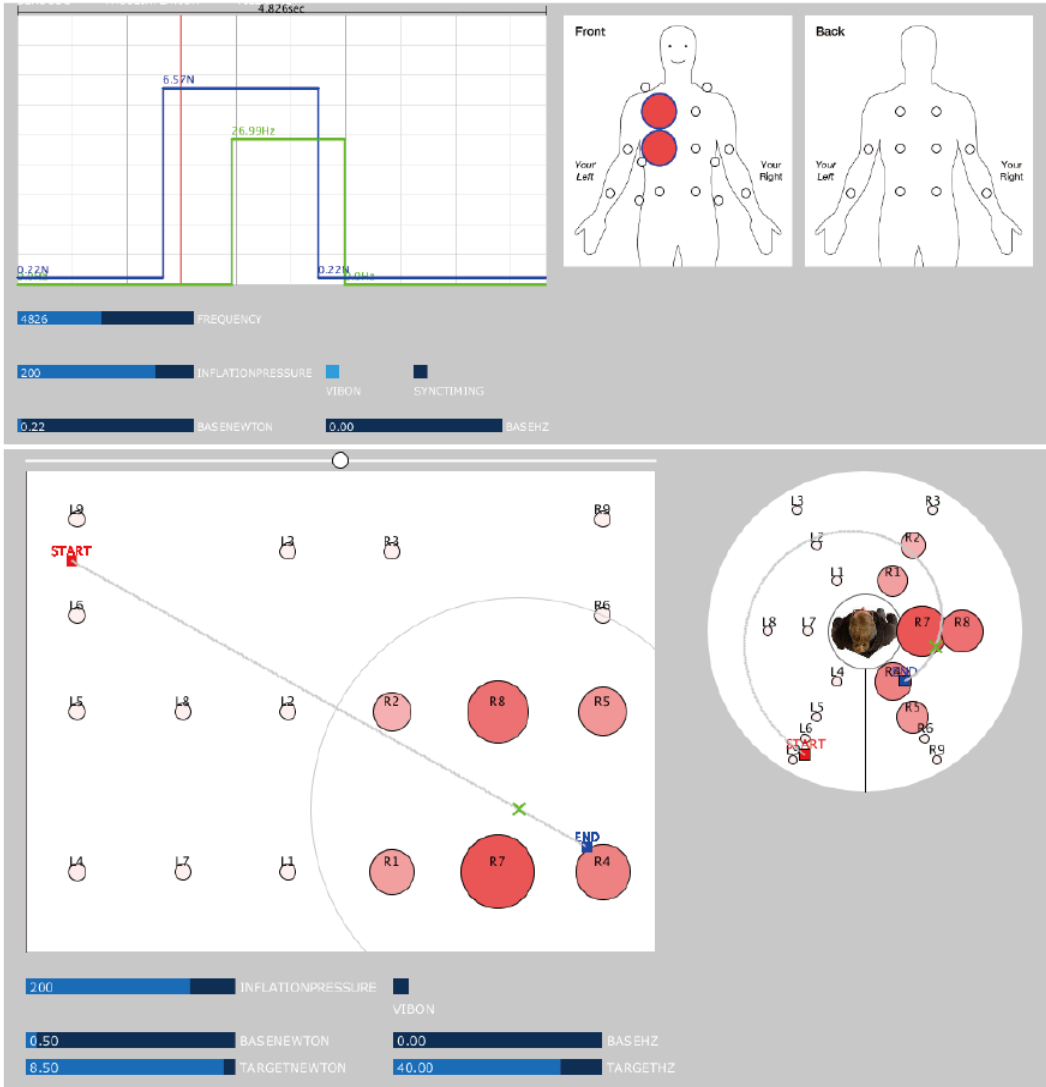
There was a tendency to feel the lower arm location toward the wrist. Shoulder locations were biased toward the upper back rather than centered on top of the shoulders.

## Free Magnitude User Study

to determine how perceived pressure magnitude was related to inflation magnitude of the various air compartments in the Jacket.

# Haptic Effect Editor

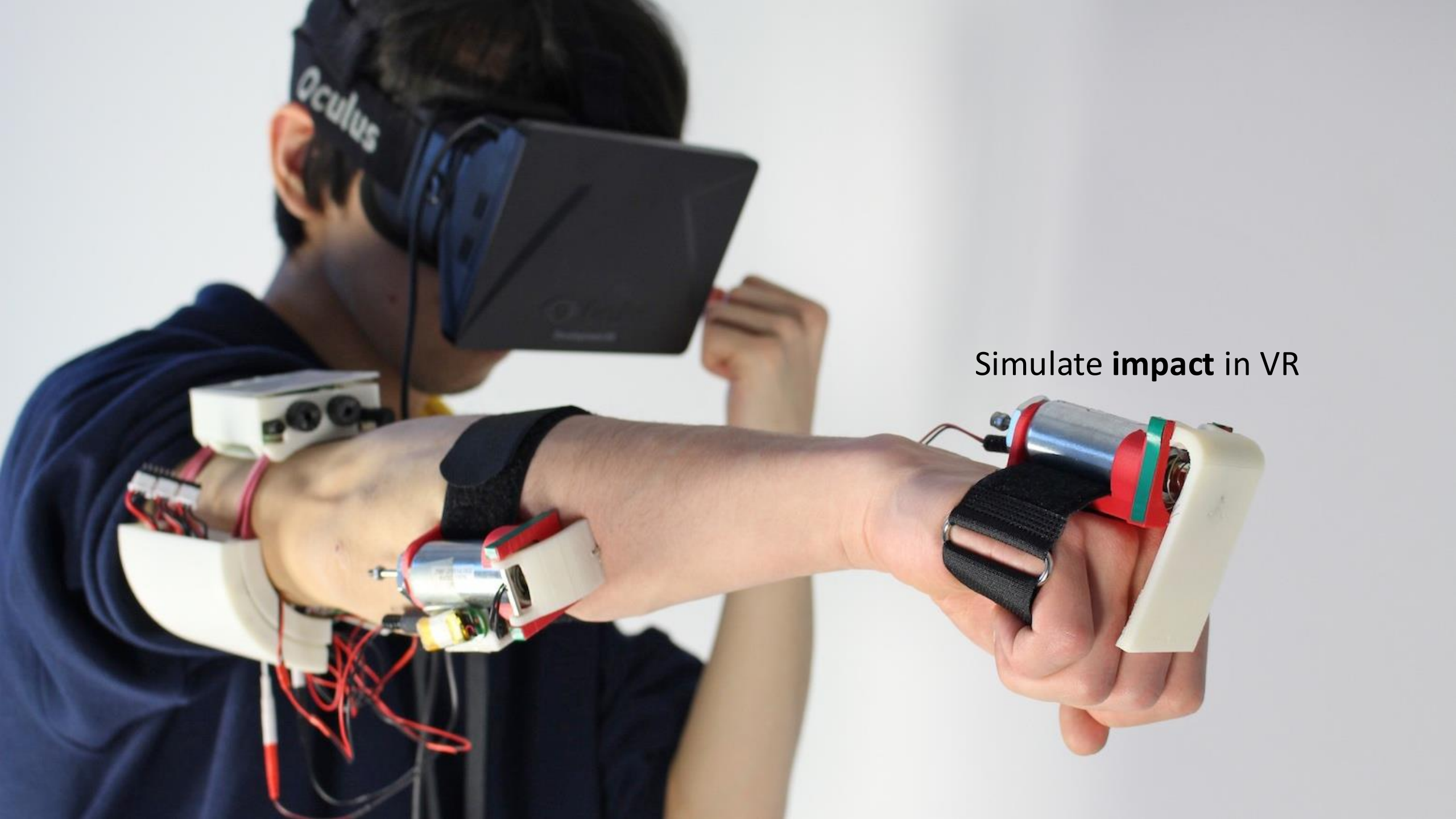
to easily create and control haptic feedback sequences



Inflation Pressure [psi]  
Target Force [N]  
Feedback Duration [ms]  
Target Frequency [Hz]  
Bags To Inflate


Applications





Simulate **impact** in VR

# Impacto: Simulating Physical Impact by Combining Tactile Stimulation with EMS



**impacto** Simulating Physical Impact  
Tactile with Electrical Muscle

Pedro Lopes, Alexandra Ion, and Patrick Baudisch

## Impacto: Simulating Physical Impact by Combining Tactile Stimulation with Electrical Muscle Stimulation

Pedro Lopes, Alexandra Ion, and Patrick Baudisch  
Hasso Plattner Institute, Potsdam, Germany  
{firstname.lastname}@hpi.de

### ABSTRACT

We present *impacto*, a device designed to render the haptic sensation of hitting and being hit in virtual reality. The key idea that allows the small and light *impacto* device to simulate a strong hit is that it decomposes the stimulus: it renders the tactile aspect of being hit by tapping the skin using a solenoid; it adds impulse to the hit by thrusting the user's arm backwards using electrical muscle stimulation. The device is self-contained, wireless, and small enough for wearable use, and thus leaves the user unencumbered and able to walk around freely in a virtual environment. The device is of generic shape, allowing it to also be worn on legs so as to enhance the experience of kicking, or merged into props, such as a baseball bat. We demonstrate how to assemble multiple *impacto* units into a simple haptic suit. Participants of our study rated impacts simulated using *impacto*'s combination of a solenoid hit and electrical muscle stimulation as more realistic than either technique in isolation.

**ACM Classification:** H.5.2 [Information interfaces and presentation]: User Interfaces: Input Devices and Strategies, Interaction Styles.

**Keywords:** haptics; impact, virtual reality; mobile; wearable; electrical muscle stimulation; solenoid; force feedback

**General terms:** Design, Human factors.

### INTRODUCTION

The objective of virtual reality systems is to provide an immersive and realistic experience [28]. While research in virtual reality has traditionally focused on the visual and auditory senses, many researchers argue that the next step towards immersion must include haptics, i.e., to allow users to experience the physical aspects of the world [12, 24, 32].

In this paper we focus on one specific category of haptic sensation, namely *impact*, i.e., the sensation of hitting or being hit by an object. Impact plays a key role in many sports simulations such as boxing, fencing, football, etc.

Simulating impact is challenging though. Creating the impulse that is transferred when hit by a kilogram-scale object, such as a boxer's fist, requires getting a kilogram-scale object into motion and colliding it with the user. This requires a very heavy device. In addition, building up an impulse requires an anchor to push against (Newton's Third Law), typically resulting in a tethered device, e.g., SPIDAR [22]. Both clash with the notion that today's virtual reality hardware is already wearable and wireless [9].

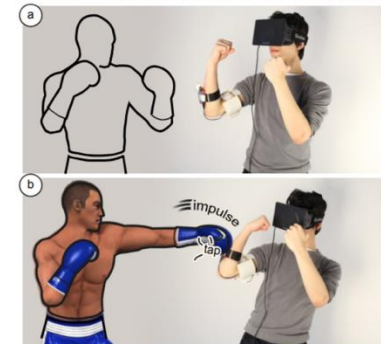


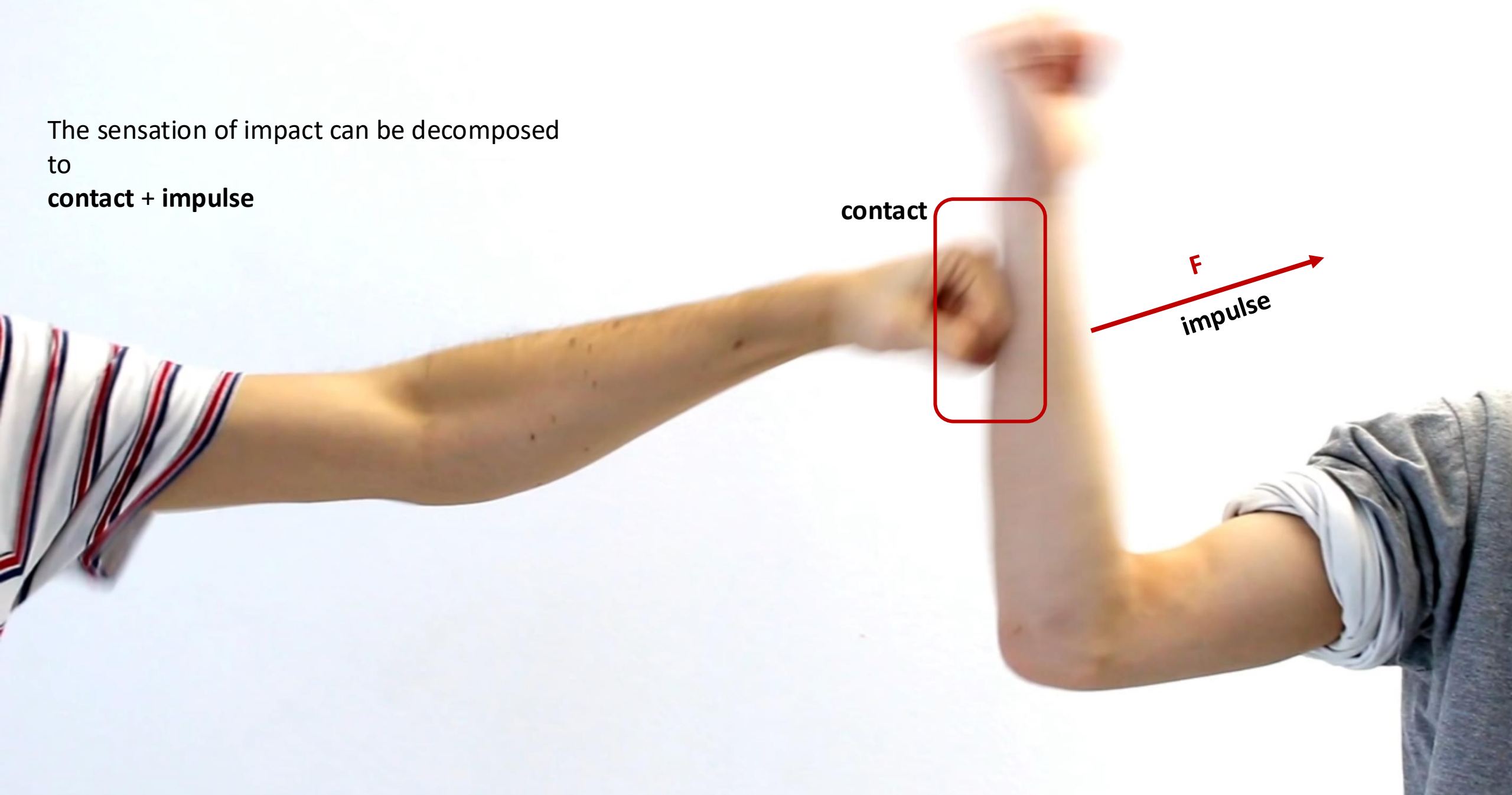
Figure 1: *Impacto* is designed to render the haptic sensation of hitting and being hit. The key idea that allows the small *impacto* device to simulate a strong hit is that it decomposes the stimulus. It renders the tactile aspect of being hit by tapping the skin using a solenoid; it adds impulse to the hit by thrusting the user's arm backwards using electrical muscle stimulation. Both technologies are small enough for wearable use.

In this paper, we propose a different approach. The key idea is to decompose the impact stimulus into two sub stimuli, each of which we can render effectively.

UIST 2015

Lopes et.al.

The sensation of impact can be decomposed  
to  
**contact + impulse**



contact

F

impulse

The sensation of impact can be decomposed  
to  
**contact + impulse**

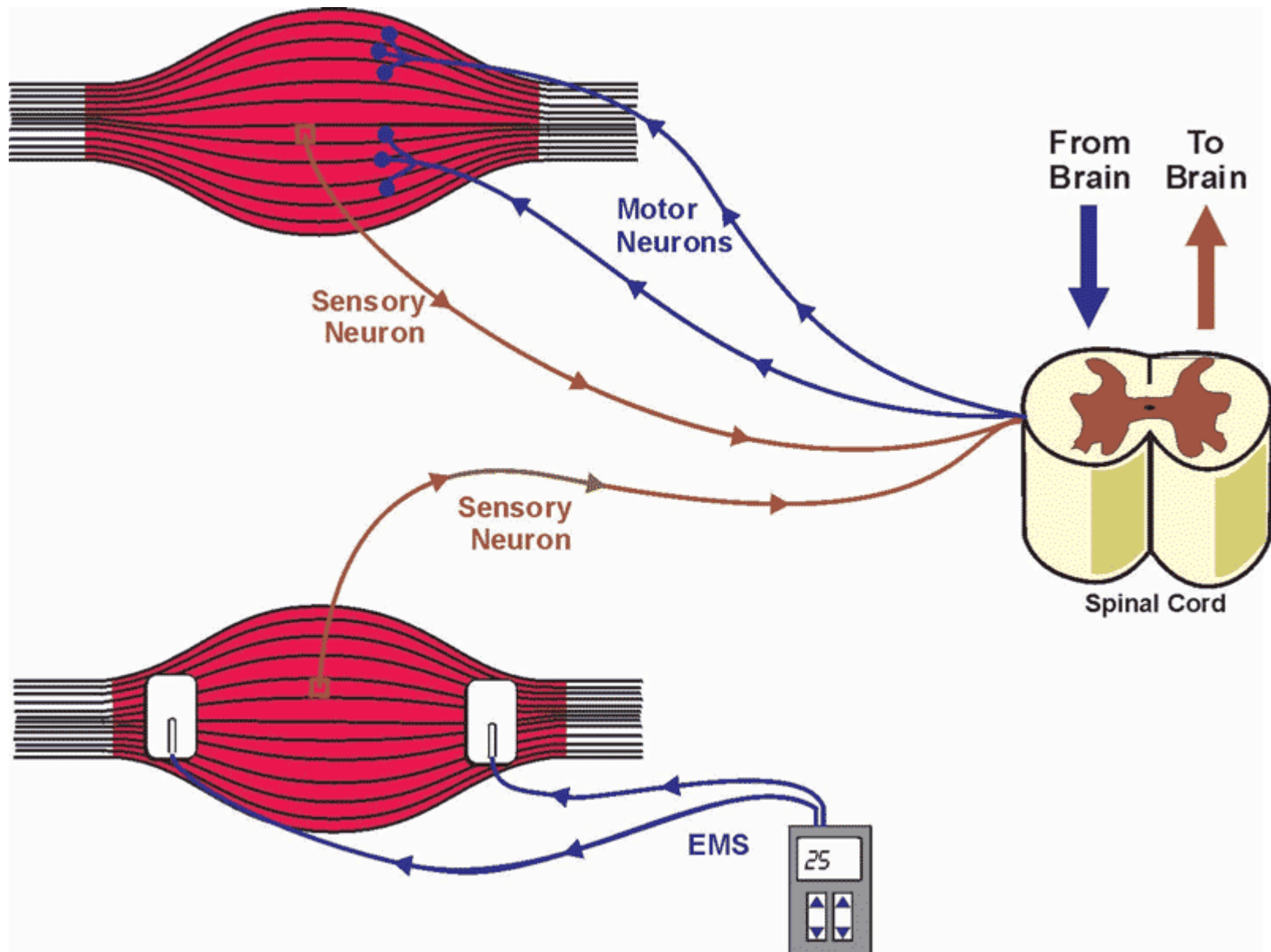
**contact**



the **impulse** component  
is rendered using  
**electrical muscle stimulation**

