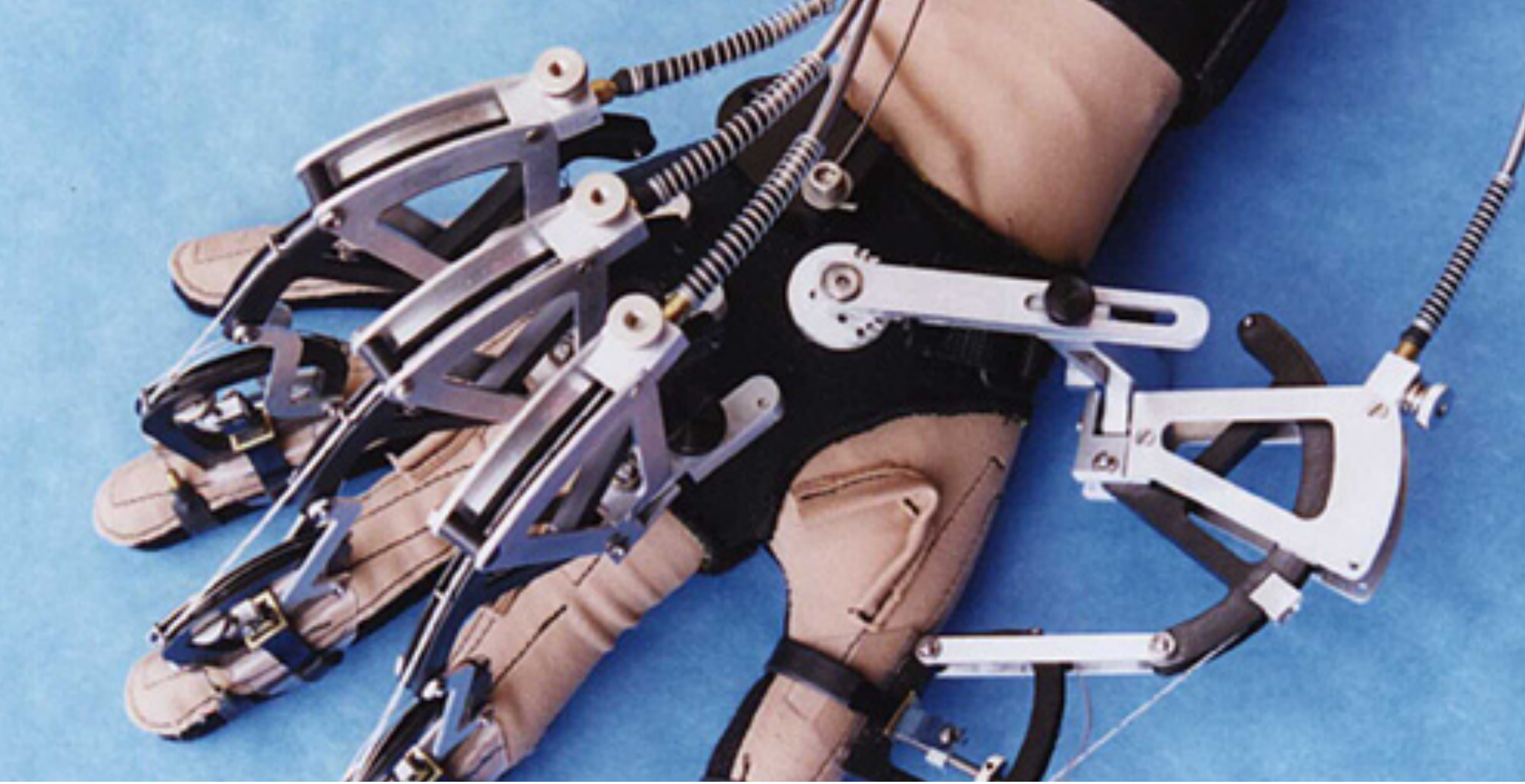


Haptics Technology

6.810 Engineering Interaction Technologies

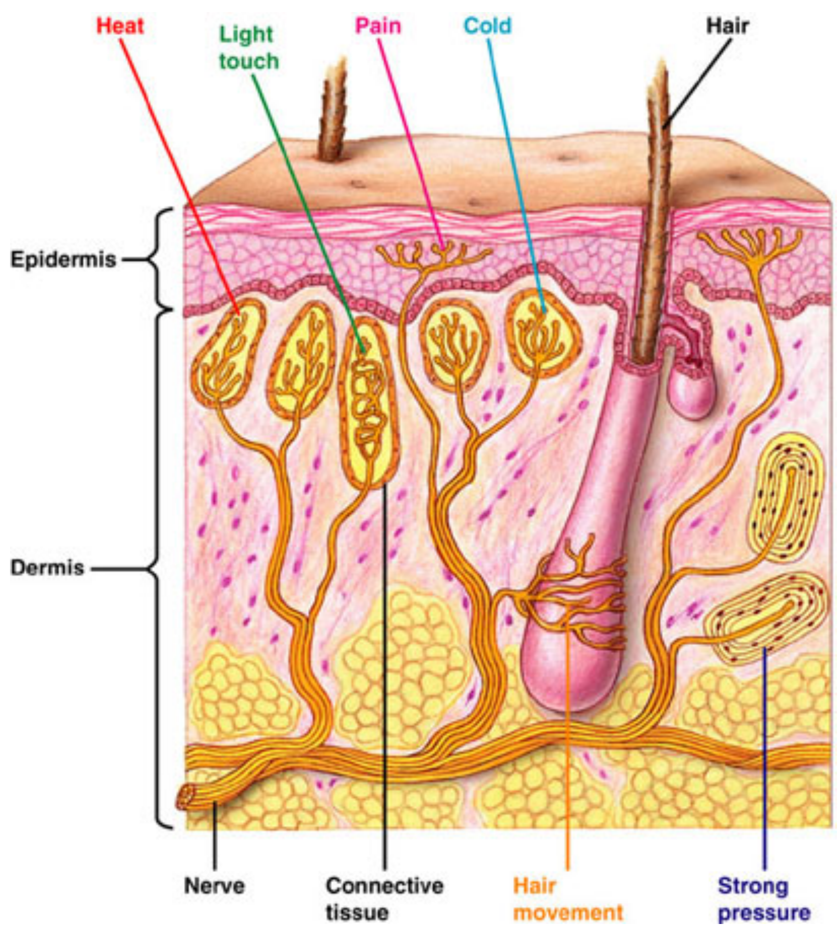
Prof. Stefanie Mueller | HCI Engineering Group

haptics technology:

- creates a sense of touch
- greek word *haptesthai* = to contact / to touch

what **sensations**
can you feel when you touch something?