it thrusts the arm backwards

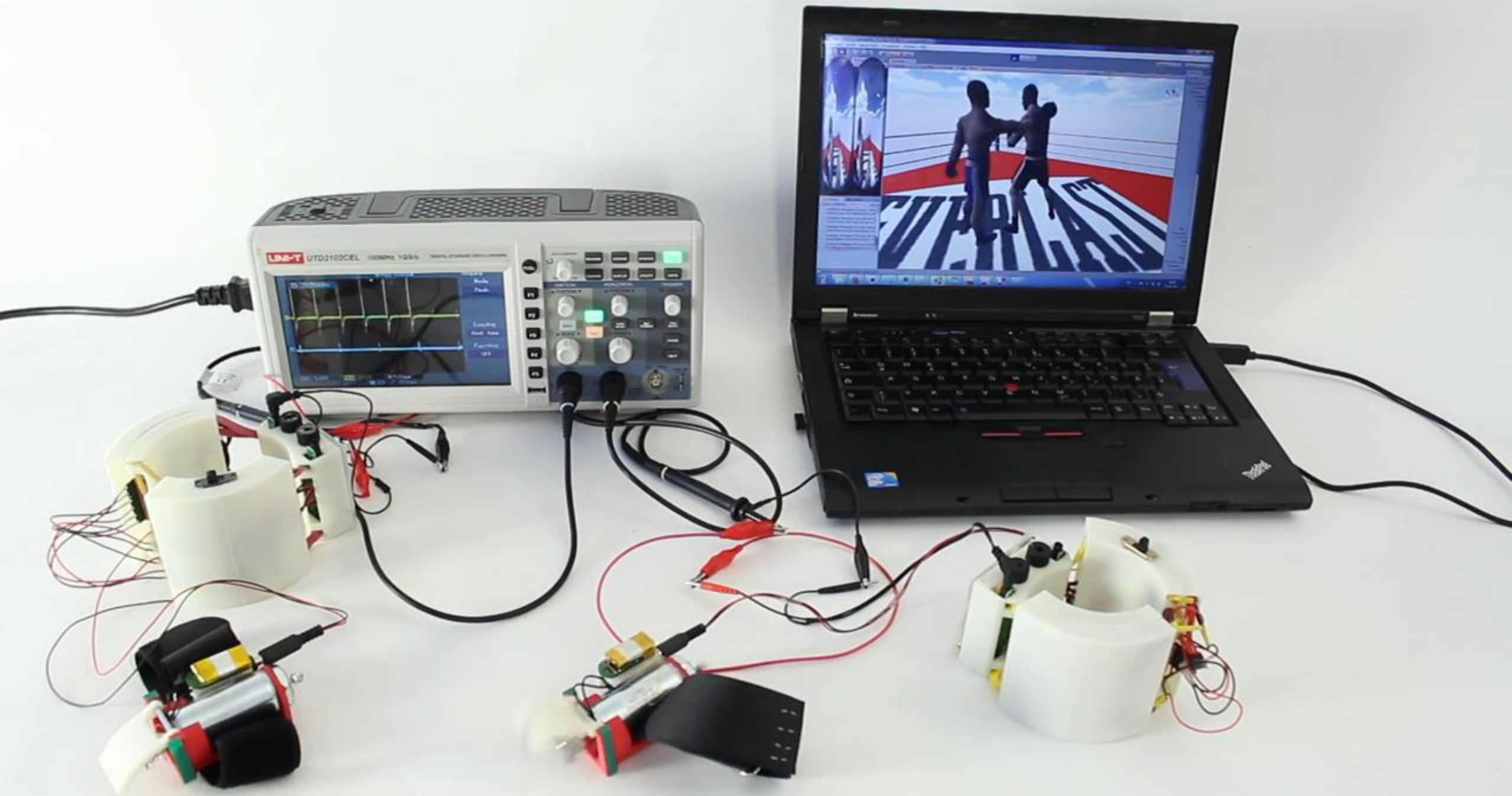


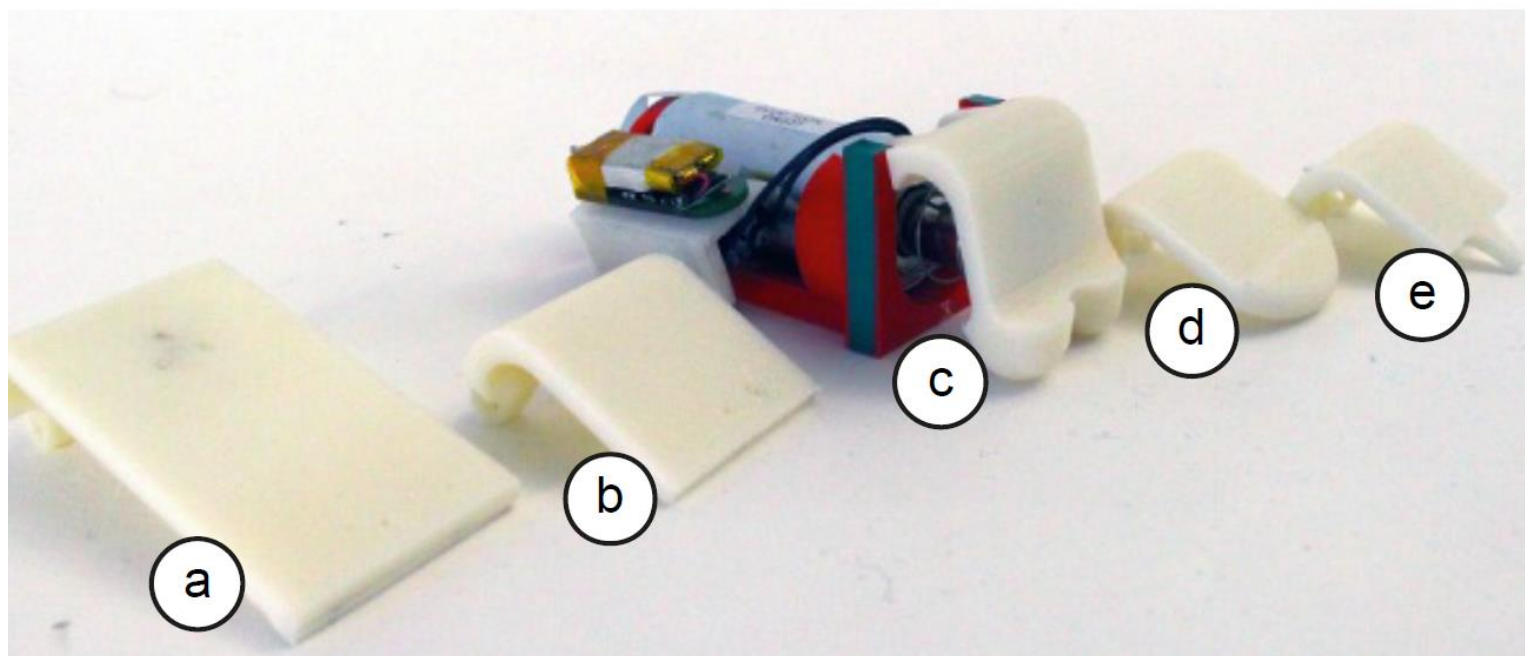
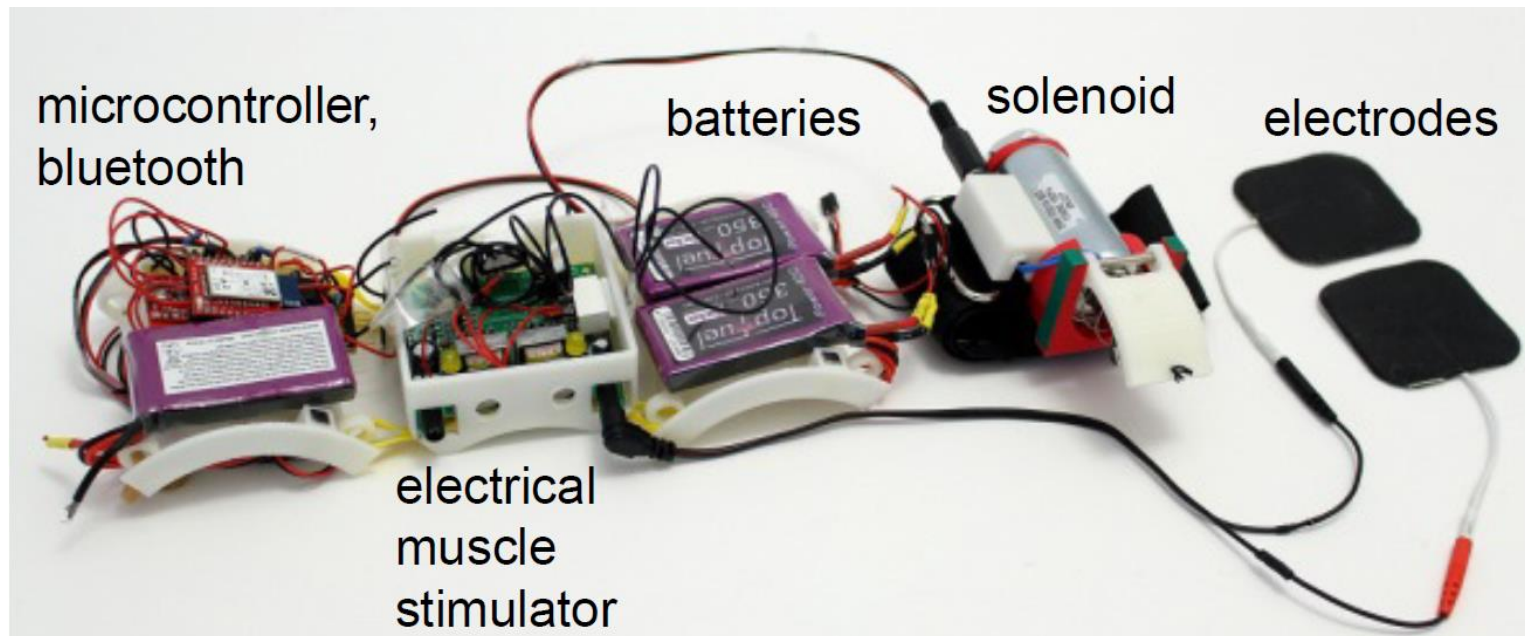


the combination is perceived  
as the **impact** caused by  
a moving mass against the body

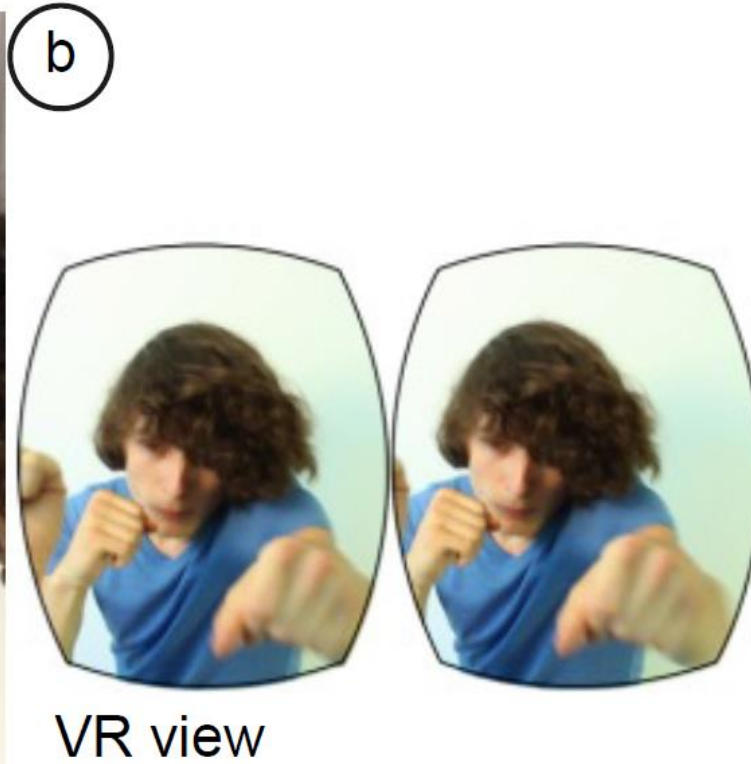
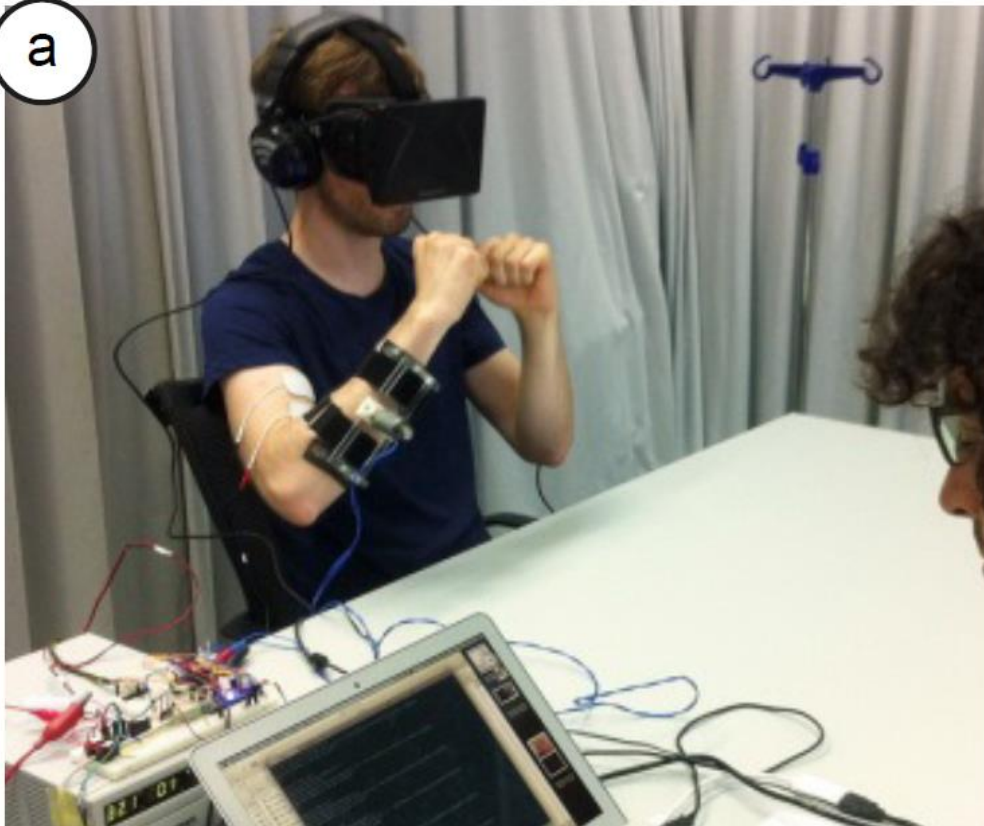


How can you build something like this?

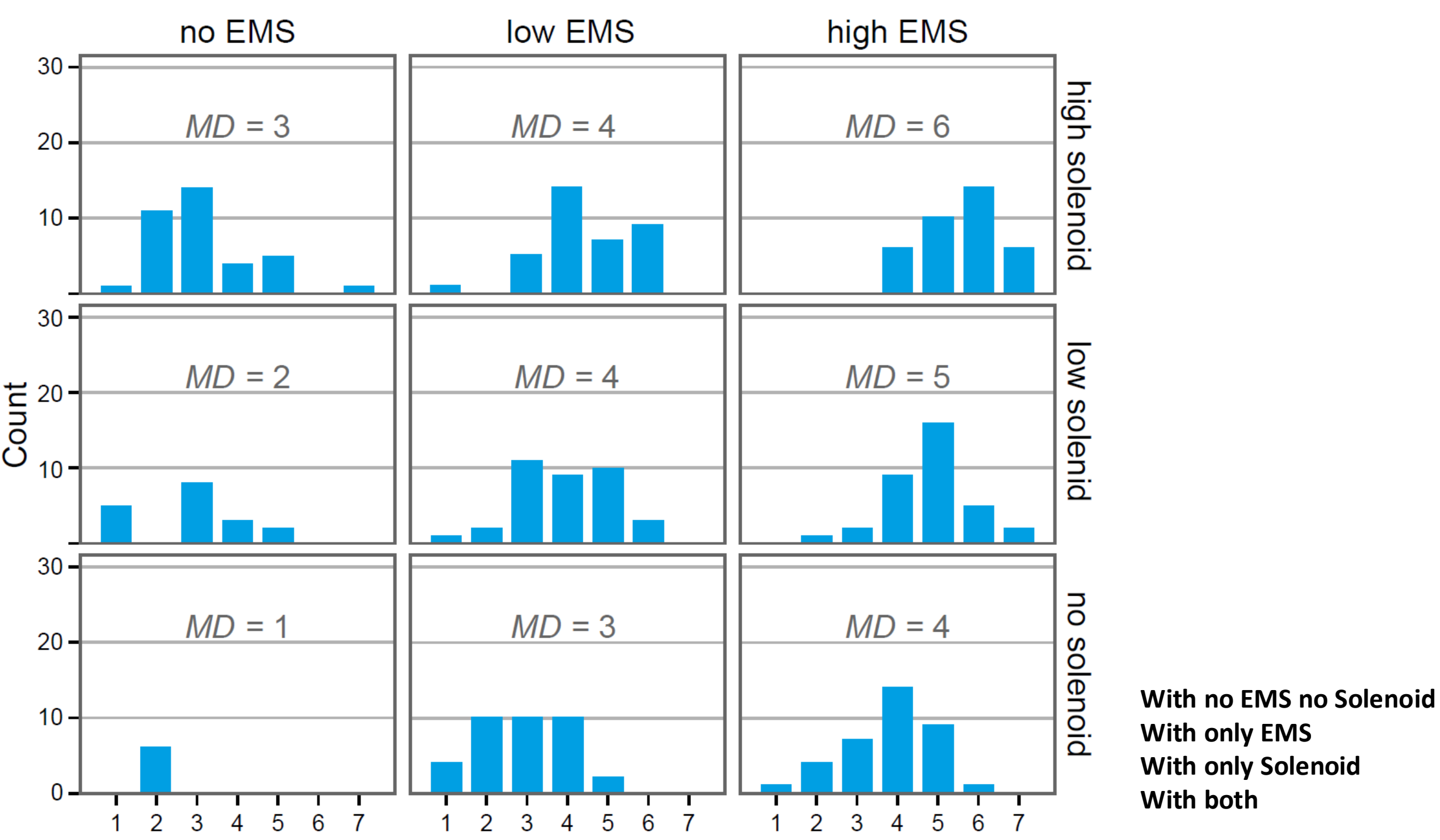


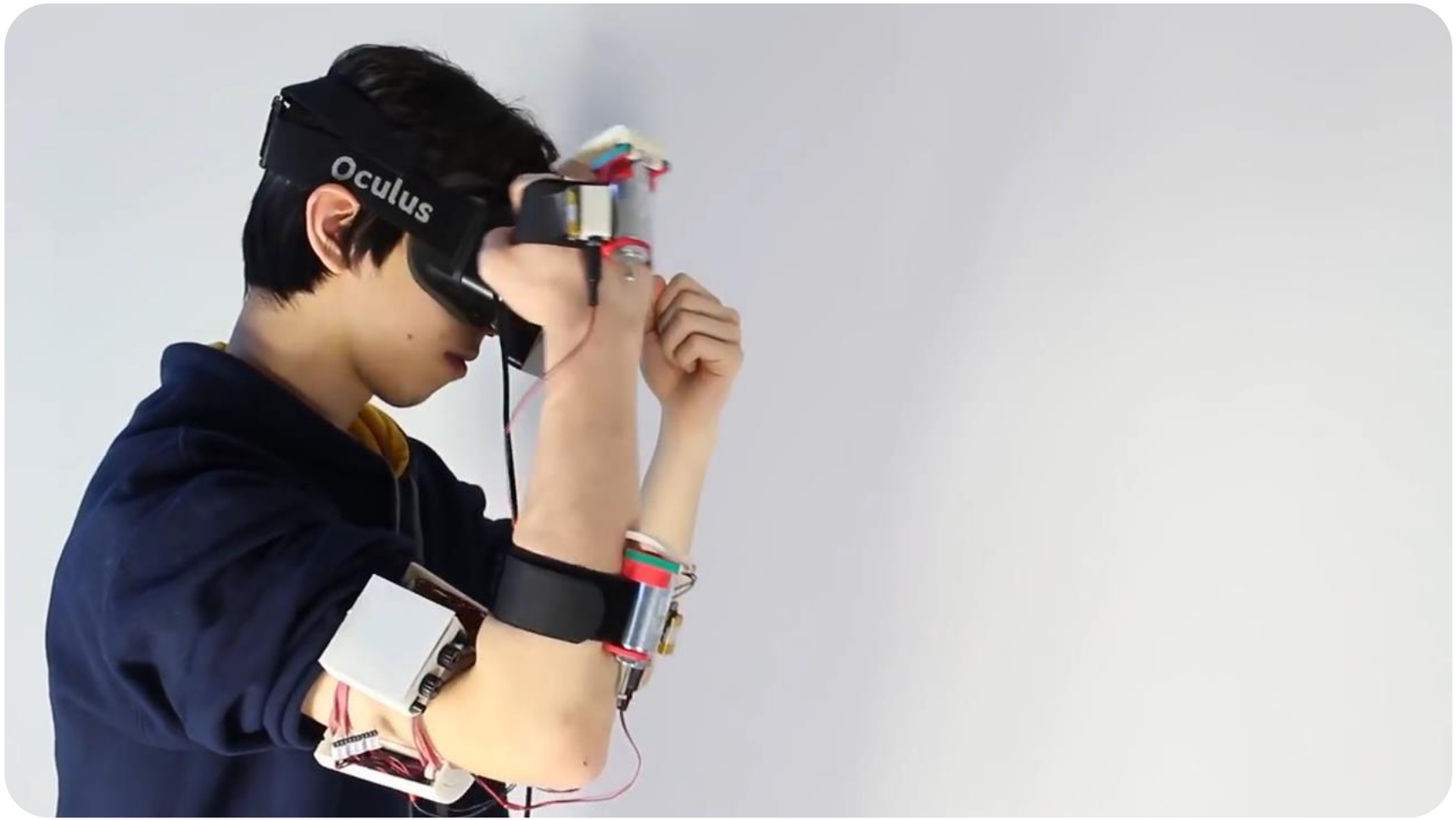


**User study to evaluate the core idea** -> decomposing an impact's haptic feedback into a tactile component (solenoid) and an impulse component (EMS)