<30 sec brainstorming>



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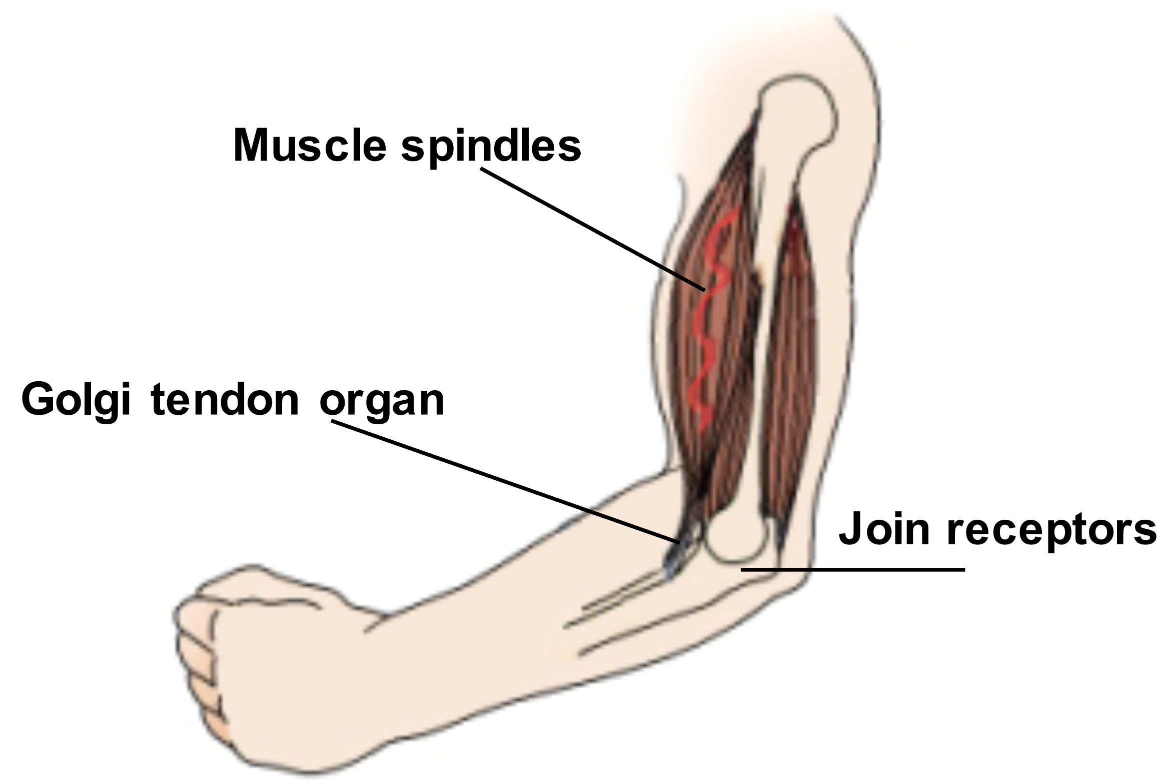


tactile sensation
through skin

(edges, curvature, and texture, hot/cold)

force sensation
through muscles

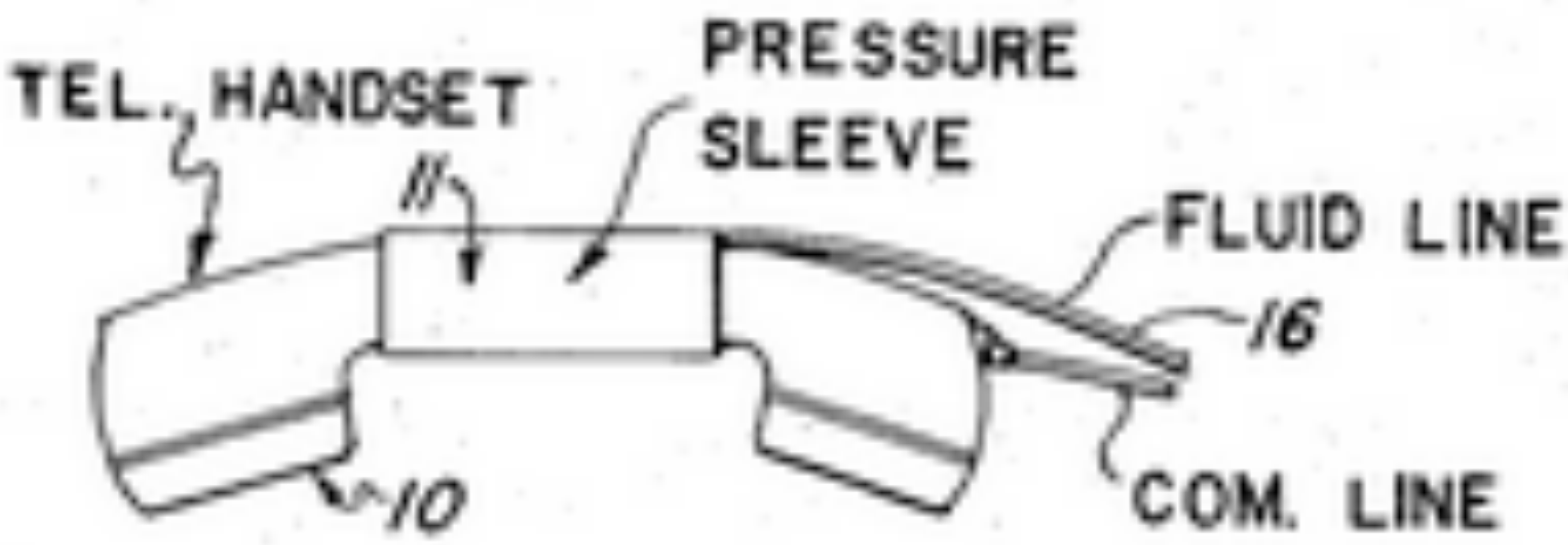
(hand position and conformation)

mainly used in VR …

… telepresence robotics …

… and for the visually impaired

history



1973 haptic phone

Tactile communication attachment

US 3780225 A

Publication number	US3780225 A
Publication type	Grant
Publication date	Dec 18, 1973
Filing date	Jan 3, 1972
Priority date	Jan 3, 1972
Inventors	T Shannon
Original Assignee	T Shannon
Export Citation	BiBTeX, EndNote, RefMan

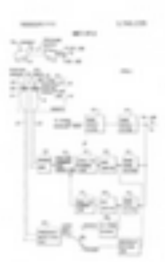
Patent Citations (4), Non-Patent Citations (1), Referenced by (5), Classifications (6)

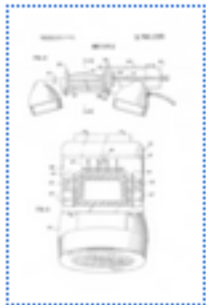
External Links: USPTO, USPTO Assignment, Espacenet

ABSTRACT

A tactile communication device including a responsive grip attachment and a control unit which are electro-mechanical in operation and are intended to be used at least in pairs, to establish or permit tactile communication between two or more parties. The two devices form a closed loop feedback control system whose output to each party is the pressure and volume variations of the responsive grip attachment experienced by both parties.