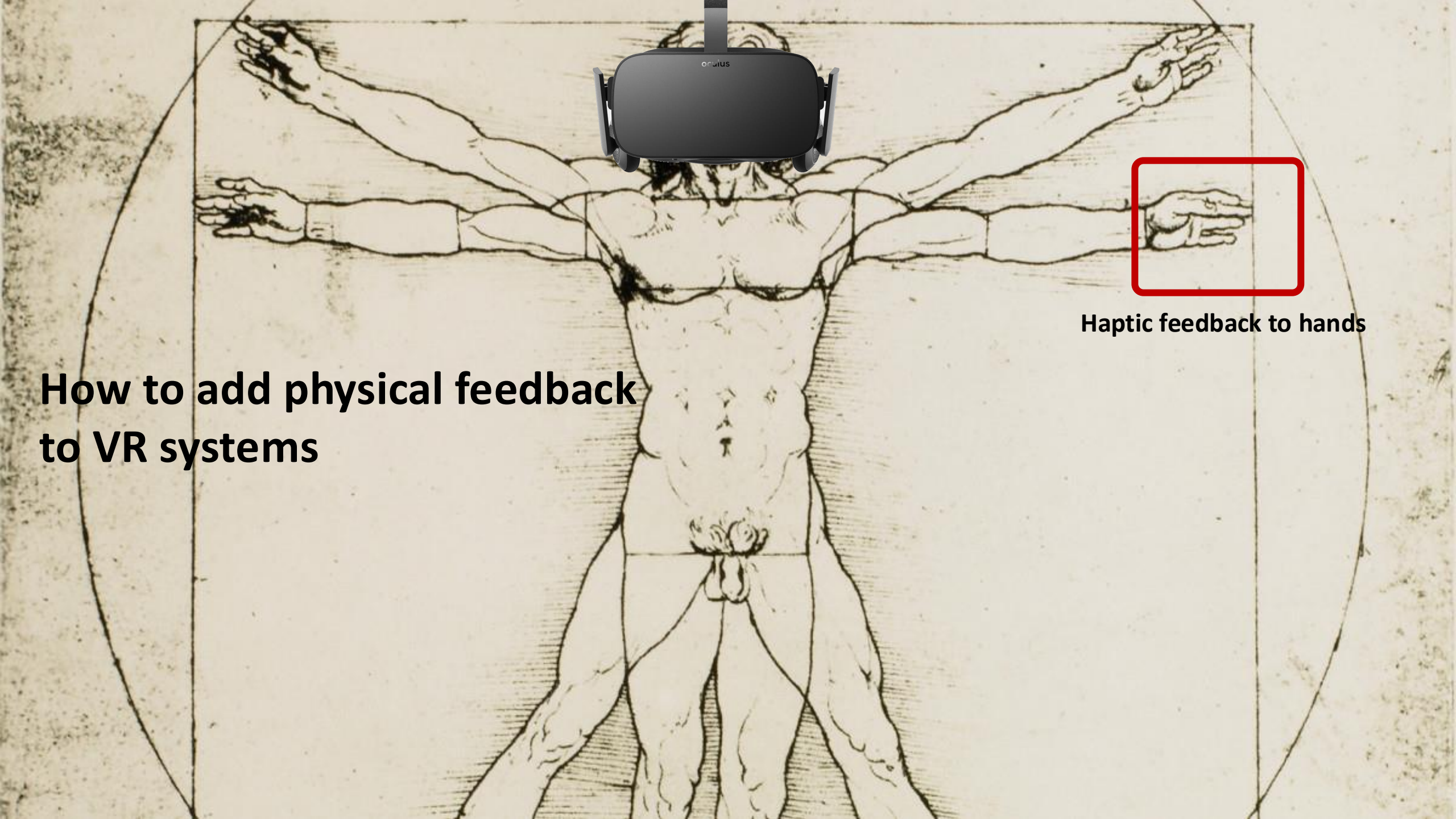
**With no EMS no Solenoid**  
**With only EMS**  
**With only Solenoid**  
**With both**





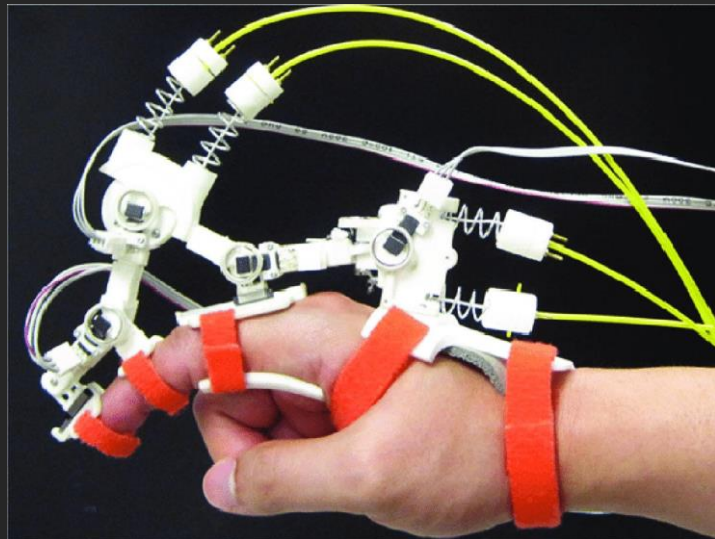
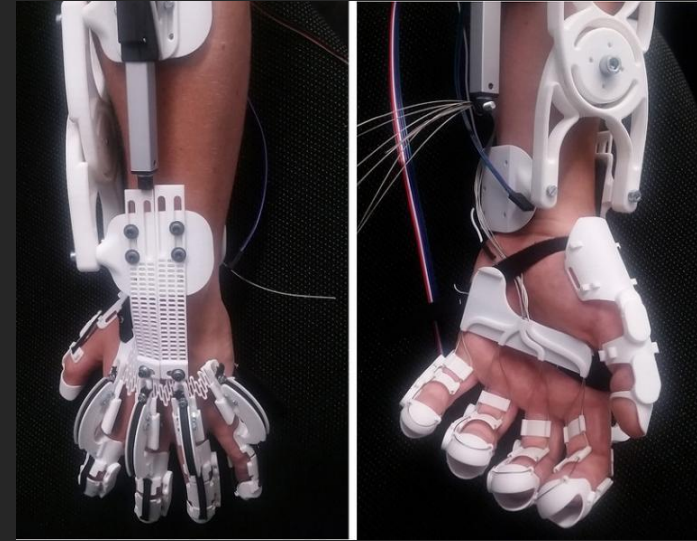
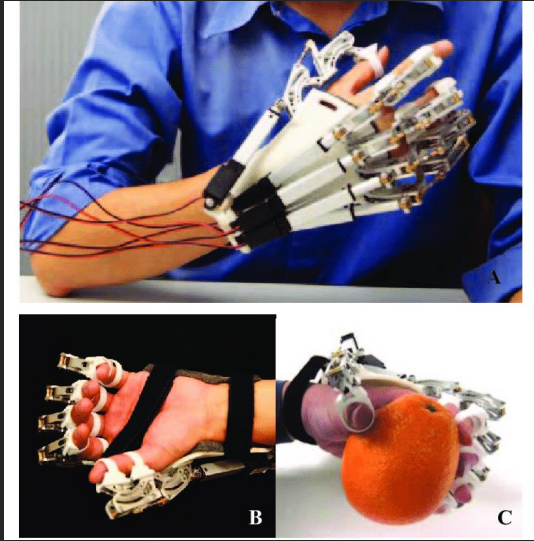
# How to add physical feedback to VR systems





Haptic feedback to hands

How to add physical feedback to VR systems



What do you see here? Any problem with exoskeleton hand solution?

# DextrES: Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake

## DextrES

### Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake

Ronan Hinchet<sup>1</sup> Velko Vechev<sup>2</sup> Herbert Shea<sup>1</sup> Otmar Hilliges<sup>2</sup>  
<sup>1</sup>EPFL <sup>2</sup>ETH Zurich

Session 17: Haptics and VR

UIST 2018, October 14–17, 2018, Berlin, Germany

## DextrES: Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake

Ronan Hinchet<sup>1</sup>, Velko Vechev<sup>2</sup>, Herbert Shea<sup>1</sup>, Otmar Hilliges<sup>2</sup>

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{ronan.hinchet, herbert.shea}@epfl.ch, {velko.vechev, otmar.hilliges}@inf.ethz.ch

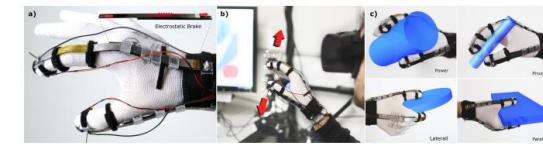


Figure 1. DextrES is a flexible and thin form-factor haptic feedback mechanism for precise manipulation of virtual objects in VR and AR. a) Our approach provides kinesthetic feedback via electrostatic brakes and piezoelectric actuators for cutaneous feedback. b) We experimentally show that DextrES improves precision of virtual object manipulations in VR across c) a number of different types of grasps, each affecting different hand poses.

### ABSTRACT

We introduce DextrES, a flexible and wearable haptic glove which integrates both kinesthetic and cutaneous feedback in a thin and light form factor (weight is less than 8g). Our approach is based on an electrostatic clutch generating up to 20 N of holding force on each finger by modulating the electrostatic attraction between flexible elastic metal strips to generate an electrically-controlled friction force. We harness the resulting braking force to rapidly render on-demand kinesthetic feedback. The electrostatic brake is mounted onto the index finger and thumb via modular 3D printed articulated guides which allow the metal strips to glide smoothly. Cutaneous feedback is provided via piezo actuators at the fingertips. We demonstrate that our approach can provide rich haptic feedback under dexterous articulation of the user's hands and provides effective haptic feedback across a variety of different grasps. A controlled experiment indicates that DextrES improves the grasping precision for different types of virtual objects. Finally, we report on results of a psychophysical study which identifies discrimination thresholds for different levels of holding force.

<sup>1</sup>Authors contributed equally to this work.

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ISBN 978-1-4503-5948-1/18/00...\$15.00  
DOI: <https://doi.org/10.1145/3242587.3242587>

### Author Keywords

Haptics; VR; electrostatic brake; dexterous interaction

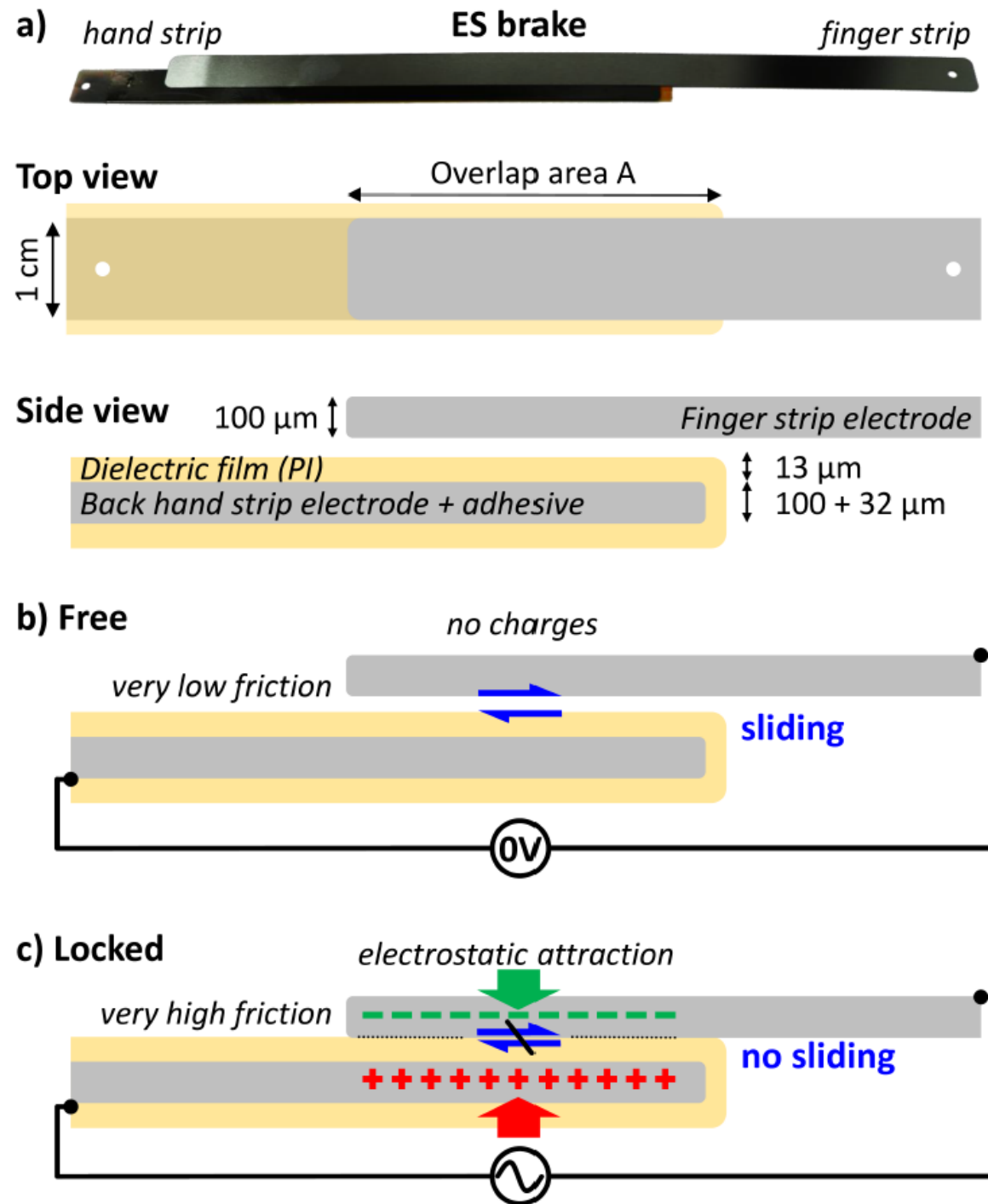
### INTRODUCTION

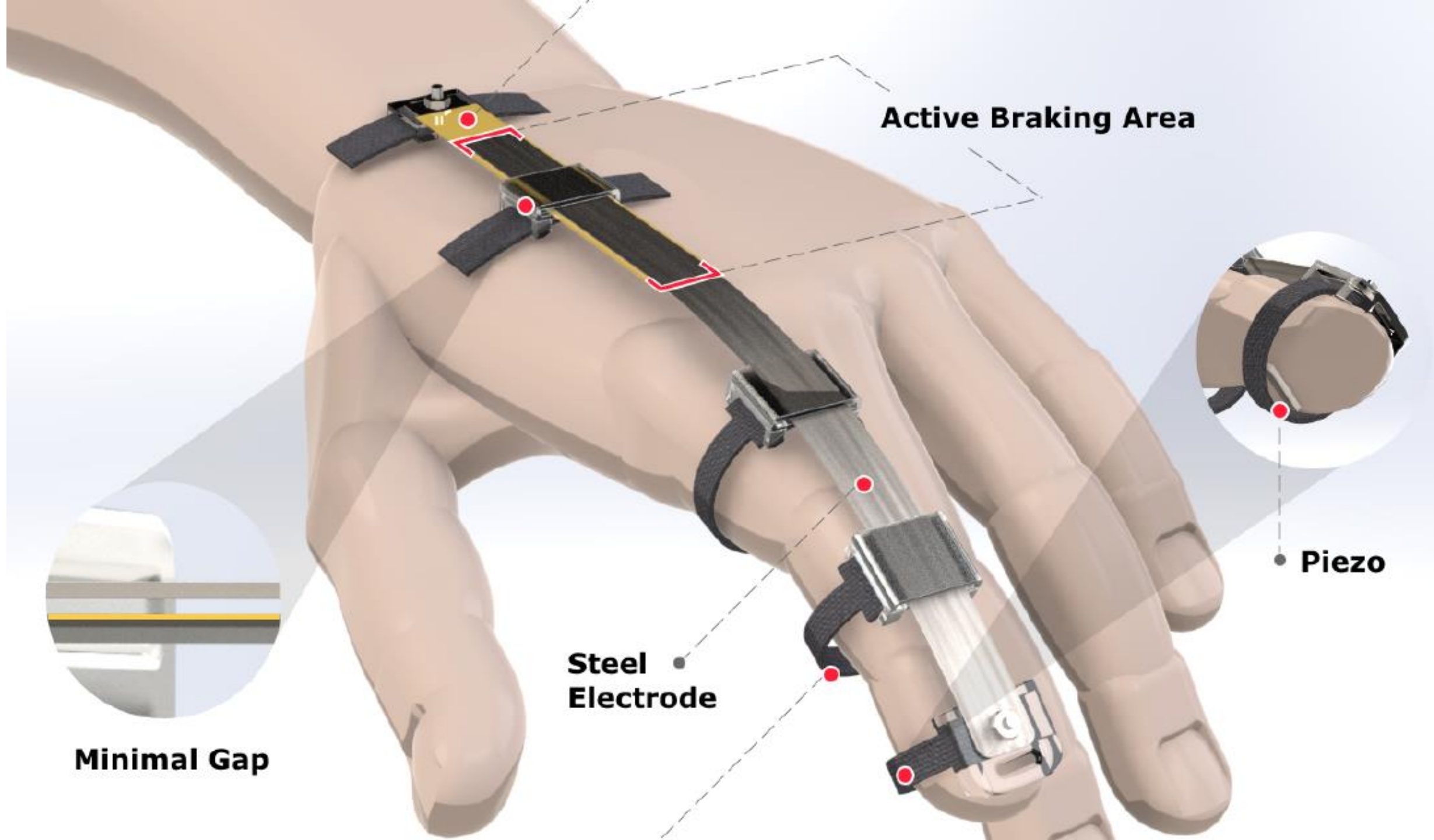
The dexterity of the human hand enables us to perform a number of useful everyday tasks such as actively exploring surfaces and grasping and moving objects [20, 16]. In Virtual Reality (VR), dexterous manipulation using the hand is a popular means of interaction. It allows us to leverage learned motor skills and vice versa, to train for real-world scenarios in VR [19]. While rapid progress has been made on the input side (display and sensing technologies), haptic interfaces providing physical feedback to the hand lag behind in their fidelity. In particular, the lack of appropriate kinesthetic feedback limit our ability to precisely steer and place grasped objects in 3D space [34].

The ability to grasp objects is amongst the most useful skills we can perform in VR [8]. One challenging aspect is the wide array of possible grasps which require the fingers to be free to move into different configurations [16]. Traditionally, grasping feedback in VR has been supported via glove-based exoskeletons which create braking forces on the fingers [12, 21], render localized tactile feedback on the fingertips [13, 31], or combine aspects of both [10, 22]. These devices often employ complex mechanisms placed around the hand which may either add weight, constrain the movement of the fingers, or both. As a result, the full range of interaction capabilities of the human hand are under-utilized.

To address this challenge, we introduce DextrES, a finger-mounted haptic mechanism capable of achieving up to 20N of holding force on each finger when flexing inward. Our

# Electrostatic braking mechanisms





**Active Braking Area**

**Piezo**

**Steel Electrode**

**Minimal Gap**



# PuPoP: Pop-up Prop on Palm for Virtual Reality

always-available physical proxies for generating grasping haptic feedback in VR.

The poster features the title 'PuPoP: Pop-up Prop on Palm for Virtual Reality' in large white font on a dark background. Below the title, the authors' names 'Shan-Yuan Teng, Tzu-Sheng Kuo, Chi Wang, Chi-huan Chiang, Da-Yuan Huang, Liwei Chan' are listed, followed by their affiliations: 'National Taiwan University, National Chiao Tung University, National Taiwan University of Science and Technology'. At the bottom, there are logos for National Taiwan University, National Chiao Tung University, and National Taiwan University of Science and Technology.

Also pneumatic system, but hands-worn

## PuPoP: Pop-up Prop on Palm for Virtual Reality

Shan-Yuan Teng<sup>1</sup> Tzu-Sheng Kuo<sup>2</sup> Chi Wang<sup>3</sup> Chi-huan Chiang<sup>4</sup>  
Da-Yuan Huang<sup>1</sup> Liwei Chan<sup>5</sup> Bing-Yu Chen<sup>6</sup>  
National Taiwan University, Taipei, Taiwan<sup>1</sup> National Chiao Tung University, Hsinchu, Taiwan<sup>2</sup>  
National Taiwan University of Science and Technology, Taipei, Taiwan<sup>3</sup>  
tanyuan@cmlab.csie.ntu.edu.tw {b03901032, b03202036, robin}@ntu.edu.tw<sup>4</sup>  
m10615047@mail.ntust.edu.tw dayuan.huang@acm.org liweichan@cs.nctu.edu.tw<sup>5</sup>



Figure 1. PuPoP is a wearable pneumatic shape-proxy interface for VR capable of popping up to primitive shapes and flattening on the palm. We demonstrate grasping emulation of picking up a virtual Lightsaber with a cylindrical PuPoP and throwing a virtual bomb with a spherical PuPoP.

### ABSTRACT

The sensation of being able to feel the shape of an object when grasping it in Virtual Reality (VR) enhances a sense of presence and the ease of object manipulation. Though most prior works focus on force feedback on fingers, the haptic emulation of grasping a 3D shape requires the sensation of touch using the entire hand. Hence, we present *Pop-up Prop on Palm (PuPoP)*, a light-weight pneumatic shape-proxy interface worn on the palm that pops several airbags up with predefined primitive shapes for grasping. When a user's hand encounters a virtual object, an airbag of appropriate shape, ready for grasping, is inflated by way of the use of air pumps; the airbag then deflates when the object is no longer in play. Since PuPoP is a physical prop, it can provide the full sensation of touch to enhance the sense of realism for VR object manipulation. For this paper, we first explored the design and implementation of PuPoP with multiple shape structures. We then conducted two user studies to further understand its applicability. The first study shows that, when in conflict, visual sensation tends to dominate over touch sensation, allowing a prop with a fixed

size to represent multiple virtual objects with similar sizes. The second study compares PuPoP with controllers and free-hand manipulation in two VR applications. The results suggest that utilization of dynamically-changing PuPoP, when grasped by users in line with the shapes of virtual objects, enhances enjoyment and realism. We believe that PuPoP is a simple yet effective way to convey haptic shapes in VR.

### Author Keywords

Haptics; Virtual Reality; Airbag; Shape-Proxy

### INTRODUCTION

Direct hand manipulation is how humans interact with objects in reality. We grasp objects and perceive their rich haptic feedback to manipulate them [14]. For Virtual Reality (VR), wearable haptic devices have been developed to simulate object grasping using different mechanisms [1, 6, 37, 10, 9]. Although highly mobile, they focus on force feedback on fingers to generate the feeling of firm grasping, the skin contact sensation with the surface of objects during hand manipulation is not provided.

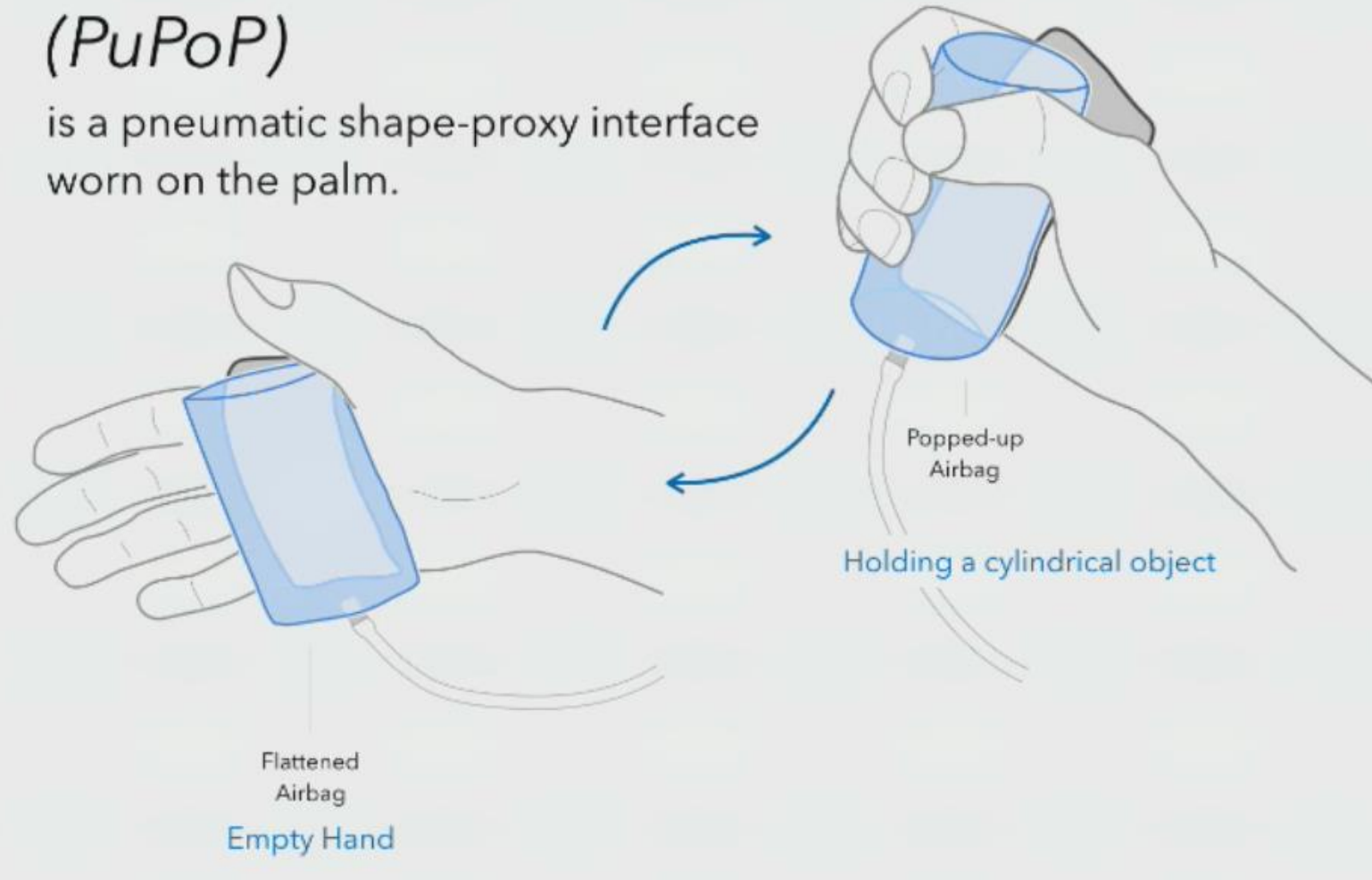
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UIST 2018

Teng et.al.

# Pop-up Prop on Palm (PuPoP)

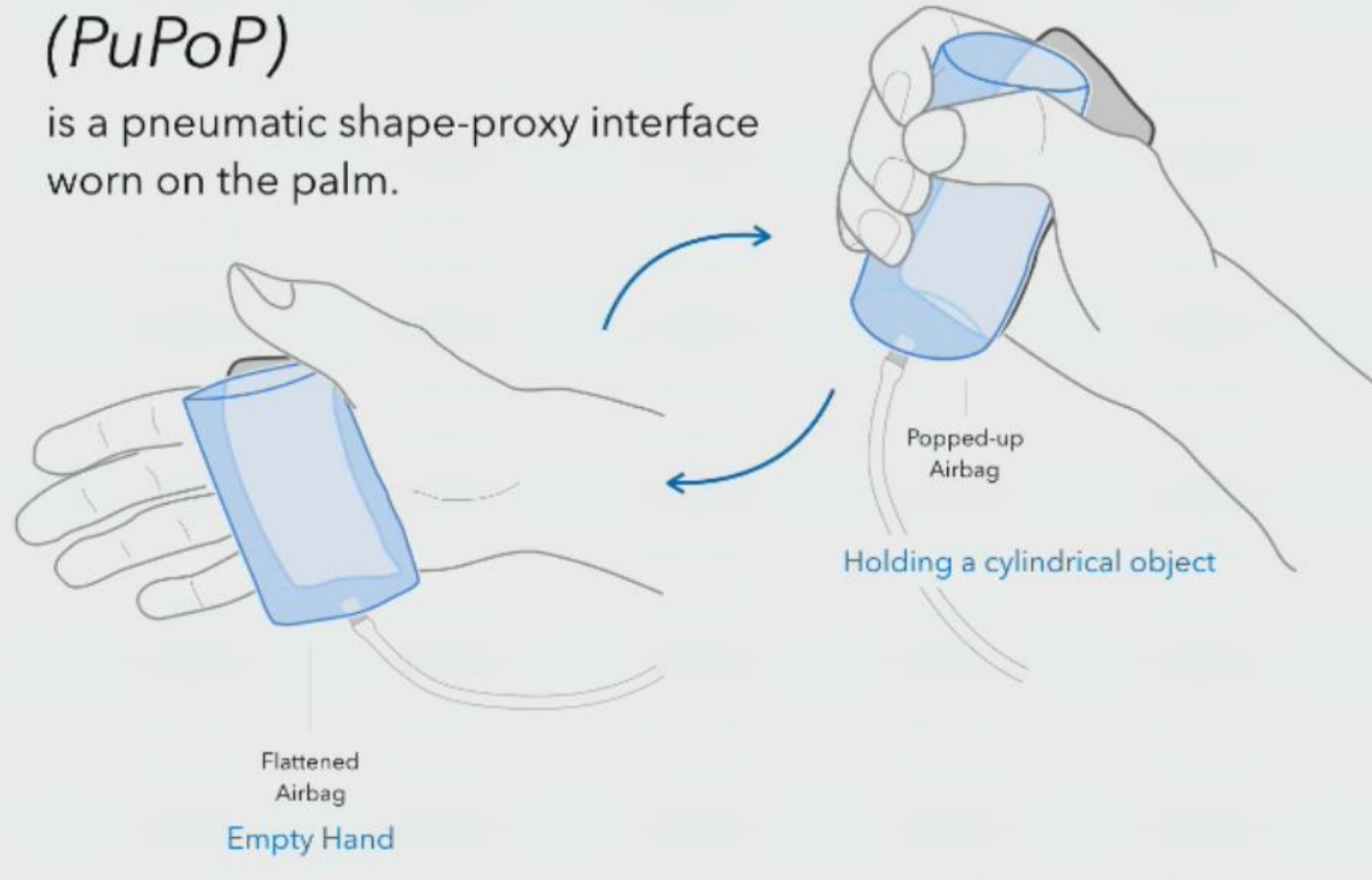
is a pneumatic shape-proxy interface worn on the palm.



What problem does this paper trying to solve?

# Pop-up Prop on Palm (PuPoP)

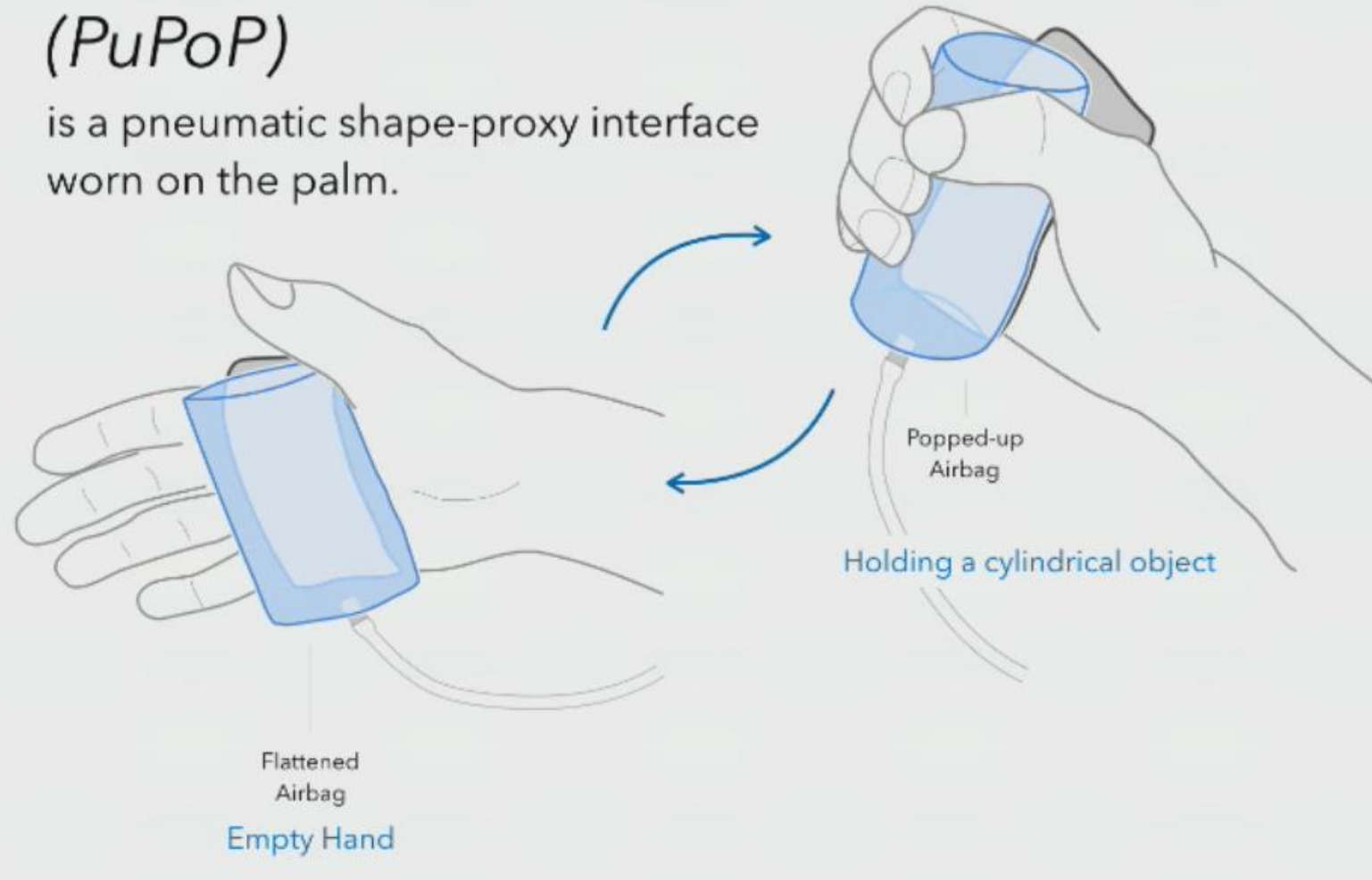
is a pneumatic shape-proxy interface worn on the palm.



How does this paper solve it?

# Pop-up Prop on Palm (PuPoP)

is a pneumatic shape-proxy interface worn on the palm.



What are the potential challenges for this solution?



There will be limited shapes that can be rendered, how to decide what shape to generate?

# Identify Primitive Shapes

## VR Game Objects

*111 hand-held objects found in 20 game trailers.*

**Sphere** balls in sports, snowballs, bombs, and grenades, etc.

**Cylinder** rackets, bottles, hammers, and swords, etc.

**Box** sandwiches, books, milk package, and camera, etc.

**Disk** Frisbee

**Cone** carrot

**Hemisphere** bowl

**Others** scissors, clothes, chain, fish, cat, etc.



Sphere



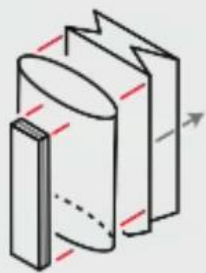
Cylinder



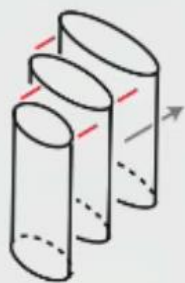
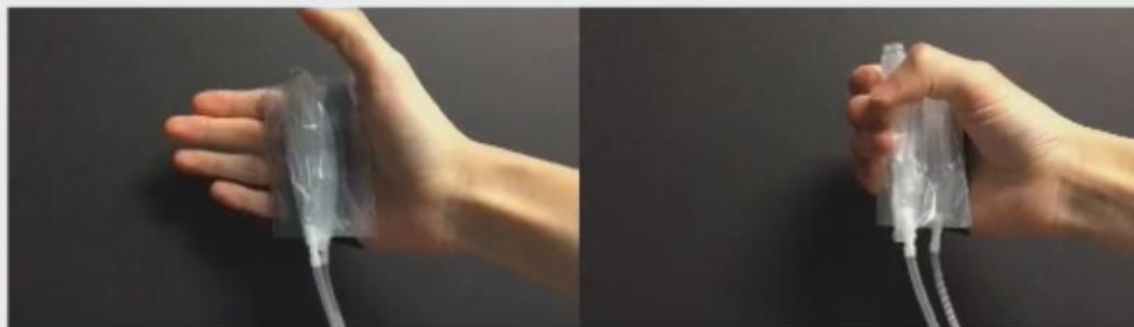
Box

# Props on Palm

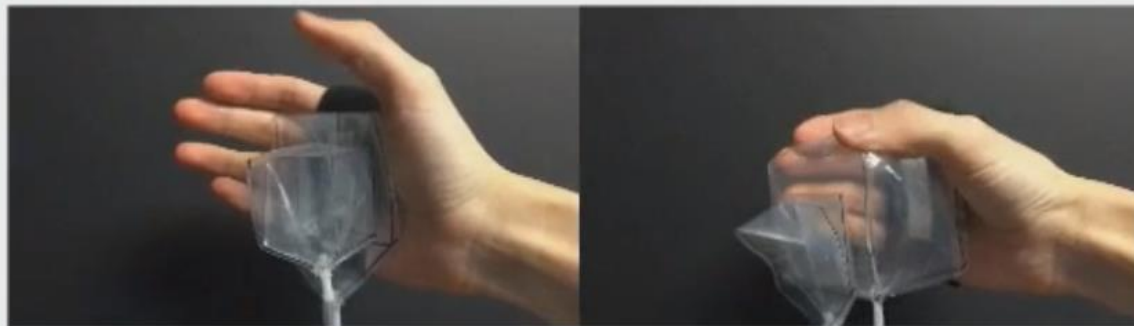
## Prop Stacking



Shape Stacking



Size Stacking



# Pneumatic Control System

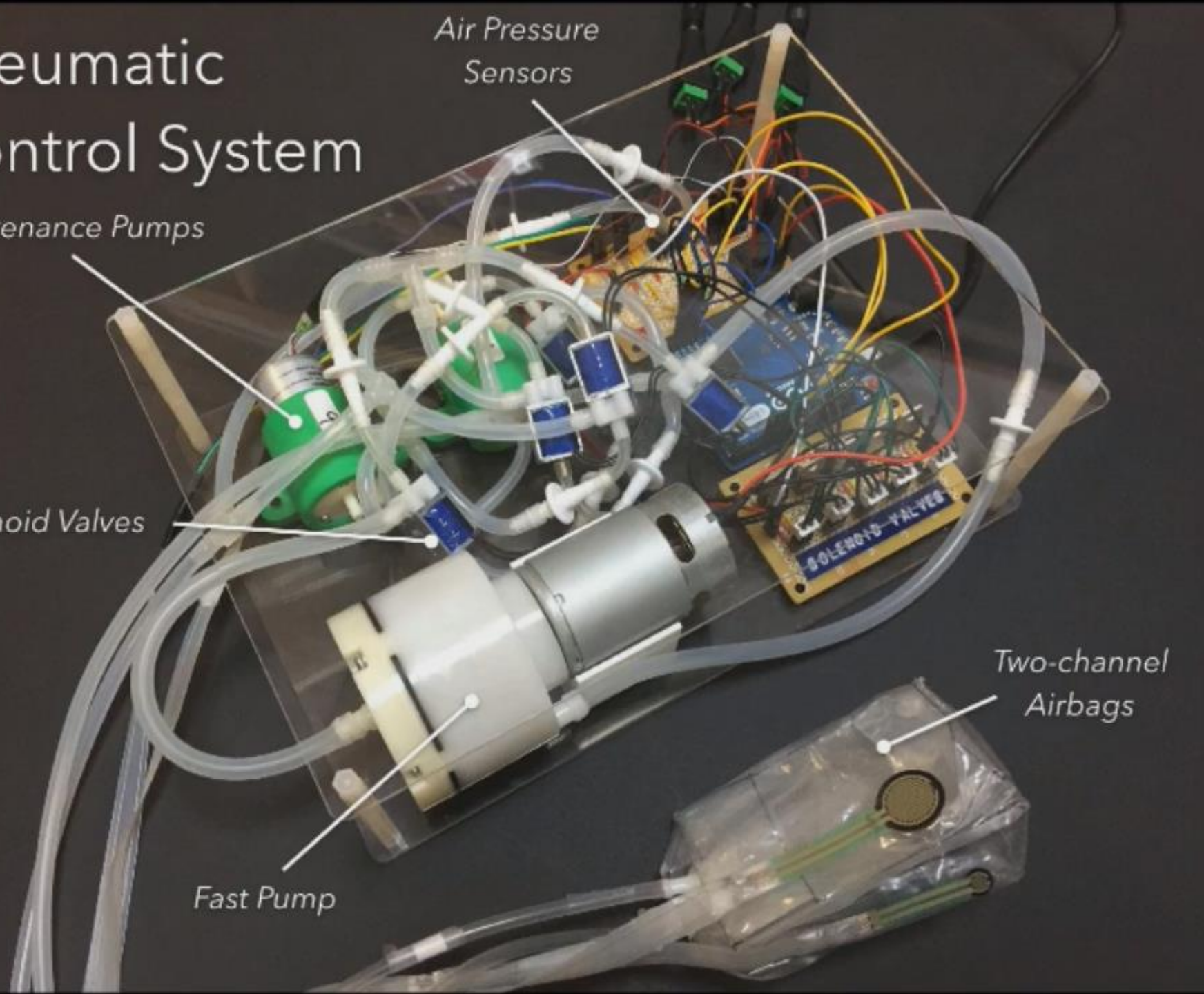
Air Pressure  
Sensors

Maintenance Pumps

Solenoid Valves

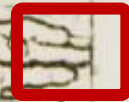
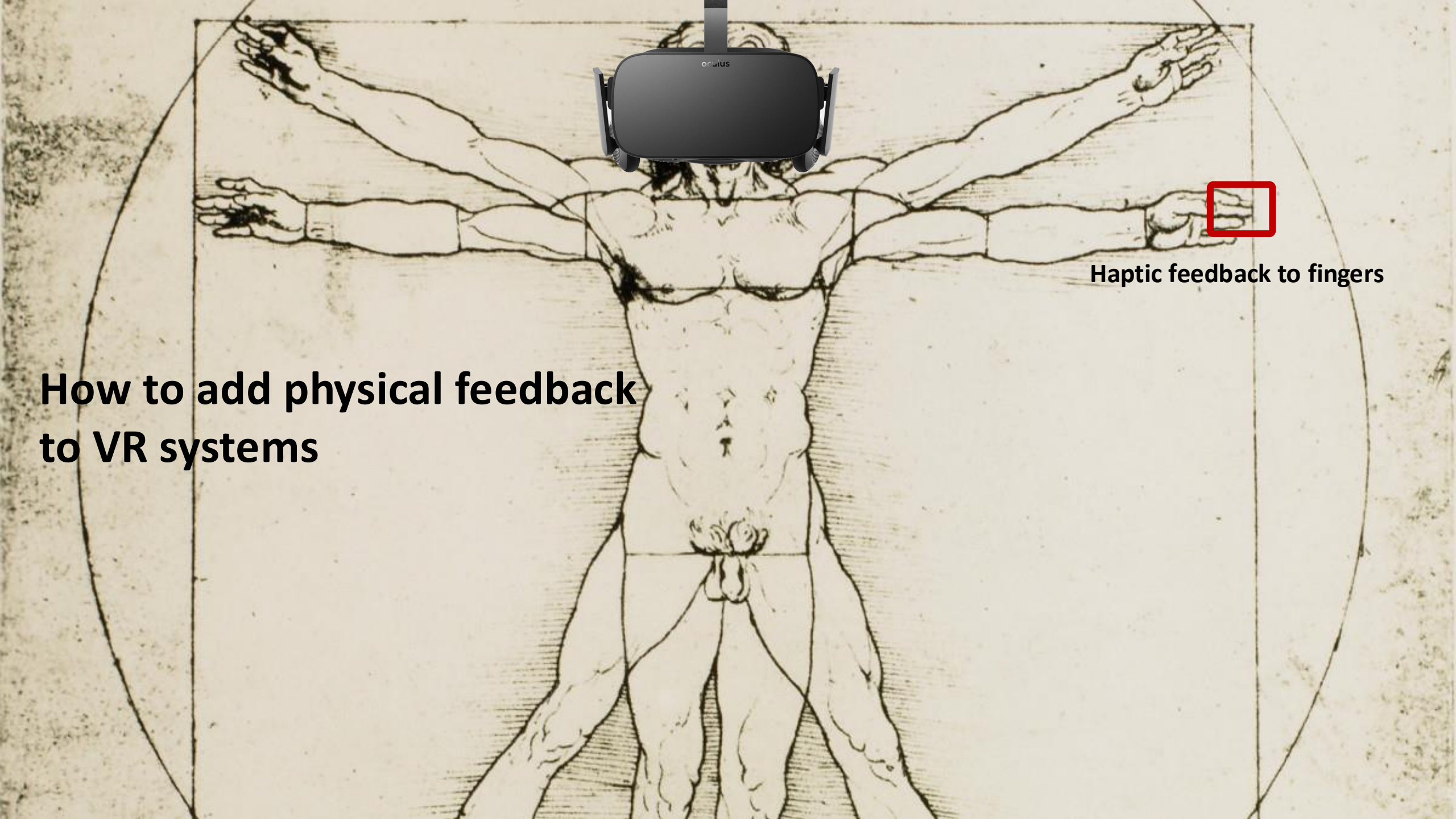
Fast Pump