IMAGES (2)





DESCRIPTION (OCR text may contain errors)

CLAIMS available in

United States Patent Shannon Dec. 18, 1973 TACTILE COMMUNICATION OTHER PUBLICATIONS ATTA HMENT C IBM Technical Disclosure Bulletin, Portable Blood Inventor: Thomas Shannon 486 Broadway Pressure Monitor," L. J. Fiegel, Vol. 9 No. 6, Novem- New York ber 1966, page 558 [22] Filed: Jan. 3, 1972 Primary ExaminerWilliam C. Cooper [21] Appl' 214892 Assistant Examiner-Randall P. Myers 52 us. 01 179/2 A, 17/2 DP, 340/407 7 ABSTRACT gg A tactile communication device including a responsive [5 1 12 grip attachment and a control unit which are electro- Q I A 2 A mechanical in operation and are intended to be used at least in pairs, to establish or permit tactile communication between two or more parties. The two de- [56] References Cited vices form a closed loop feedback

1973 haptic phone

2010 haptic phone actually built

[Hemmert, Intimate Mobiles ’10]

Intimate Mobiles: Grasping, Kissing and Whispering as a Means of Telecommunication in Mobile Phones

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ABSTRACT

In this paper, we explore how direct physical cues of interpersonal nearness can be achieved in mobile phones. Exemplarily, we present three novel means of communication for mobile phones: grasping, kissing and whispering. Reviewing the related work , we point to a research gap in direct physical near-body actuation in mobile telecommunication. To assess this gap, we present three prototypes that implement the proposed novel means of communication. We present initial user comments on the prototypes, which point to acceptance issues. We conclude in a set of research questions for future explorations in this field.

Author Keywords

Mobile phone, grasping, kissing, whispering, intimacy.

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.

General Terms

Design, Human Factors

INTRODUCTION

Conceptualizing the past decades ' changes in the ways in which we interact with computers, Dourish proposes *Embodied Interaction* [6] as the new paradigm: it combines *Tangible Computing* and *Social Computing*. The social and the tangible, both taken to their extremes, can lead to the intimate. A substantial body of research about the psychology of intimacy exists, including research that investigates different levels of proximity and a theory of an 'intimacy equilibrium' [2], variations between individuals [14] , the therapeutic effects of touch [8], and

Figure 1: Grasping prototype, grasping telecommunication through pressure sensing and tightness actuation.

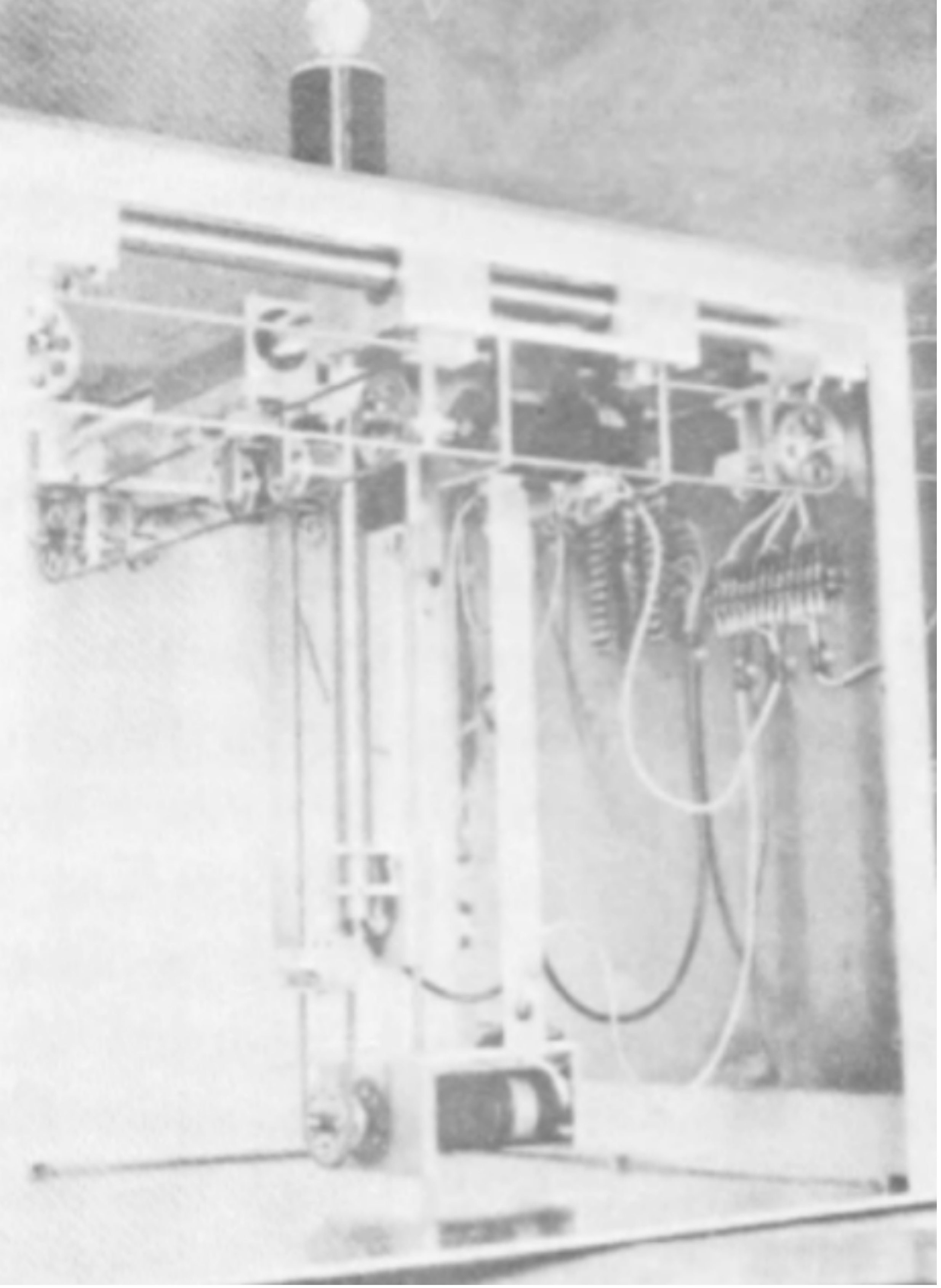
a scale for the 'need for touch' [12]. Its role in HCI , however, may not have been fully explored yet.

In their current form, mobile phones rely primarily on text, speech, and video communication. This may suit information exchange, but may lack the capacity to give users a feeling of physical proximity.

The question that this project seeks to answer is how mobile communication devices could provide users with direct physical cues of interpersonal nearness , in order to stimulate a discussion on how we want to communicate in the future.

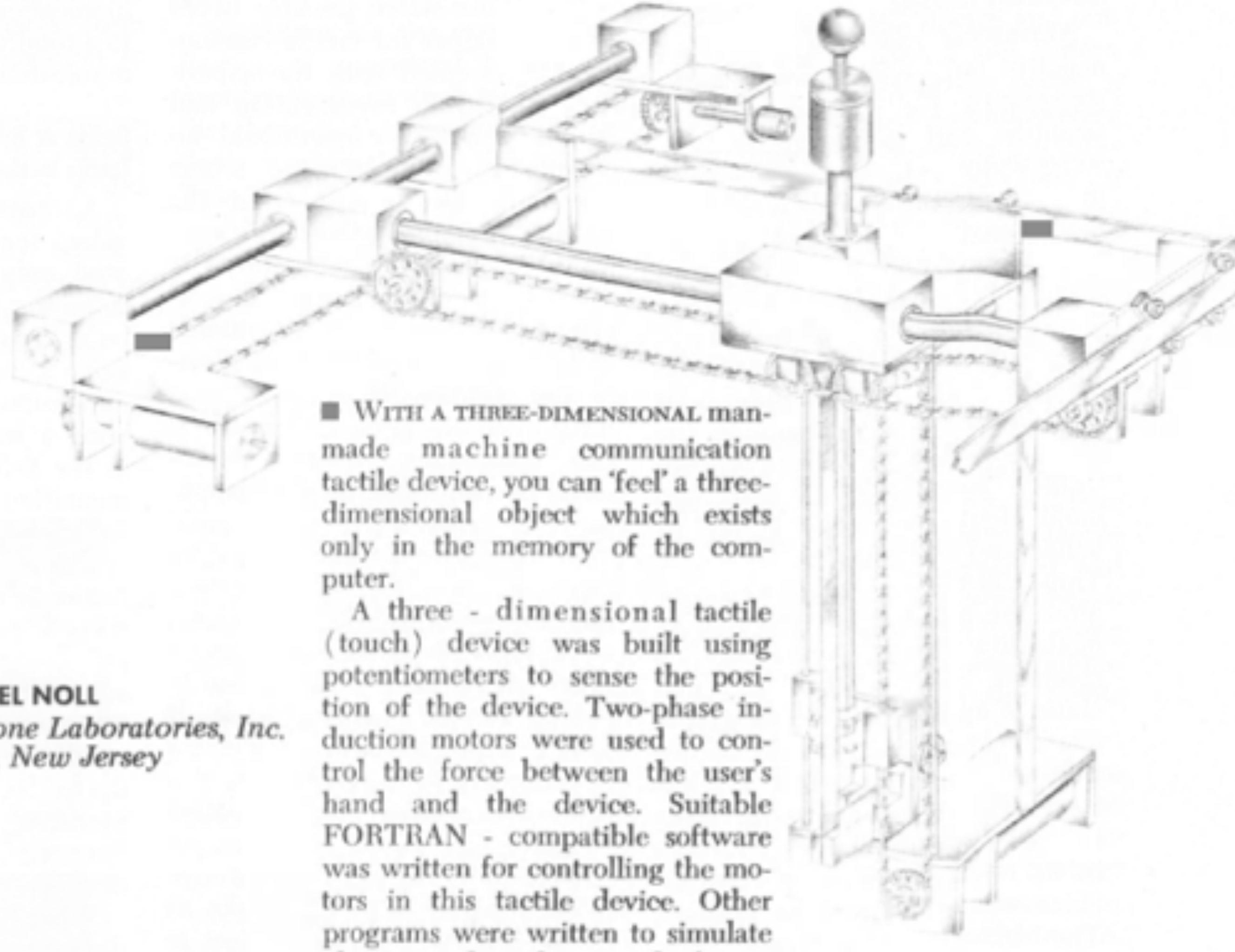
BACKGROUND

Intimate interaction and physical telepresence are emerging fields of research. On the theoretical side, research includes Paulos et al.'s work on personal tele -embodiment [13] and Tollmar and Persson's analysis of remote presen ce [16], Vetere et al.'s proposals of me diated intimacy [17], and – most recently, Hassenzahl et al.'s work on technology for people in love [9].



- potentiometer sense the position
- motors determine movement force

1975 three-dimensional haptic feedback



■ WITH A THREE-DIMENSIONAL man-made machine communication tactile device, you can 'feel' a three-dimensional object which exists only in the memory of the computer.

A three - dimensional tactile (touch) device was built using potentiometers to sense the position of the device. Two-phase induction motors were used to control the force between the user's hand and the device. Suitable FORTRAN - compatible software was written for controlling the motors in this tactile device. Other programs were written to simulate objects and surfaces and also to position the tactile device at a specified point.

Results thus far suggest that tactile man-machine communication is useful for "depicting" surfaces and objects which would be virtually impossible to display visually. Man-machine tactile communication also has potential as a practical scheme for computer "graphics" for the blind. In addition, the non-blind have here a possible scheme for a better and totally different "feel" for computer graphics.