Two-channel  
Airbags



A blurred screenshot of a VR application, likely a fantasy-themed game. The scene is out of focus, showing a character in a dark, possibly blue or black, outfit with a white element, possibly a hat or a piece of armor. The background is a mix of dark and light tones, suggesting an indoor or outdoor environment with some lighting effects. The overall aesthetic is that of a high-quality VR game.

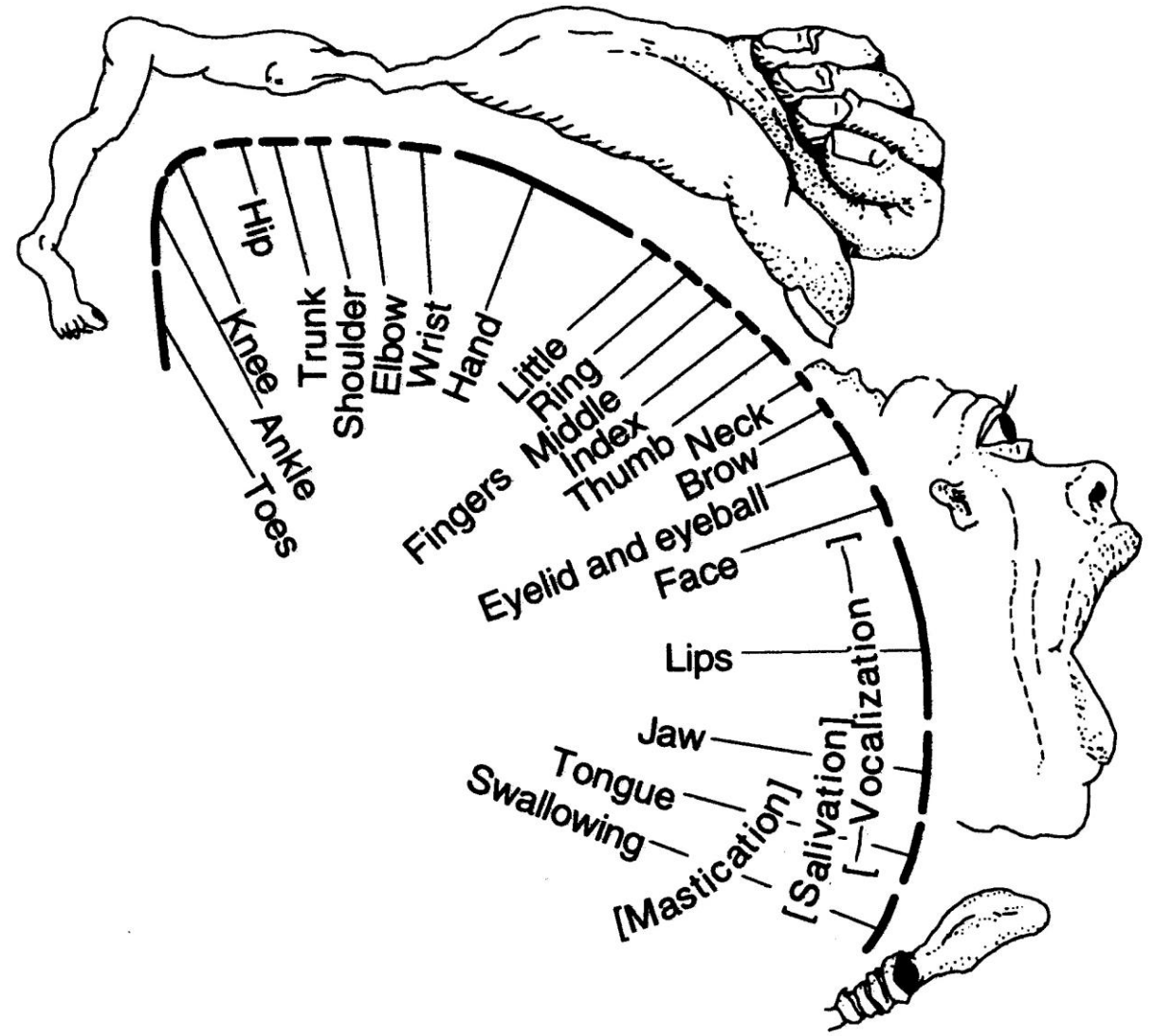
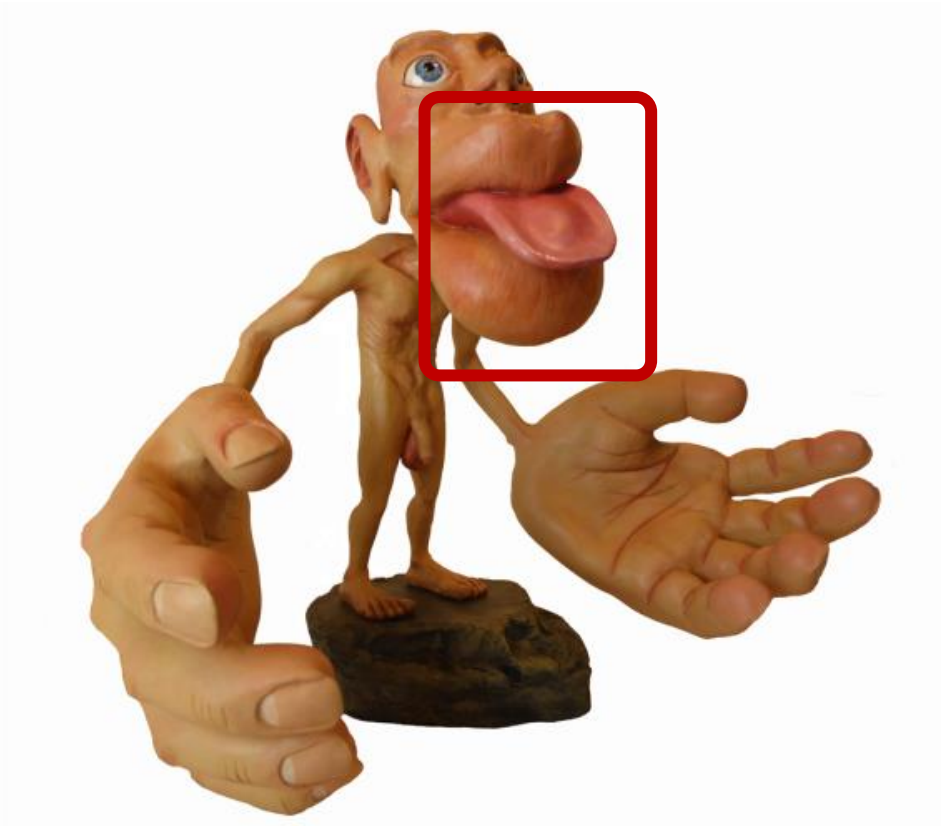
We demonstrate  
two fantasy VR applications  
using PuPoP



Haptic feedback to fingers

How to add physical feedback to VR systems

# Sensory homunculus



mapping the human somatosensory cortex

# Mouth Haptics in VR using a Headset Ultrasound Phased Array

Vivian Shen      Craig Shultz      Chris Harrison



## Mouth Haptics in VR using a Headset Ultrasound Phased Array

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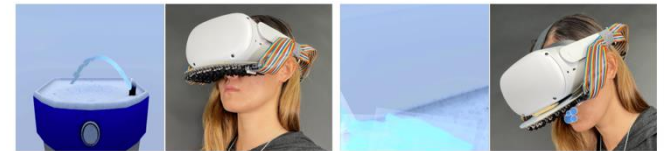


Figure 1: Our system can deliver rich, non-contact haptic feedback to the mouth using a thin array of ultrasonic transducers integrated into the underside of a VR headset. Here a user leans forward to drink from a virtual water fountain, and can feel a sensation of a stream of water on their lips and teeth.

### ABSTRACT

Today's consumer virtual reality (VR) systems offer limited haptic feedback via vibration motors in handheld controllers. Rendering haptics to other parts of the body is an open challenge, especially in a practical and consumer-friendly manner. The mouth is of particular interest, as it is a close second in tactile sensitivity to the fingertips, offering a unique opportunity to add fine-grained haptic effects. In this research, we developed a thin, compact, beamforming array of ultrasonic transducers, which can render haptic effects onto the mouth. Importantly, all components are integrated into the headset, meaning the user does not need to wear an additional accessory, or place any external infrastructure in their room. We explored several effects, including point impulses, swipes, and persistent vibrations. Our haptic sensations can be felt on the lips, teeth and tongue, which can be incorporated into new and interesting VR experiences.

### CCS CONCEPTS

• Human-centered computing → Virtual reality; Haptic devices.

### ACM Reference Format:

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<https://doi.org/10.1145/3491102.3501960>

### 1 INTRODUCTION

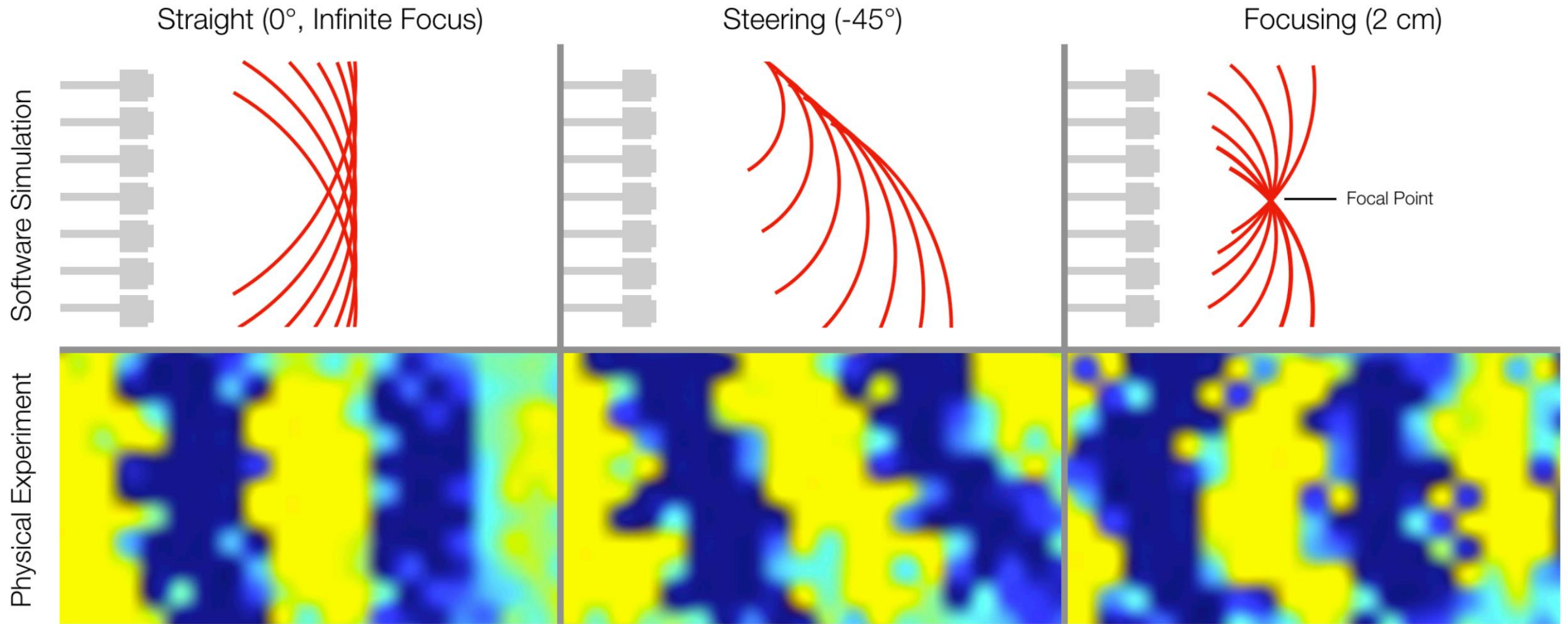
Virtual and augmented reality (VR/AR) headsets continue to make impressive strides in immersion and realism, particularly in visual and audio content. However, the delivery of rich tactile sensations continues to be a significant and open challenge. Critically, consumers want robust and integrated solutions – ones that do not require any extra devices or limit freedom of movement. For this reason, vibration motors in handheld controllers are the current consumer state of the art. While more sophisticated approaches exist (e.g., exoskeletons [1, 4, 42, 46], haptic vests [2, 16], body-cantilevered accessories [6], in-room air cannons [27, 65]), they have yet to see even modest consumer adoption.

Simultaneously, the mouth has been largely overlooked as a haptic target in VR/AR, despite being second in terms of sensitivity and density of mechanoreceptors, only behind the fingertips [14, 63, 73]. Equally important, the proximity of the mouth to the headset offers a significant opportunity to enable on- and in-mouth haptic effects, without needing to run wires or wear an extra accessory. However, consumers do not want to cover their entire face, let alone put something up against (or into) their mouth. For AR, the industry is trending towards glasses-like form factors, so as to preserve as much facial expression as possible for human-human communication. Even in VR, smaller headsets are the consumer trend, with the mouth exposed and unencumbered.

In this research, we built a thin, compact, beamforming array of ultrasonic transducers (Figure 3), which could be integrated into future headsets in a practical and consumer-friendly way. We use this hardware to focus air-borne acoustic energy onto the lips and into the mouth, creating sensations such as licks and continuous vibrations, which we can also animate along arbitrary 3D paths. In addition to the lips, our effects can be felt on the teeth and tongue. When coupled with coordinated graphical feedback, the effects are convincing, boosting realism and immersion. We built a variety of

CHI 22

Shen et al.

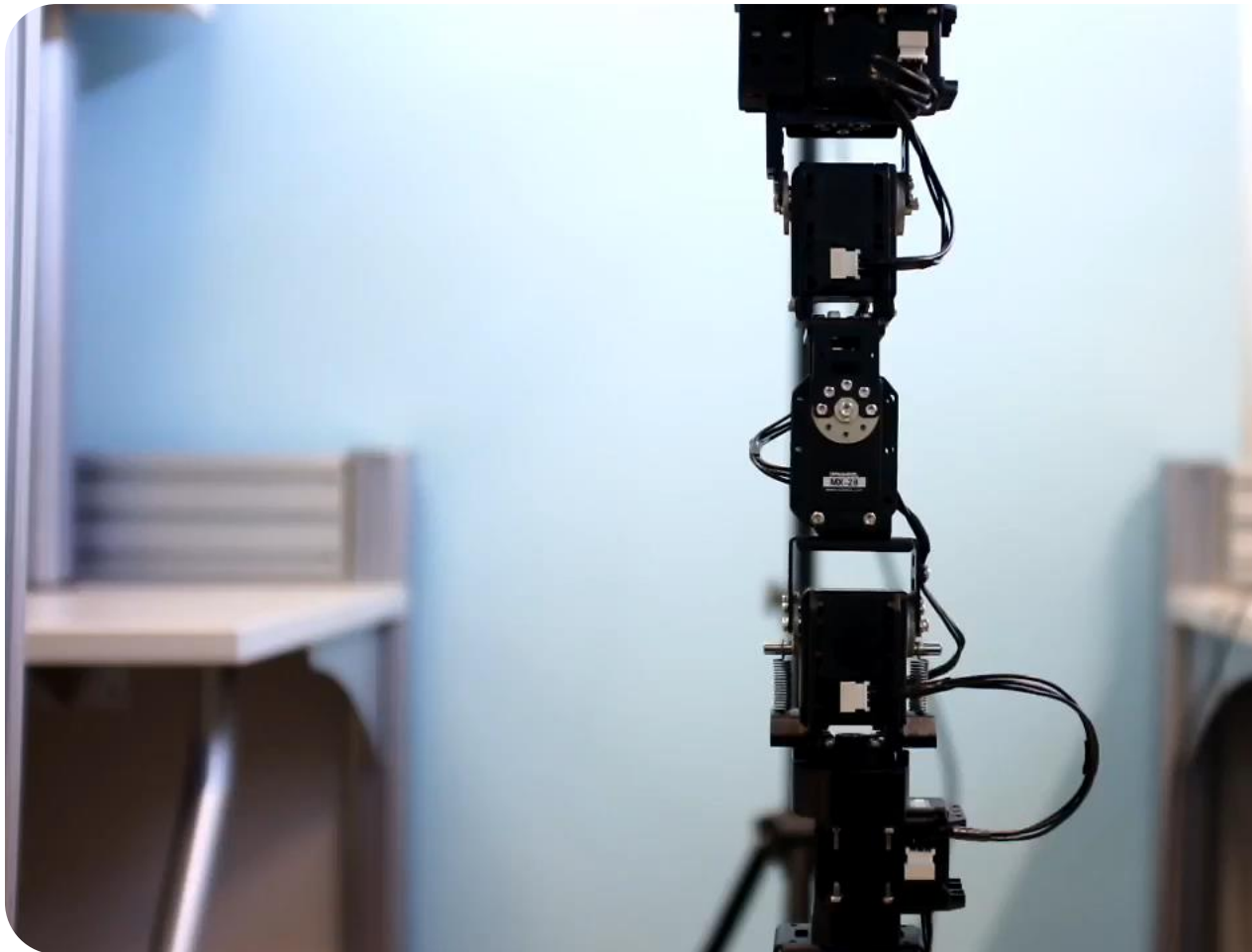


**Figure 2.** We performed software simulations and physical experiments to better understand ultrasonic beamforming in air (seen here from above, 40 kHz transducers with 13mm on-center spacing). Yellow denotes high acoustic energy, while blue denotes low energy. See also Video Figure.

So far haptics are all from **body-worn** devices

Other approaches to offer tangible feedback for VR? – Encountered Haptic

# Snake Charmer: Physically Enabling Virtual Objects



## Snake Charmer: Physically Enabling Virtual Objects

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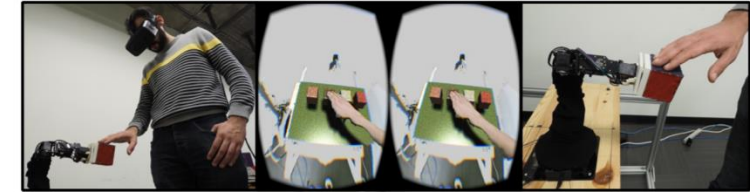


Figure 1: A user wears a head-mounted display to render a virtual scene. When the user attempts to touch a virtual object, the robotic arm spatially aligns with that object's virtual representation and provides a physical surface, matching one or more of the object's shape, texture, and temperature, for the user to touch and feel.