By A. MICHAEL NOLL
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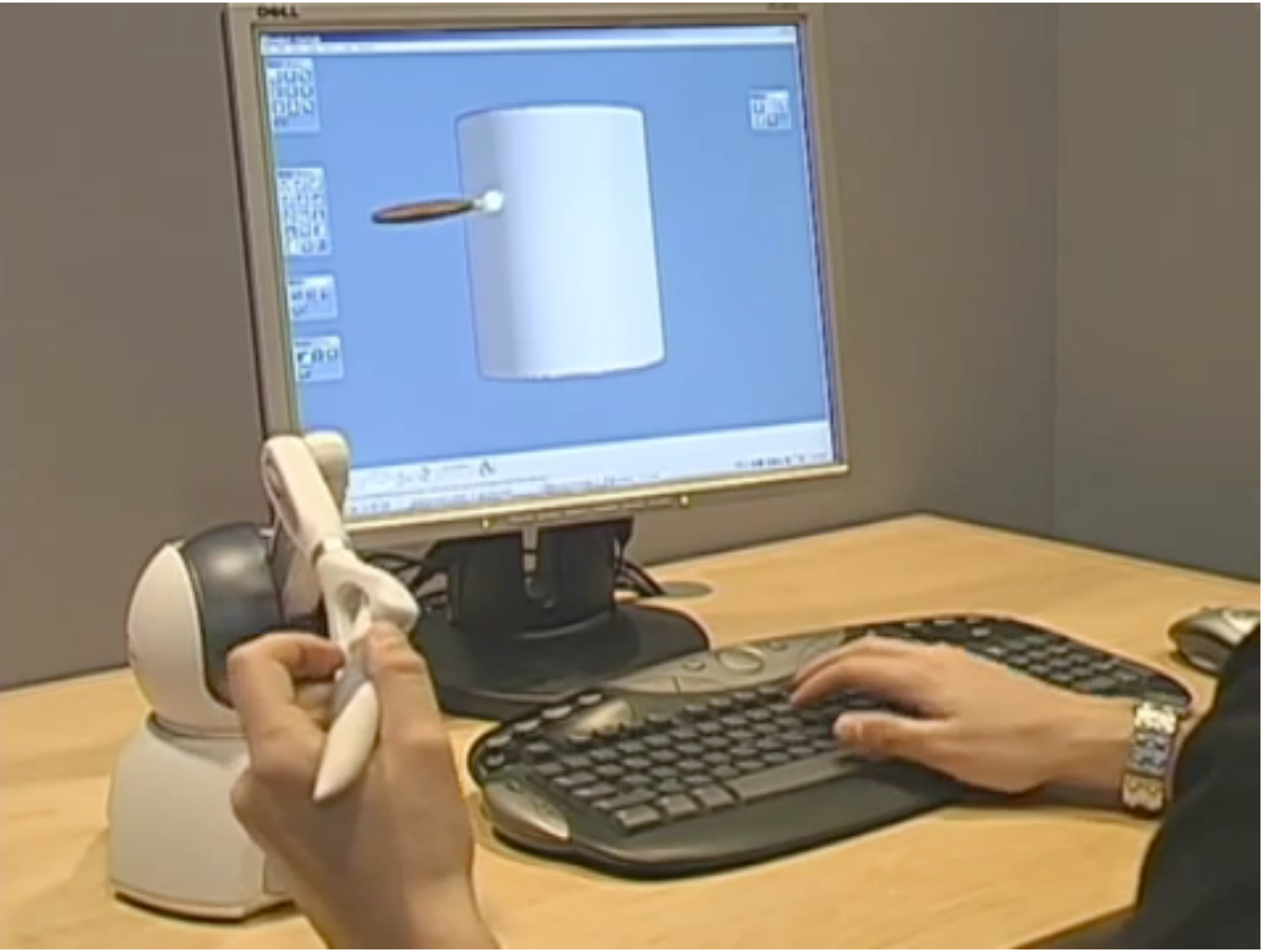
MAN-MACHINE TACTILE COMMUICATION

1975 three-dimensional haptic feedback

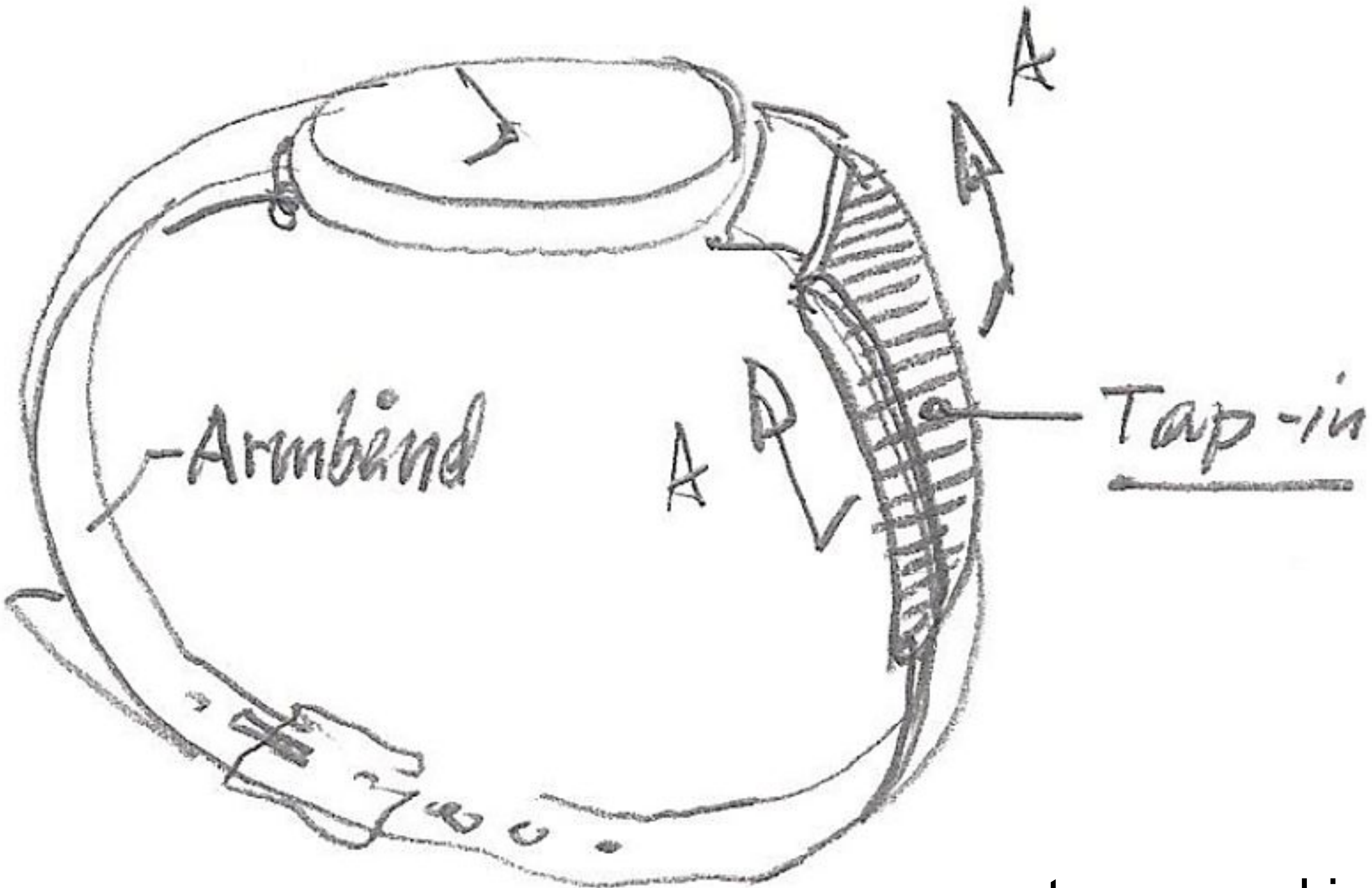
[PHANToM, senseable]