### ABSTRACT

Augmented and virtual reality have the potential of being indistinguishable from the real world. Holographic displays, including head mounted units, support this vision by creating rich stereoscopic scenes, with objects that appear to float in thin air - often within arm's reach. However, one has but to reach out and grasp nothing but air to destroy the suspension of disbelief. Snake-charmer is an attempt to provide physical form to virtual objects by revisiting the concept of *Robotic Graphics* or *Encountered-type Haptic* interfaces with current commodity hardware. By means of a robotic arm, Snake-charmer brings physicality to a virtual scene and explores what it means to truly interact with an object. We go beyond texture and position simulation and explore what it means to have a physical presence inside a virtual scene. We demonstrate how to render surface characteristics beyond texture and position, including temperature; how to physically move objects; and how objects can physically interact with the user's hand. We analyze our implementation, present the performance characteristics, and provide guidance for the construction of future physical renderers.

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### INTRODUCTION

*Virtual reality* has long been sought in both academic and corporate labs. In recent years, advances in pixel densities, display latency, tracking, and other innovations have brought forward a new generation of head-mounted displays. These displays have brought increasingly realistic virtual reality to consumer-level devices, and demonstrate the power of head-mounted displays for creating a sense of realism.

These efforts have largely focused on visual and auditory rendering; largely absent from these recent commercial offerings is rendering for the sense of touch. Of course, significant past efforts have been expended to attempt to further augment virtual reality with physicality, but each approach seen so far has distinct limitations. As an example, the popular *Phantom* device [21] is highly effective at producing the feeling of poking at an object with a handheld probe - which must remain in the user's hand throughout the experience. While past efforts have attempted to provide hands-free physical feedback, their reliance on air or electrical signals limits their range of sensation [15, 20, 27].

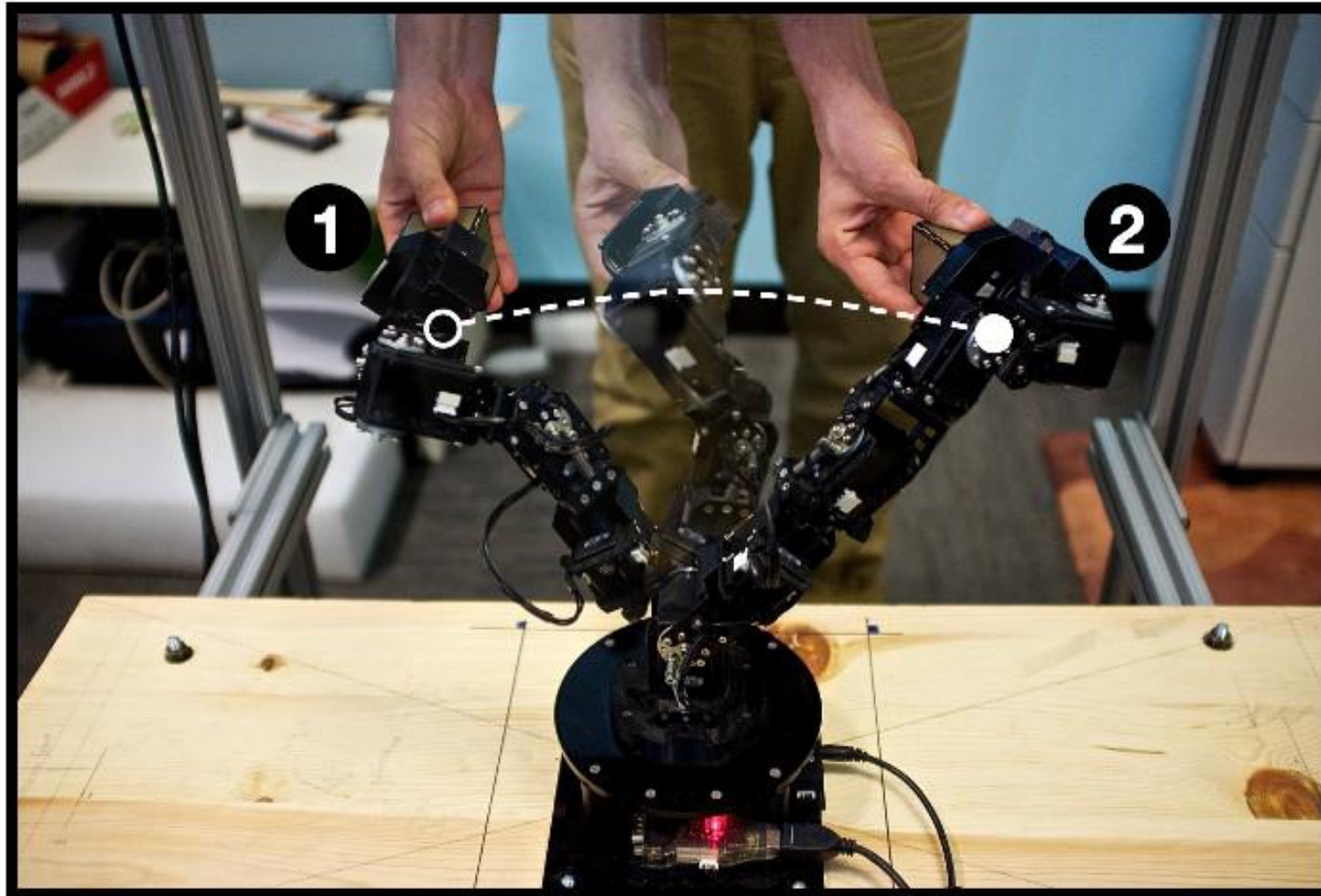
Another approach, known as *Robotic Graphics* or as *Encountered-type Haptic* interfaces [22, 32], utilizes robotic arms as actual physical objects to provide haptic feedback. They provide solid physical feedback, without requiring anything to be held in the hand. In this paper, we present *Snake Charmer*, shown in Figure 1, which builds on this past work of encountered-type haptic interfaces. Snake Charmer combines a head-mounted display (HMD) and, similar to past work, a robotic arm to dynamically simulate the physical presence of virtual content. We improve on earlier work

TEI 2016

Araujo et.al.



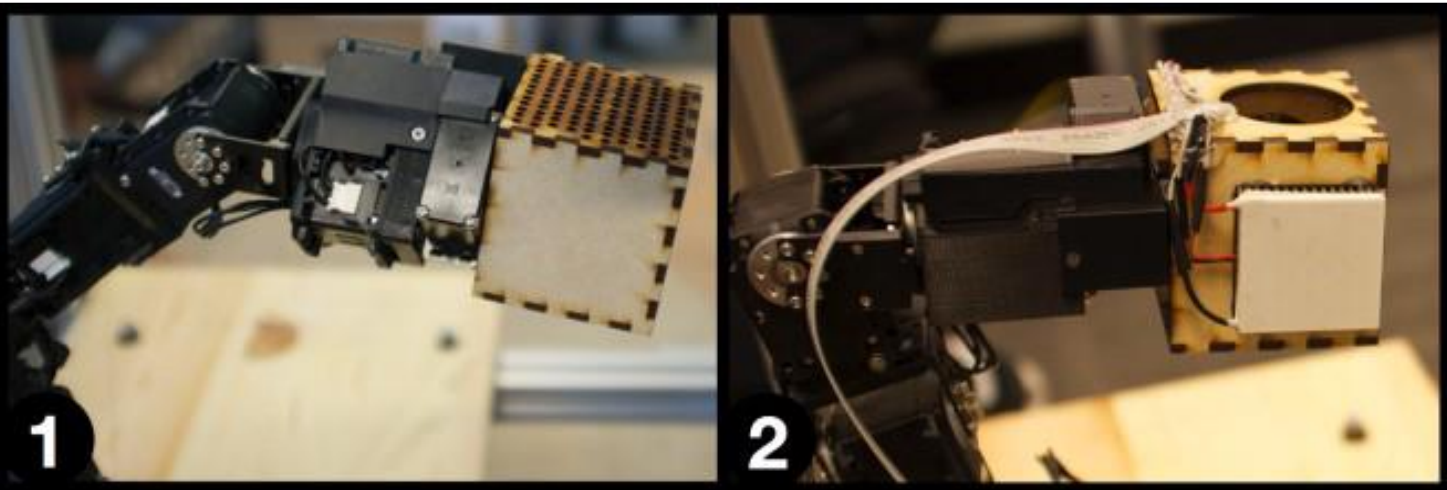
Based on hand's trajectory and VR content  
Robotic arm will pose the corresponding surface at the right location



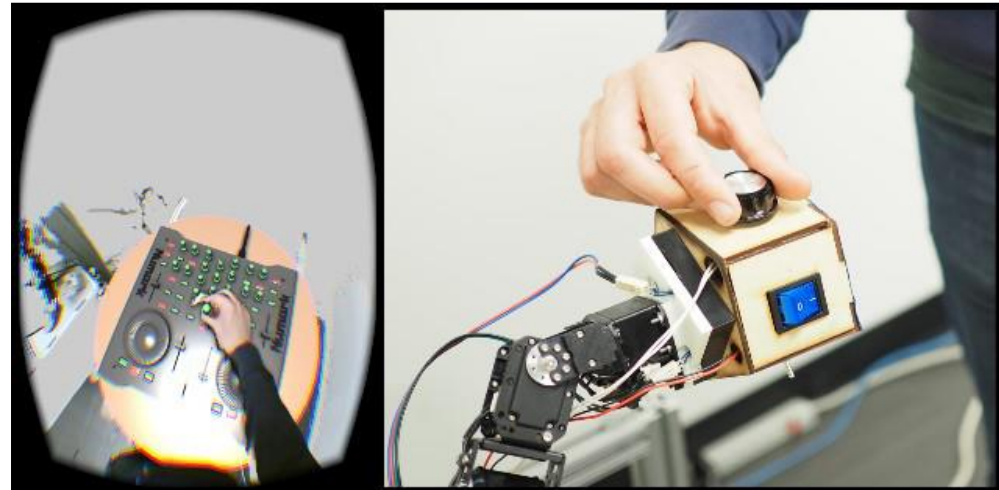
Back-driving: the user can physically move the virtual object.



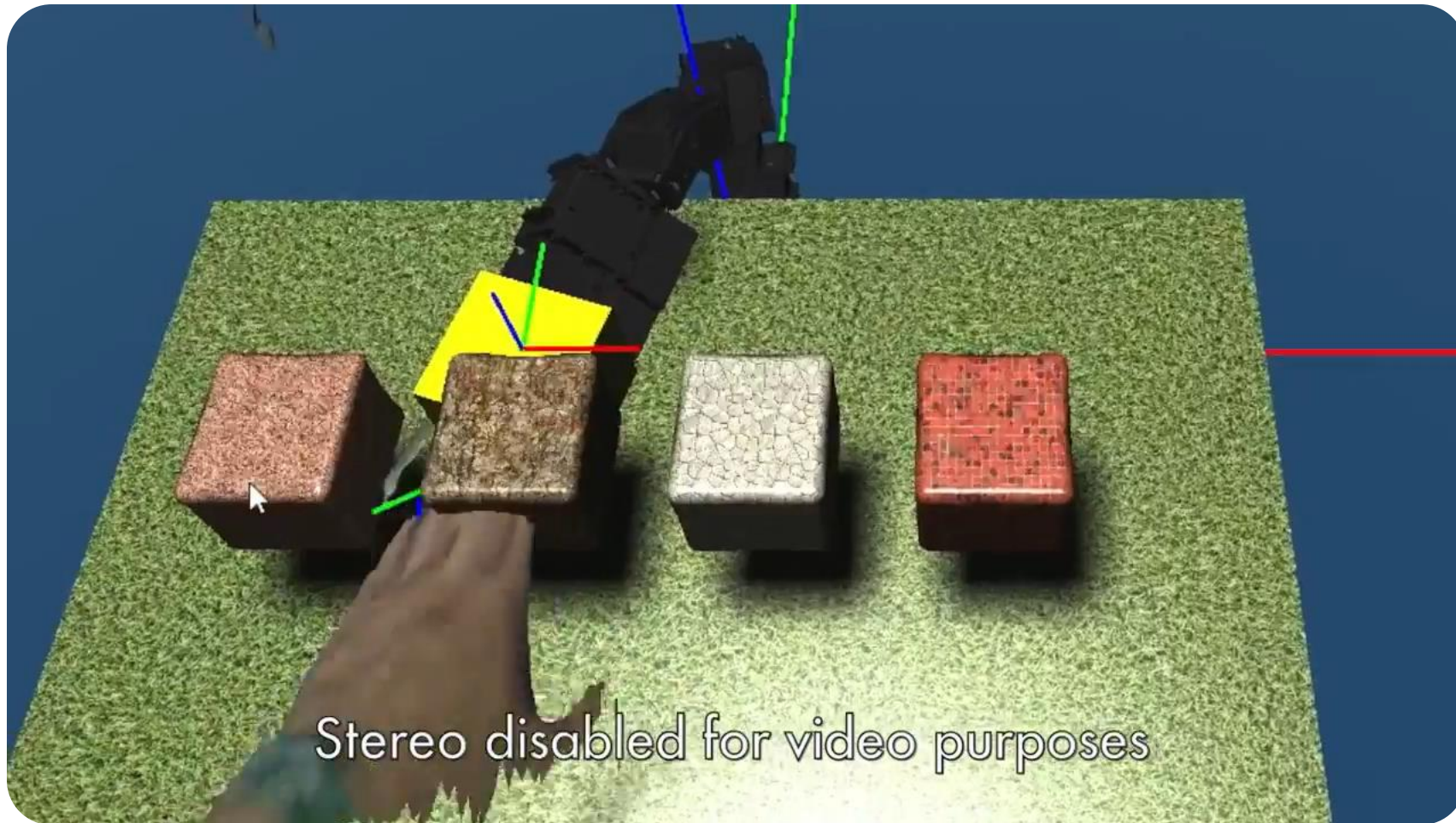
Robotic arm can change the interactive surface based on VR content  
Even change to active props



Air flow; Temperature



virtual DJ mixer



Robotic arm has its range -> which can be an limitation for the interaction area  
Improvement?

The number of physical props and the speed at which they can be changed seem to be major bottlenecks for encountered haptics?

# Haptic Retargeting

## Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality

Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson  
Microsoft Research

SIGCHI 2016

VR & Feedback

#chi4good, CHI 2016, San Jose, CA, USA

### Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences

Mahdi Azmandian<sup>1,2</sup>, Mark Hancock<sup>1,3</sup>, Hrvoje Benko<sup>1</sup>, Eyal Ofek<sup>1</sup>, Andrew D. Wilson<sup>1</sup>  
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<sup>3</sup>University of Waterloo Waterloo, ON, Canada mark.hancock@uwaterloo.ca

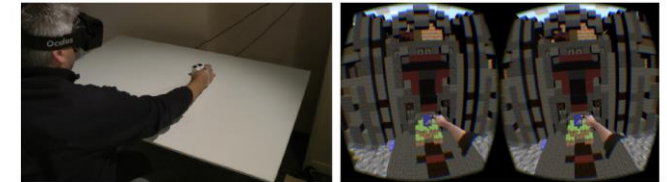


Figure 1. User building a virtual castle by arranging and stacking multiple virtual cubes mapped to a single physical cube.

#### ABSTRACT

Manipulating a virtual object with appropriate passive haptic cues provides a satisfying sense of presence in virtual reality. However, scaling such experiences to support multiple virtual objects is a challenge as each one needs to be accompanied with a precisely-located haptic proxy object. We propose a solution that overcomes this limitation by hacking human perception. We have created a framework for repurposing passive haptics, called *haptic retargeting*, that leverages the dominance of vision when our senses conflict. With haptic retargeting, a single physical prop can provide passive haptics for multiple virtual objects. We introduce three approaches for dynamically aligning physical and virtual objects: world manipulation, body manipulation and a hybrid technique which combines both world and body manipulation. Our study results indicate that all our haptic retargeting techniques improve the sense of presence when compared to typical wand-based 3D control of virtual objects. Furthermore, our hybrid haptic retargeting achieved the highest satisfaction and presence scores while limiting the visible side-effects during interaction.

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DOI: <http://dx.doi.org/10.1145/2858036.2858226>

#### Author Keywords

Virtual Reality; Haptics; Perception.

#### ACM Classification Keywords

H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial, Augmented, and Virtual Realities; H.5.2 [User Interfaces]: Haptic I/O.

#### INTRODUCTION

Over the past few years, virtual reality (VR) has experienced a resurgence. With the proliferation of consumer-level head-mounted displays and motion tracking devices, an unprecedented quantity of immersive experiences have been created. Though optics, rendering, and audio technologies have improved substantially, a component that has remained underdeveloped is haptics—the sense of touch expected when reaching out and grabbing virtual objects.

A key objective in virtual reality is establishing a sense of presence. When shown an environment with photorealistic rendering, people can be convinced by the illusion of reality, and describe the experience as immersive [37], but when reaching out to touch a virtual object, the illusion can be shattered when one's hand unexpectedly passes through the rendered visuals.

One method for adding a sense of touch to virtual objects is through *passive haptics* [17], where physical props are placed around the environment to match their virtual counterparts. The result can be a compelling tactile sensation when reaching and touching an object. However, this technique requires each virtual object to have a physical prop of the same size and shape, in the correct position, to create this

CHI 2016

Azmandian et.al.

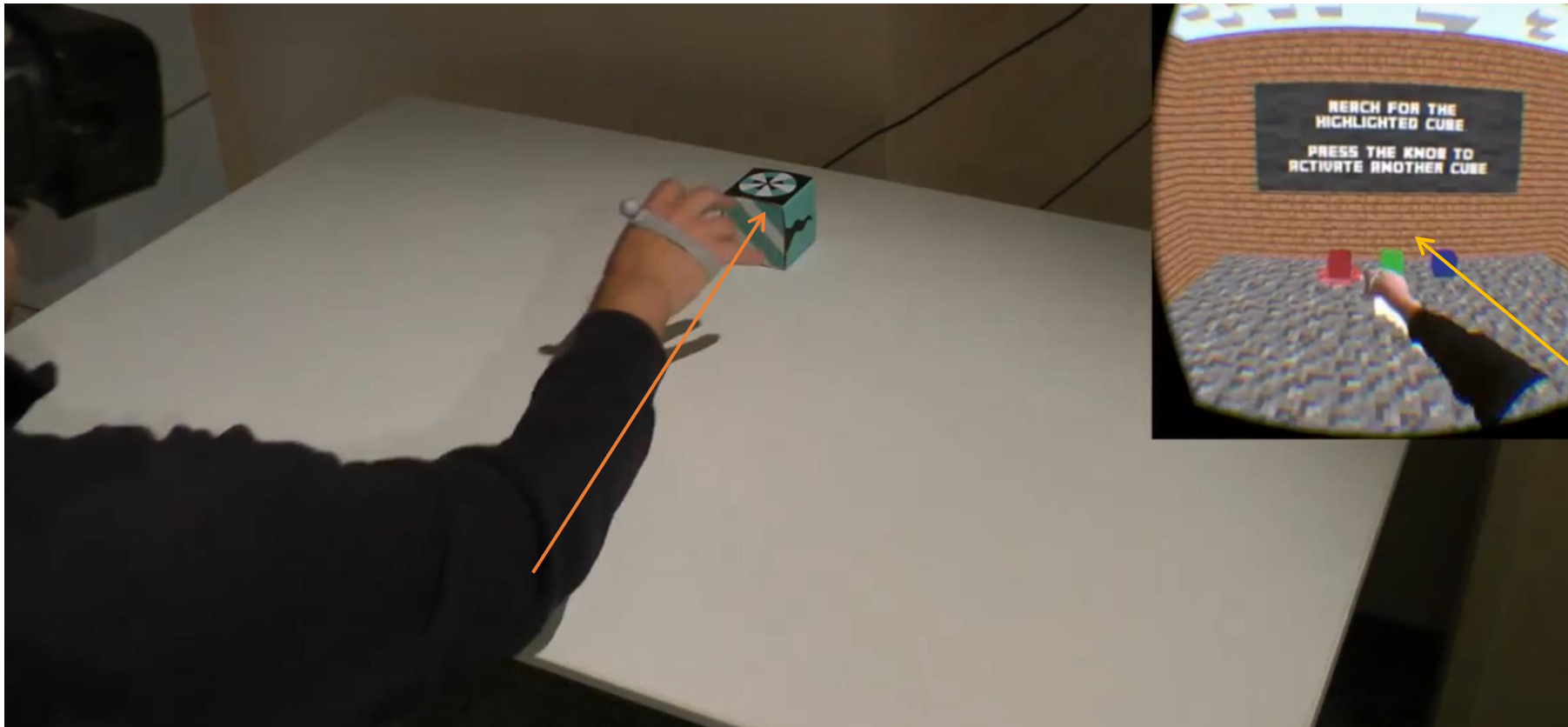
Repurposes a single physical prop to provide a passive haptic sensation for a variety of virtual world objects thus increasing the user's sense of presence and improving the overall quality of the experience

Why this works? -> when senses conflict, vision often dominates.