[Falcon]

2000-ish… state of the art commercial devices ($500 - $1500) **‘feel a virtual shape’**



2000-ish… state of the art commercial devices ($500 - $1500) **‘feel a virtual shape’**



- got no award in a competition

1995 watch with tactile feedback for short messages

2015 "it taps you on the wrist” [Apple watch 2015] generating ‘true’ haptics is still difficult…

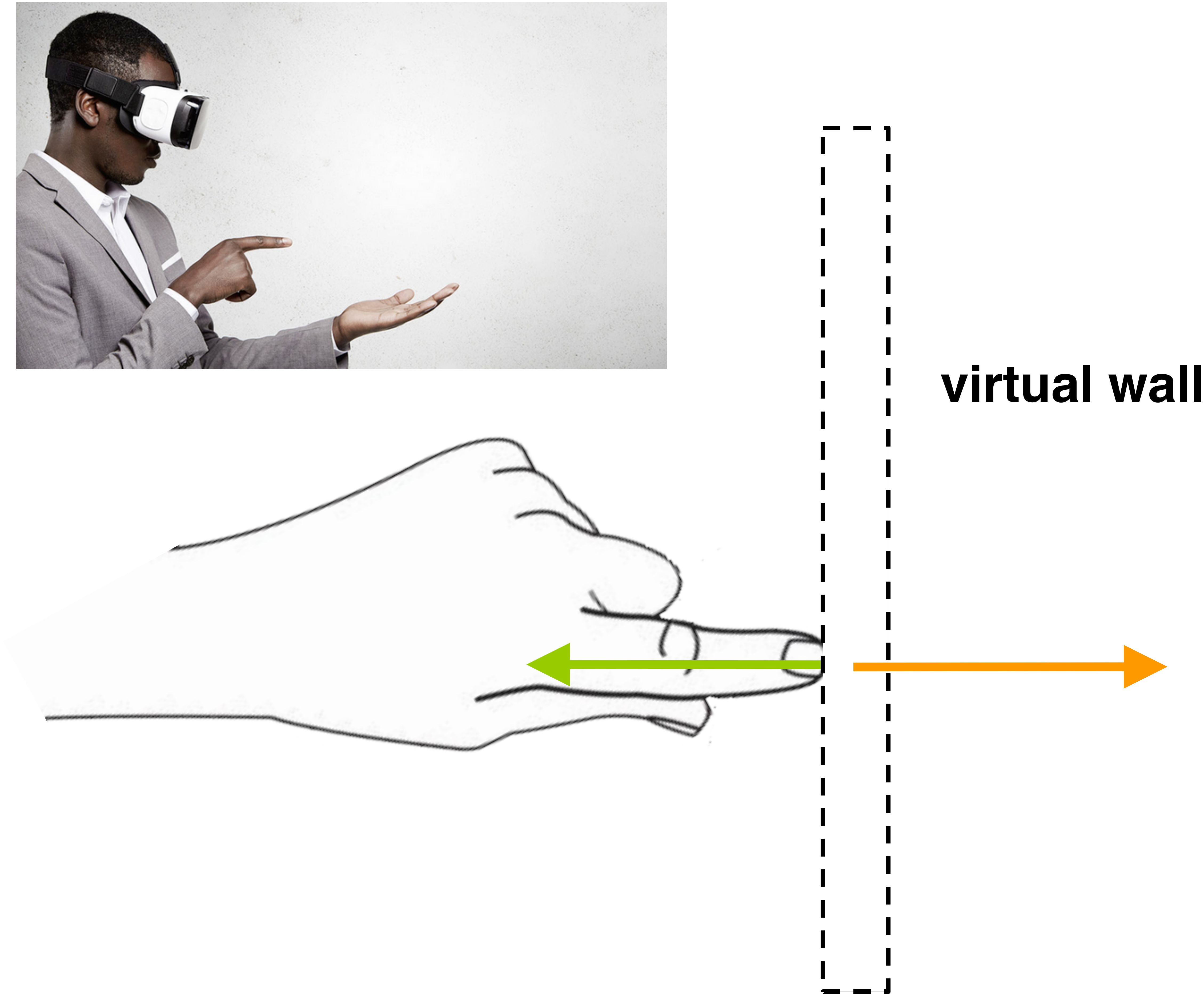
types of haptics

(1) force feedback

(2) tactile feedback

(vibration, sound, air, lasers)

#1
force feedback

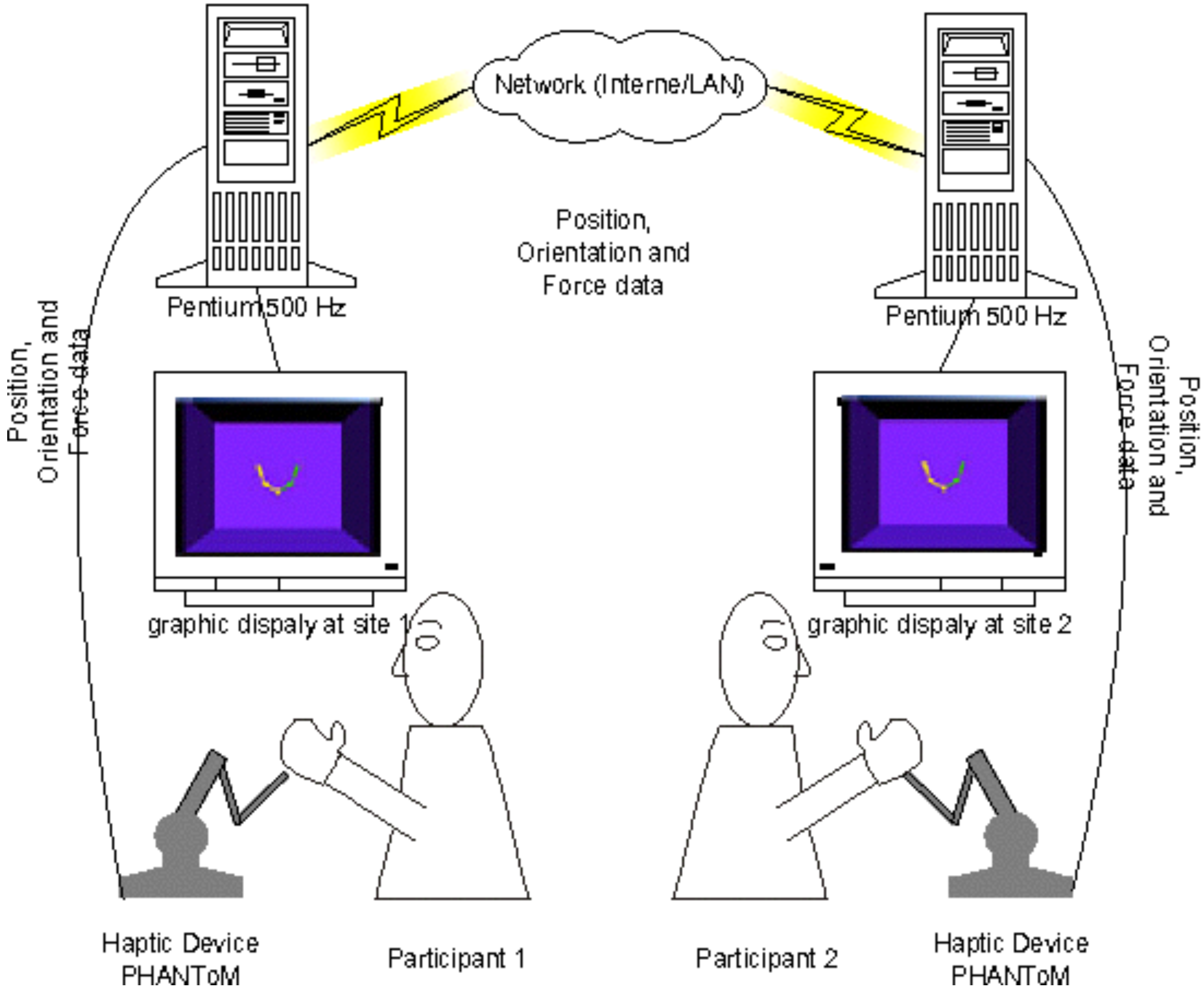

virtual wall

solution 1:
push with hand
against mounted base

[PHANToM, senseable]

[Falcon]

2000-ish… state of the art commercial devices ($500 - $1500) **‘feel a virtual shape’**



2001 Tele-Handshake with Phantom device

Tele-Handshake: A Cooperative Shared Haptic Virtual Environment

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Abstract

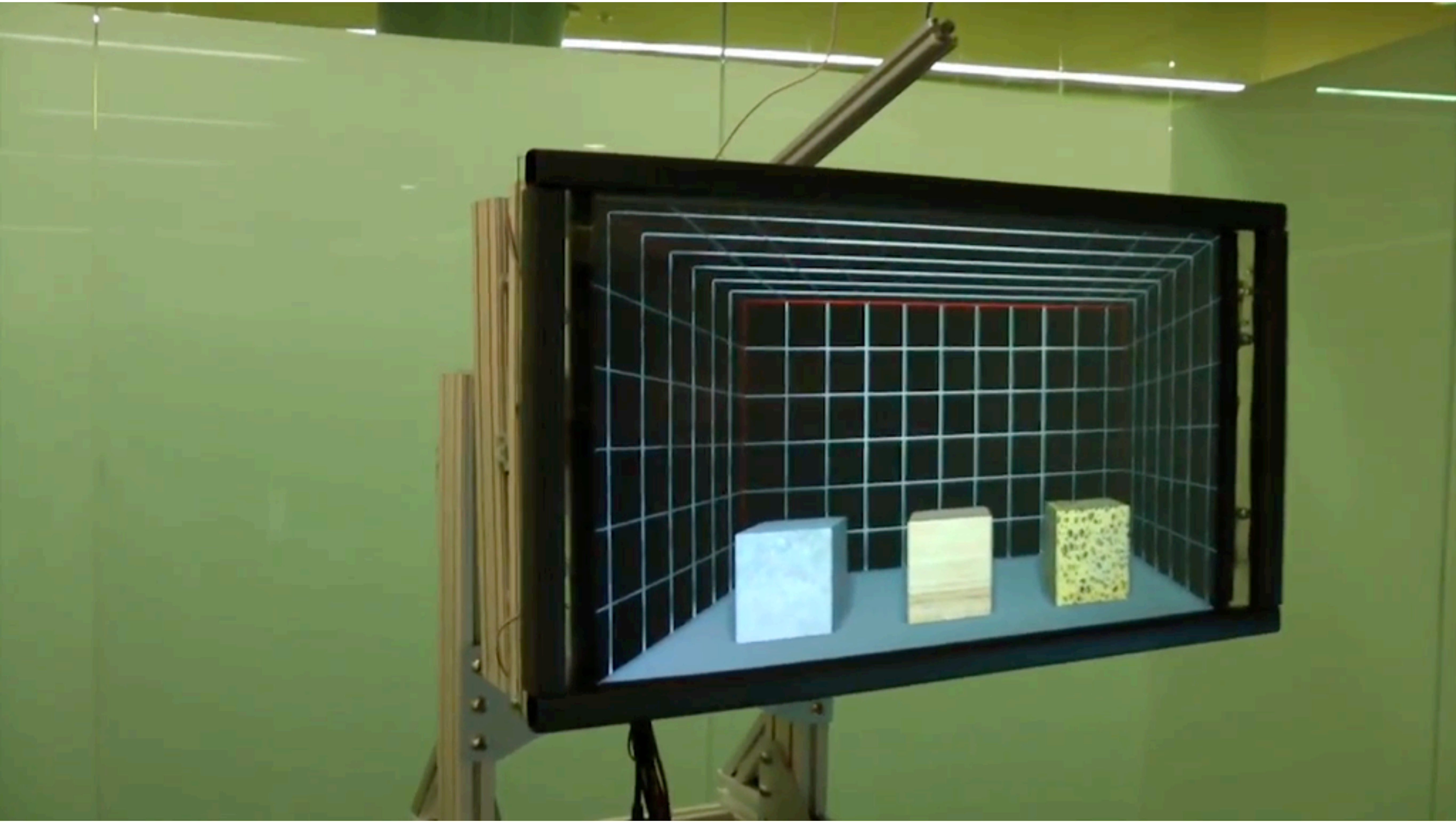
A cooperative shared haptic virtual environment, where the users can kinesthetically interact and simultaneously feel each other, is beneficial for many VR simulations. We have implemented a tele-handshake system that enables the participants to shake hands over a network and feel each other's pushing concurrently. A client-server architecture has been used with a specific implementation to meet the requirements of the haptic device. The users were able to feel each other simultaneously and shake their hands in an intuitive way. An objective evaluation based on force feedback was conducted. The results showed that the force feeling induced at the remote site was very close to that felt at the remote site. Also, a subjective evaluation based on a rating questionnaire is described. The results prove that the feeling was instant without any perceptible delay.