**Body Warping** – Manipulating the virtual representation of the person’s body (e.g., arms) such that, at the point of contact with the real object, the body part also appears to be at the virtual object;

**World Warping** – Manipulating the virtual world’s coordinate system to align virtual and physical objects;

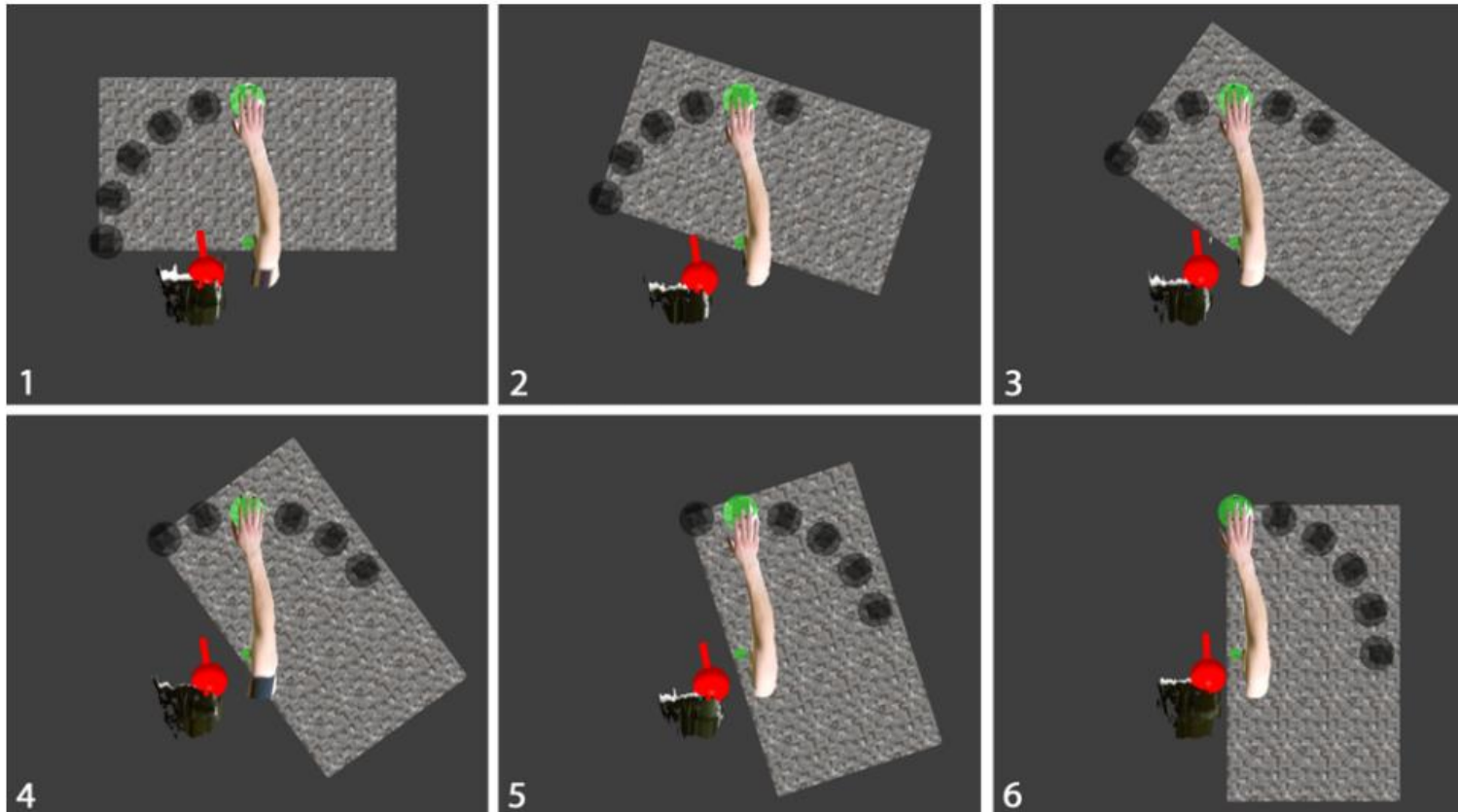
**Hybrid Warping** – A dynamic combination of Body and World Warping.



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**Hybrid Warping** – A dynamic combination of Body and World Warping.



# **Haptic Retargeting**

## Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences

Mahdi Azmandian, Mark Hancock  
Hrvoje Benko, Eyal Ofek, Andy Wilson  
Microsoft Research

SIGCHI 2016

Next?

Does the robotic arm have to be grounded to one location?

# RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots

## RoomShift

Room-scale Dynamic Haptics for VR  
with Furniture-moving Swarm Robots

x2



# How to add physical feedback to VR systems

If you are going to design a system to **offer full body physical feedback**, how will you do it?



## How to add physical feedback to VR systems

If you are going to design a system to offer full body haptics **and motion**, how will you do it?



VRLADER

DATENFLUG

DATENFLUG



Motion platforms are expensive, large, heavy and thus stationary – Alternative approach?



Human actuators!



**Haptic Turk: a Motion Platform Based on People**



let me fly a virtual hangglider

How does it work?

## Haptic Turk: a Motion Platform Based on People

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### ABSTRACT

Motion platforms are used to increase the realism of virtual interaction. Unfortunately, their size and weight is proportional to the size of what they actuate. We present *haptic turk*, a different approach to motion platforms that is light and mobile. The key idea is to replace motors and mechanical components with humans. All haptic turk setups consist of a *player* who is supported by one or more *human-actuators*. The player enjoys an interactive experience, such as a flight simulation. The motion in the player's experience is generated by the actuators who manually lift, tilt, and push the player's limbs or torso. To get the timing and force right, timed motion instructions in a format familiar from rhythm games are displayed on actuators' mobile devices, which they attach to the player's body. We demonstrate a range of installations based on mobile phones, projectors, and head-mounted displays. In our user study, participants rated not only the experience as player as enjoyable (6.1/7), but also the experience as an actuator (4.4/7). The approach of leveraging humans allows us to deploy our approach anytime anywhere, as we demonstrate by deploying at an art festival in the Nevada desert.

### Author Keywords

Haptics; force-feedback; motion platform; immersion.

### ACM Classification Keywords

I5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces.

### INTRODUCTION

For a long time, the key to immersion in interactive experience and games was sought in photorealistic graphics [8]. More recently, game makers made games more immersive by requiring players to physically enact the game such as with Wii (<http://wii.com>) and Kinect [26]. With graphics and user interaction now part of many games, many researchers argue that *haptics and motion* are the next step towards increasing immersion and realism, i.e., applying the forces triggered by the game onto the player's body during the experience.

While some game events can be realistically rendered using one or more vibrotactile actuators (e.g., driving over gravel in a racing game [14]), a much larger number of gaming events result in *directional forces*, such as artificial

railing. Such events have been simulated using motion platforms [27]. Motion platforms are able to move one or more users around and have been used to add realism to flight simulators [22] and theme park rides.

Unfortunately, the size and weight of motion platforms tends to be proportional to what they actuate. As a result, motion platforms not only tend to be prohibitively expensive, but also large and heavy and thus stationary, limiting their use to arcades and lab environments.



Figure 1: Haptic turk allows producing motion experiences anywhere anytime. Here, the suspended player is enjoying an immersive hang gliding game. The four actuators create just the right physical motion to fill in the player's experience.

In this paper, we present *haptic turk*, a software platform that allows experiencing motion anywhere there is people. Its key idea is to substitute the motors and mechanical components of traditional motion platforms with humans.

### HAPTIC TURK

Haptic turk is a motion platform based on people. The name is inspired by the 18<sup>th</sup> century chess automaton "The Turk" [20] that was powered by a human chess master.

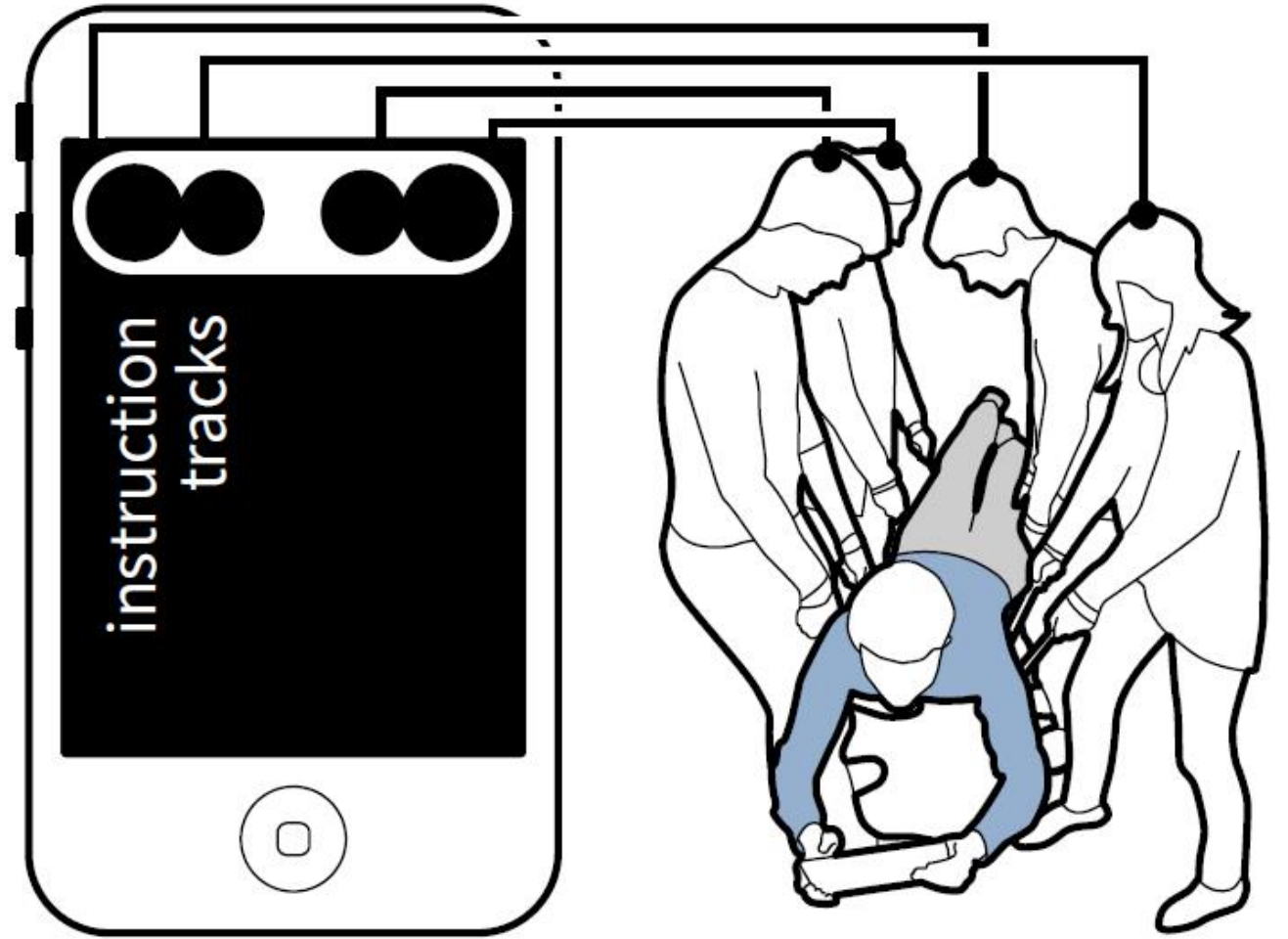
The specific configuration shown in Figure 1 involves one *player* located in the center. The player is enjoying an immersive experience, here a first-person simulation of flying a hang-glider, running on a hand-held device (iPad). In the shown setup, the player can steer the hang-glider by tilting the iPad.

UIST 2015

Cheng et.al.

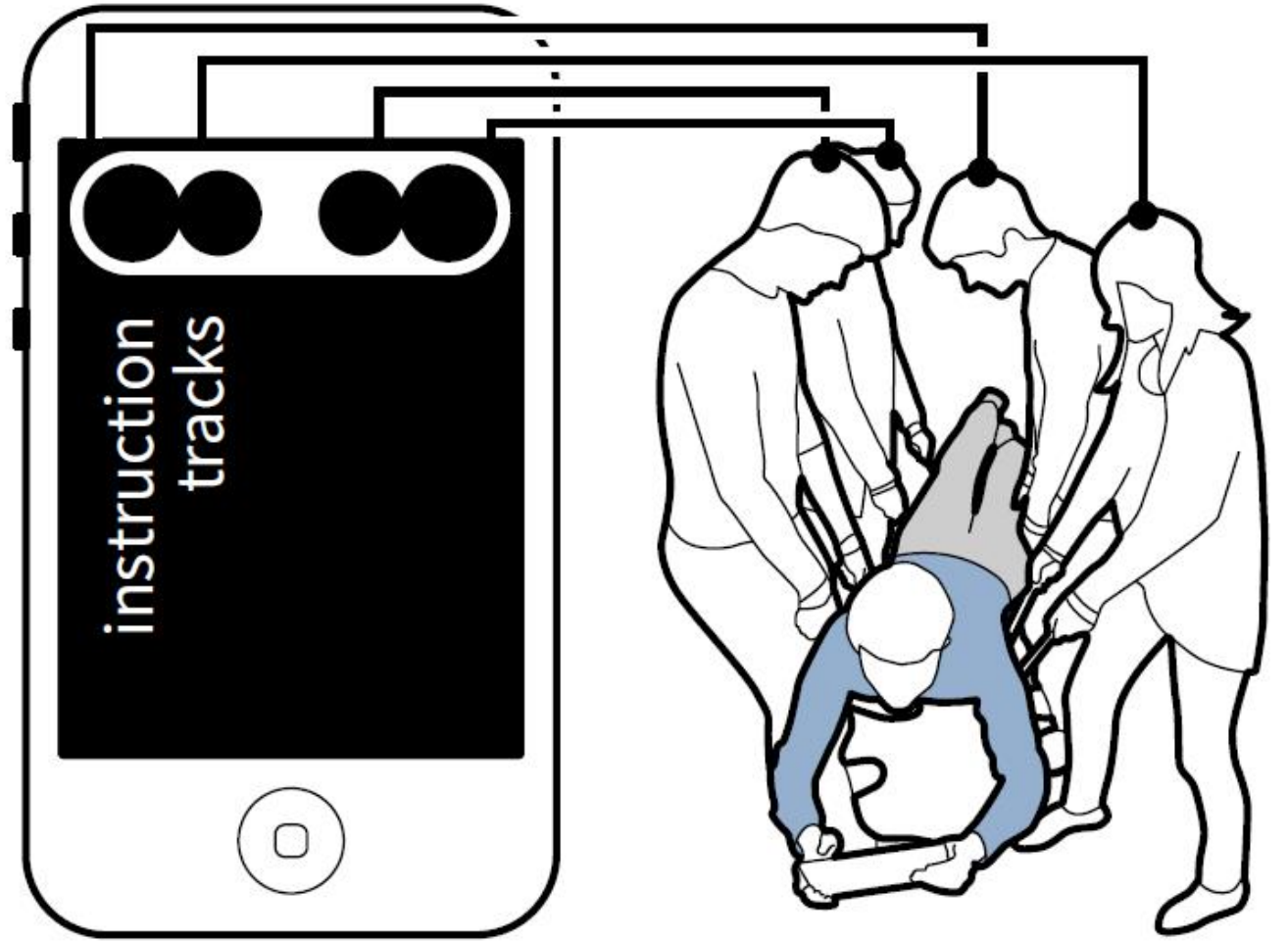


A scheduler for each of the human actuator  
The instructions can generate **preemptive** warnings  
Similar to Tap-Tap-Revenge





Because its mainly a software contribution, it is scalable and flexible





Limitation?

1. We don't always have multiple friends available
2. 4+ are supporting and only 1 is playing



### **Mutual Human Actuation**

run pairs of users **at the same time** and have them provide human actuation to **each other**



## Mutual Human Actuation

Lung-Pan Cheng, Sebastian Marwecki, Patrick Baudisch  
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Figure 1: (a) This user, alone in his virtual world, is trying to pull a huge creature out of the water. He feels how the creature is struggling and pulling on his fishing rod. (b) At the same time, this other user, also alone in her virtual world, is struggling to control her kite during a heavy storm, which is whipping her kite through the air. (c) While users' experiences of force might suggest the presence of a force feedback machine, Mutual Turk achieves force feedback instead using *shared props* that transmit forces *between* users. The system orchestrates users so as to actuate their prop at just the right moment and with just the right force to produce the correct experience for the other user.

### ABSTRACT

Human actuation is the idea of using people to provide large-scale force feedback to users. The Haptic Turk system, for example, used four human actuators to lift and push a virtual reality user; TurkDeck used ten human actuators to place and animate props for a single user. While the experience of human actuators was decent, it was still inferior to the experience these people could have had, had they participated as a user. In this paper, we address this issue by making *everyone* a user. We introduce *mutual* human actuation, a version of human actuation that works without dedicated human actuators. The key idea is to run pairs of users at the same time and have them provide human actuation to *each other*. Our system, Mutual Turk, achieves this by (1) offering shared props through which users can exchange forces while obscuring the fact that there is a human on the other side, and (2) synchronizing the two users' timelines such that their way of manipulating the shared props is consistent across both virtual worlds. We demonstrate mutual human actuation with an example experience in which users pilot kites through storms, tug fish out of ponds, are pummeled by hail, battle monsters, hop across chasms, push loaded carts, and ride in moving vehicles.

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### Author Keywords

Virtual reality; haptics; immersion; Haptic Turk.

### ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

### INTRODUCTION

Many researchers argue that the next step in virtual reality is to allow users to not only see and hear, but also *feel* virtual worlds [8]. Researchers initially explored the use of mechanical machinery for that purpose, such as exoskeletons [1] or passive [13,19], robotically actuated [11] props.

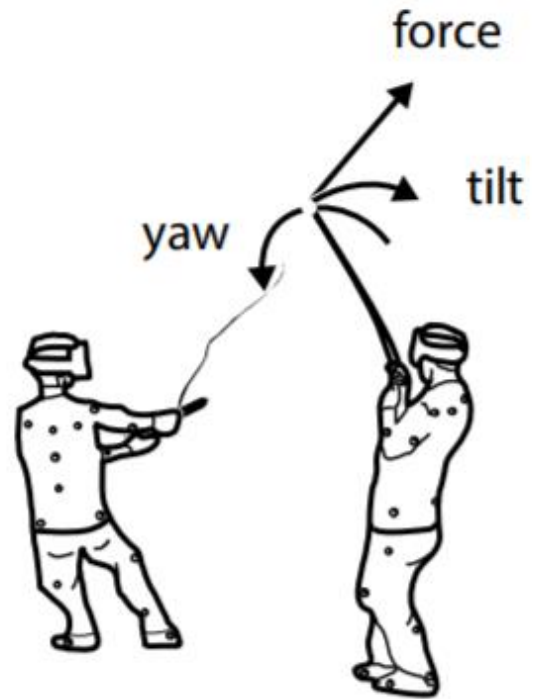
Unfortunately, the size and weight of such mechanical equipment tends to be proportional to what they actuate, often constraining such equipment to arcades and lab environments.

Researchers therefore proposed creating similar effects by replacing the mechanical actuators with *human* actuators. Haptic Turk, for example, uses four such human actuators to lift, bump, and shake a single human user [2]. TurkDeck brings human actuation to real walking [3]. It allows a single user to explore a virtual reality experience that is brought to life by ten human actuators that continuously rearrange physical props and apply forces to the user.

UIST 2017

Cheng et.al.

## Shared Props

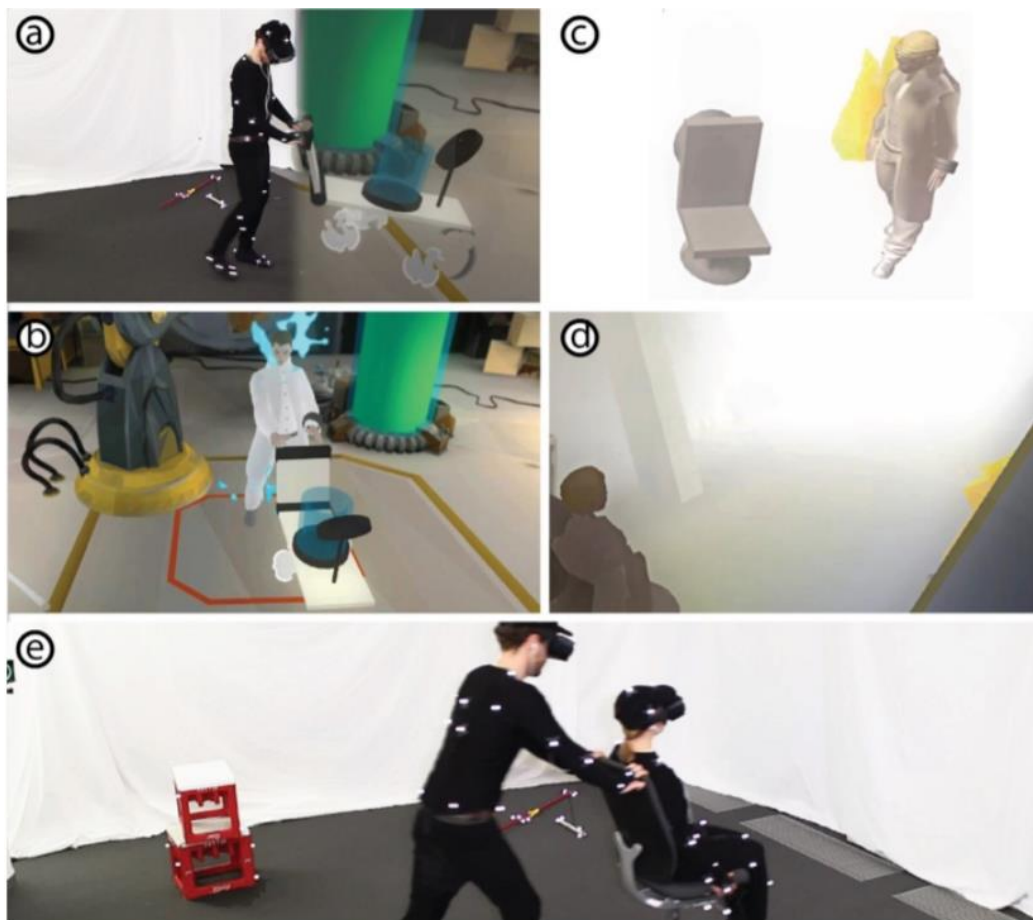


1. Continuous exchange of force between users' hands

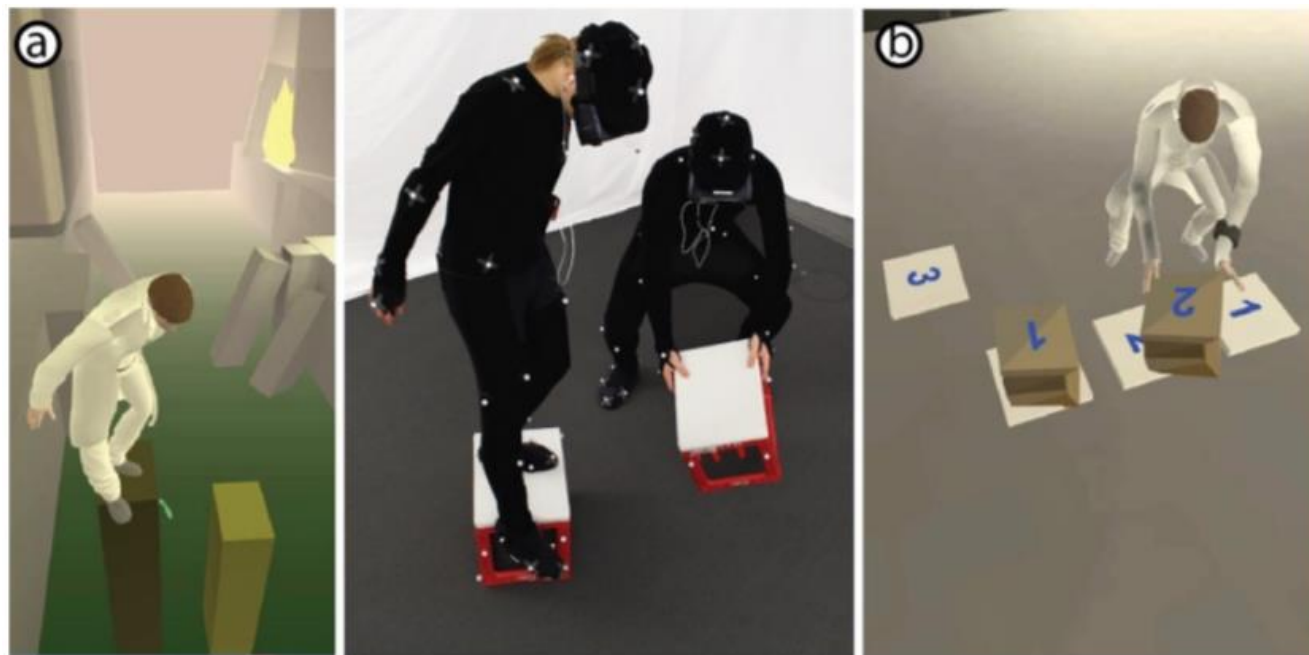


2. Impact

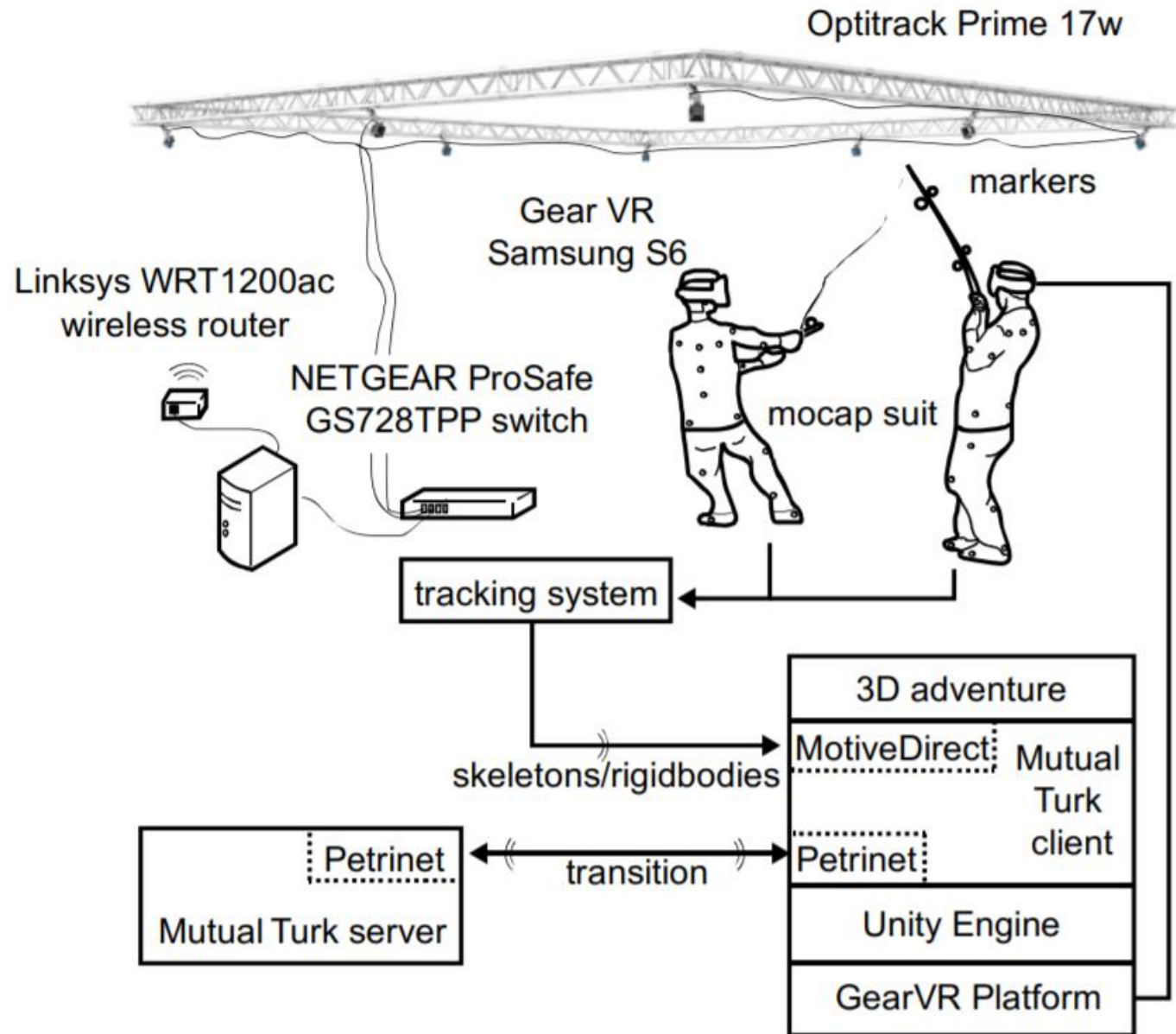
## Shared Props



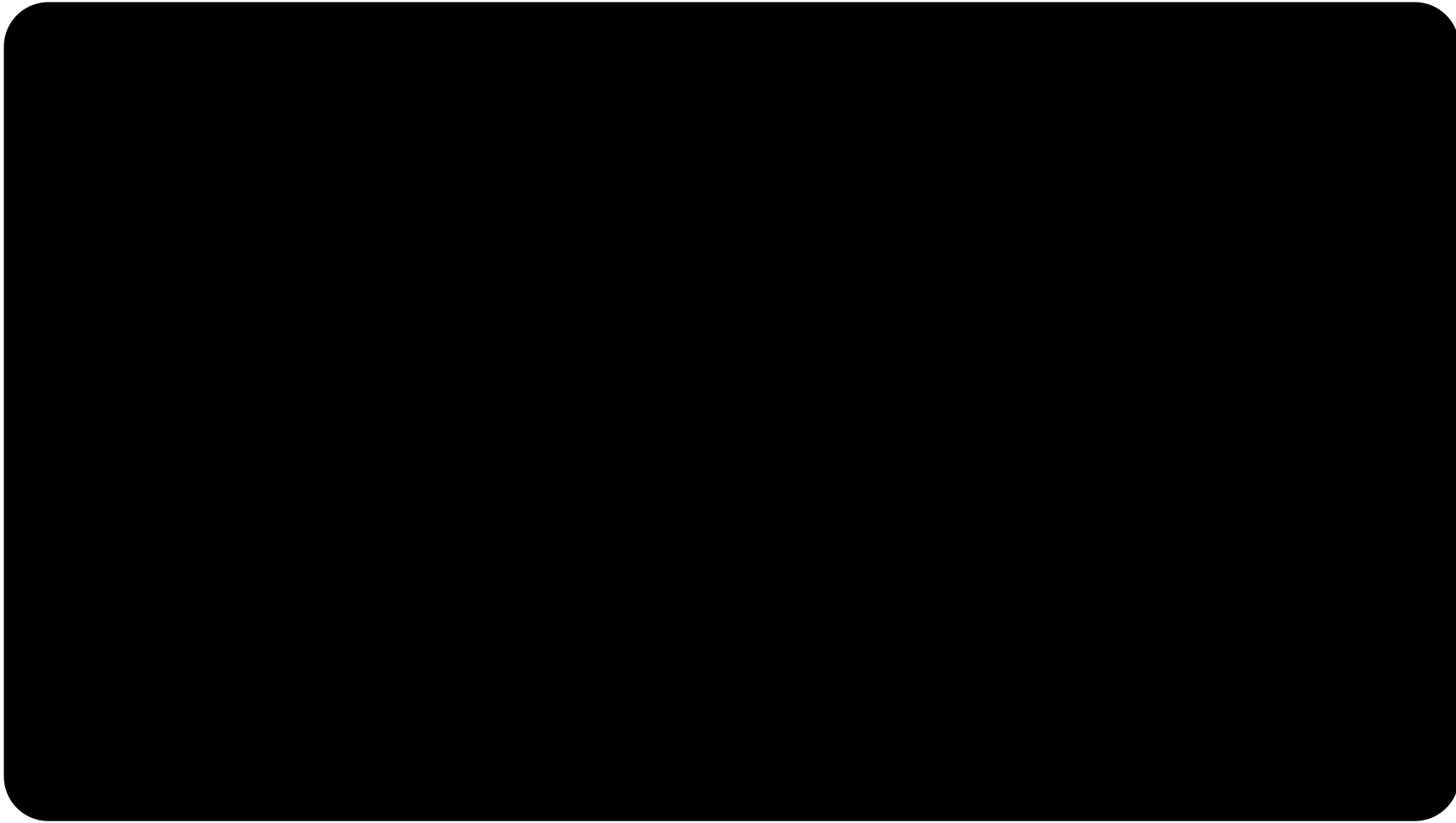
3. Continuous motion



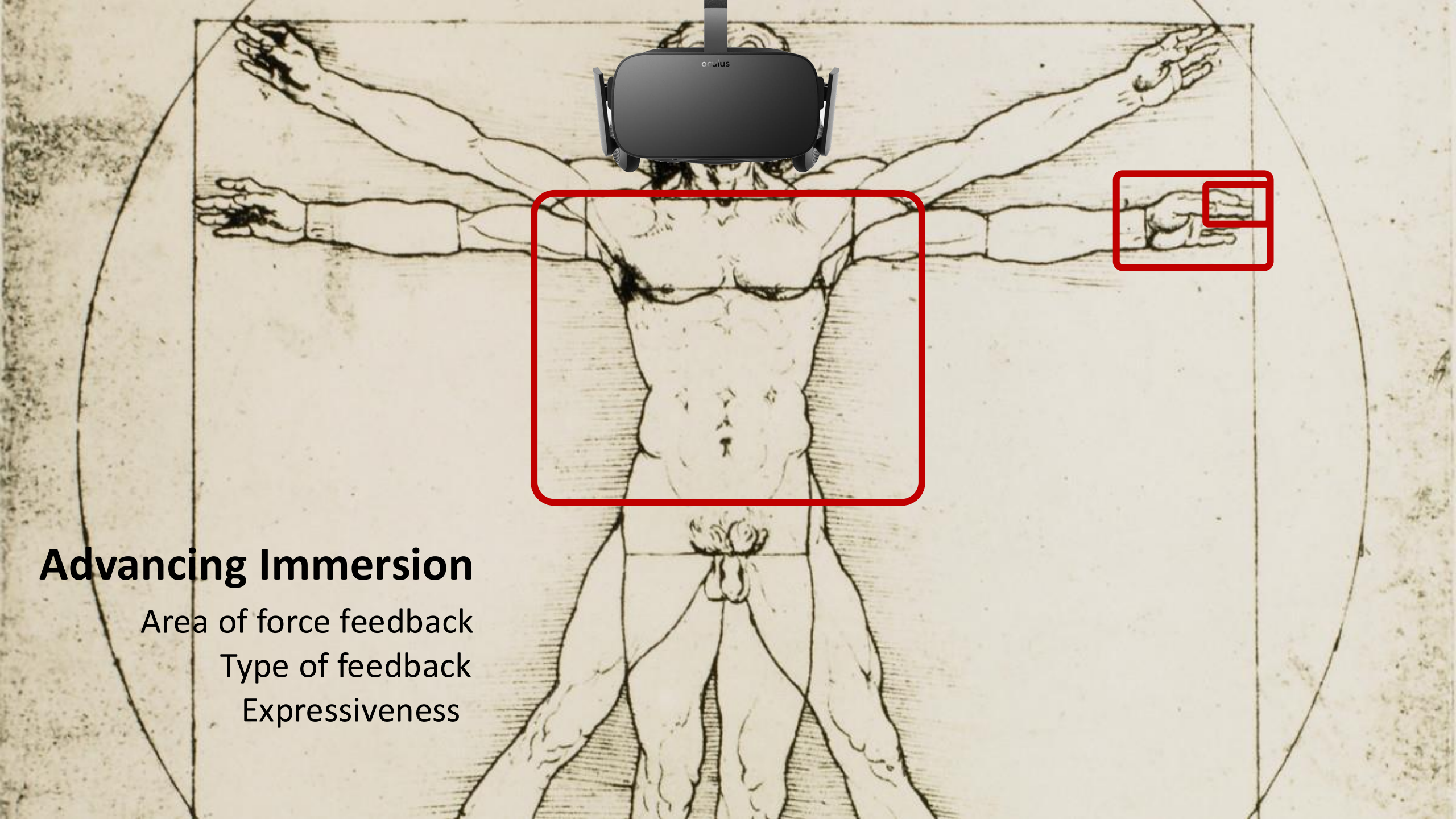
4. Rearranging props



But again, mainly a software scheduling problem



VR scenes need to be carefully designed to map the mutual motion



## Advancing Immersion

Area of force feedback

Type of feedback

Expressiveness

# Optional readings

CHI 2020 Paper

CHI 2020, April 25–30, 2020, Honolulu, HI, USA

## Wireality: Enabling Complex Tangible Geometries in Virtual Reality with Worn Multi-String Haptics

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### ABSTRACT

Today's virtual reality (VR) systems allow users to explore immersive new worlds and experiences through sight. Unfortunately, most VR systems lack haptic feedback, and even high-end consumer systems use only basic vibration motors. This clearly precludes realistic physical interactions with virtual objects. Larger obstacles, such as walls, railings, and furniture are not simulated at all. In response, we developed Wireality, a self-contained worn system that allows for individual joints on the hands to be accurately arrested in 3D space through the use of retractable wires that can be programmatically locked. This allows for convincing tangible interactions with complex geometries, such as wrapping fingers around a railing. Our approach is lightweight, low-cost, and low-power, criteria important for future, worn consumer uses. In our studies, we further show that our system is fast-acting, spatially-accurate, high-strength, comfortable, and immersive.

### Author Keywords

Virtual Reality; Haptics; Force Feedback; String-Driven; Touch; Grasp.

### CSS Concepts

Human-centered computing → Human computer interaction (HCI) → Interaction devices → Haptic devices.

### INTRODUCTION

Virtual reality (VR) systems, such as the Oculus Quest [15] and HTC Vive [28], use controllers for tracking the hands, capturing buttoned input, and delivering basic vibrotactile haptic feedback. The latter is insufficient to produce immersive physical interactions with virtual objects. More critically, large obstacles like walls, railings, and furniture – key elements in most VR worlds – are not simulated at all. The current state-of-the-art in consumer VR systems is a vibration alert when a hand intersects a virtual object or obstacle – falling far short of any reality.

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ACM ISBN 978-1-4803-6708-0/20/04.  
DOI: <https://dx.doi.org/10.1145/3313831.3376470>



Figure 1. Wireality enables strong, whole-hand haptic feedback for complex objects in VR experiences.

This shortcoming has long been recognized, and researchers have looked into ways to bring rich haptics to VR experiences for many decades [36]. As we will review in greater detail, most systems have focused on hand haptics, such that virtual objects feel as though they are being held and are able to be moved in space. Less common are systems that attempt to arrest the hands *and* arms to simulate immovable objects, such as walls. To achieve this effect, systems often use mechanical exoskeletons [10, 23, 57] or fixed infrastructure in the environment [29, 40, 54], neither of which is particularly practical for consumer use.

We set out to design a new VR haptic system that was entirely self-contained and mobile. This implied a worn system, which in turn, meant our approach needed to be both lightweight and battery-powered. To simulate interactions with heavy or fixed objects, we needed a system that was both fast-acting and able to provide large arresting forces. Finally, in order to be a plausible consumer accessory, it should cost no more than \$50 in volume production.

In this paper, we present our work on *Wireality*, which meets the above design criteria. Our system is comprised of modular, spring-loaded cables, which we can programmatically lock with a ratchet gear and a solenoid-driven pawl (Figure 1). This locking action takes under 30ms, provides up to 180N of arresting force, and yet only consumes 0.024mWh of energy (allowing our approach to be battery powered and mobile). Each module is responsible for limiting one degree of freedom on the hand. With many modules acting together as a unit, Wireality enables interactions with

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## Mutual Human Actuation

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Figure 1: (a) This user, alone in his virtual world, is trying to pull a huge creature out of the water. He feels how the creature is struggling and pulling on his fishing rod. (b) At the same time, this other user, also alone in her virtual world, is struggling to control her kite during a heavy storm, which is whipping her kite through the air. (c) While users' experiences of force might suggest the presence of a force feedback machine, Mutual Turk achieves force feedback instead using *shared props* that transmit forces *between* users. The system orchestrates users so as to actuate their prop at just the right moment and with just the right force to produce the correct experience for the other user.

### ABSTRACT

Human actuation is the idea of using people to provide large-scale force feedback to users. The Haptic Turk system, for example, used four human actuators to lift and push a virtual reality user; TurkDeck used ten human actuators to place and animate props for a single user. While the experience of human actuators was decent, it was still inferior to the experience these people could have had, had they participated as a user. In this paper, we address this issue by making *everyone* a user. We introduce *mutual* human actuation, a version of human actuation that works without dedicated human actuators. The key idea is to run pairs of users at the same time and have them provide human actuation to *each other*. Our system, Mutual Turk, achieves this by (1) offering shared props through which users can exchange forces while obscuring the fact that there is a human on the other side, and (2) synchronizing the two users' timelines such that their way of manipulating the shared props is consistent across both virtual worlds. We demonstrate mutual human actuation with an example experience in which users pilot kites through storms, tug fish out of ponds, are pummeled by hail, battle monsters, hop across chasms, push loaded carts, and ride in moving vehicles.

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### INTRODUCTION

Many researchers argue that the next step in virtual reality is to allow users to not only see and hear, but also *feel* virtual worlds [8]. Researchers initially explored the use of mechanical machinery for that purpose, such as exoskeletons [1] or passive [13,19], robotically actuated [11] props.

Unfortunately, the size and weight of such mechanical equipment tends to be proportional to what they actuate, often constraining such equipment to arcades and lab environments.

Researchers therefore proposed creating similar effects by replacing the mechanical actuators with *human* actuators. Haptic Turk, for example, uses four such human actuators to lift, bump, and shake a single human user [2]. TurkDeck brings human actuation to real walking [3]. It allows a single user to explore a virtual reality experience that is brought to life by ten human actuators that continuously rearrange physical props and apply forces to the user.

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