1. Introduction

The ability to feel objects in a shared virtual environment simultaneously can markedly enhance the effectiveness of many VR applications. Haptic cooperative virtual environments, where the users can simultaneously manipulate and haptically feel the same object, is potentially beneficial and in some cases could be indispensable. It could be useful for training as in, for example, virtual surgical simulators where the team performs on the same real patient; all the other members perceive each team member interaction with the patient directly, when dealing with the patient's tissue, or indirectly because of the collisions in the limited workspace. Virtual surgical simulators offer the possibility of training surgeons without risking casualties [1] [2] [3]. However, the interaction feeling and its effect should be provided to make sure that the perceptual experience in the virtual world corresponds to that in the real world, otherwise the training would be useless, if not environment is in entertainment, which would allow the participants to kinesthetically interact with each other. This adds a new dimension of enjoyment and brings us one step closer to more realistic interactivity. Moreover, there will be a great benefit from such kinesthetic interaction in some sports training systems, especially the kind of multi-players sports that include direct contact between the players such as boxing, sumo wrestling, and football. The resulting virtual training system has the potential to be more realistic and efficient. In addition, there are many advantages of multi-hand manipulation that can be realized from daily life. More precise manipulation can be achieved using both hands [4]. Also, the manipulation with both hands is more efficient than one hand as has been mentioned by some ergonomic studies [5].

Buttolo et al. [6] proposed an architecture for shared haptic virtual environments where they pointed out the difference between collaborative and cooperative virtual environments. The collaborative environment is a sharing environment, in which the users take turns in manipulating the virtual object. Meanwhile, the cooperative environment is an interacting one, in which the users can simultaneously modify the same virtual object. According to these definitions most of the cooperative haptic environments that have been proposed in the last few years fall under the banner of collaborative haptic environments, as all of them cannot support simultaneous kinesthetic interaction between the participants. Takemura and Kishino [7] have built a cooperative environment using a virtual workspace by combining a head tracking display and a data glove. However, the users are not allowed to simultaneously alter the status of the virtual world. In other words, they cannot grasp the same object and manipulate it at the same time. They used what they called mutual exclusion to avoid simultaneous manipulation of the same object. In the shared virtual environment proposed by Buttolo et al. [8], one user at time, the active operator, is allowed to modify and feel the force from the environment.

lots of **new hardware**
being developed right now



2013: mounted touch screen base

TouchMover: Actuated 3D Touchscreen with Haptic Feedback

Mike Sinclair sinclair@microsoft.com
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Hrvoje Benko benko@microsoft.com
Microsoft Research, One Microsoft Way, Redmond, WA 98052

ABSTRACT

This paper presents the design and development of a novel visual+haptic device that co-locates 3D stereo visualization, direct touch and touch force sensing with a robotically actuated display. Our actuated immersive 3D display, called *TouchMover*, is capable of providing 1D movement (up to 36cm) and force feedback (up to 230N) in a single dimension, perpendicular to the screen plane. In addition to describing the details of our design, we showcase how TouchMover allows the user to: 1) interact with 3D objects by pushing them on the screen with realistic force feedback, 2) touch and feel the contour of a 3D object, 3) explore and annotate volumetric medical images (e.g., MRI brain scans) and 4) experience different activation forces and stiffness when interacting with common 2D on-screen elements (e.g., buttons). We also contribute the results of an experiment which demonstrates the effectiveness of the haptic output of our device. Our results show that people are capable of disambiguating between 10 different 3D shapes with the same 2D footprint by touching alone and without any visual feedback (85% recognition rate, 12 participants).

Author Keywords

3D touchscreen, haptics, physics simulation, force feedback.

ACM Classification Keywords

H.5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces; Input devices and strategies.

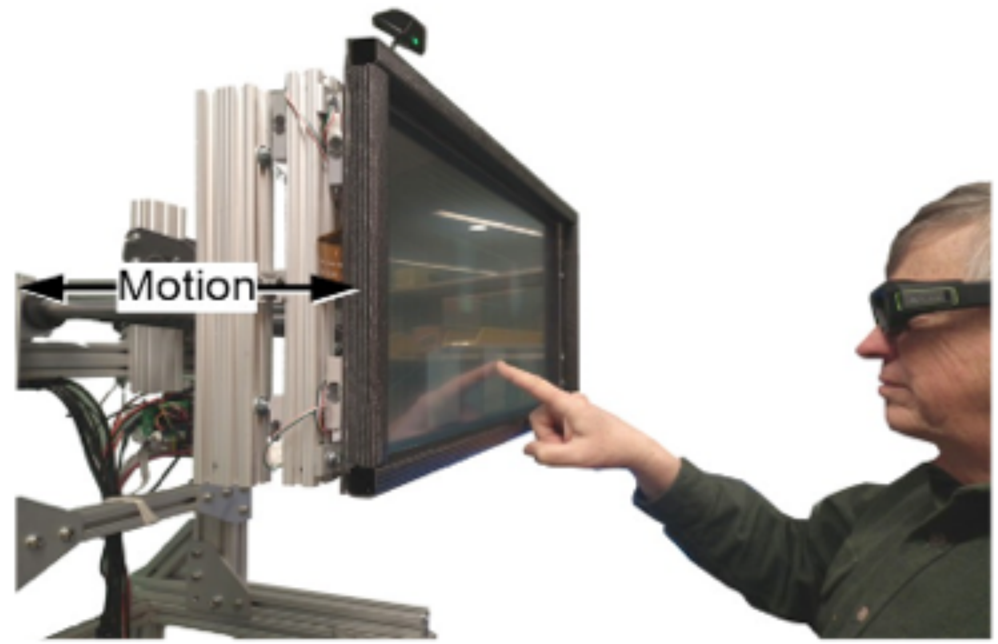
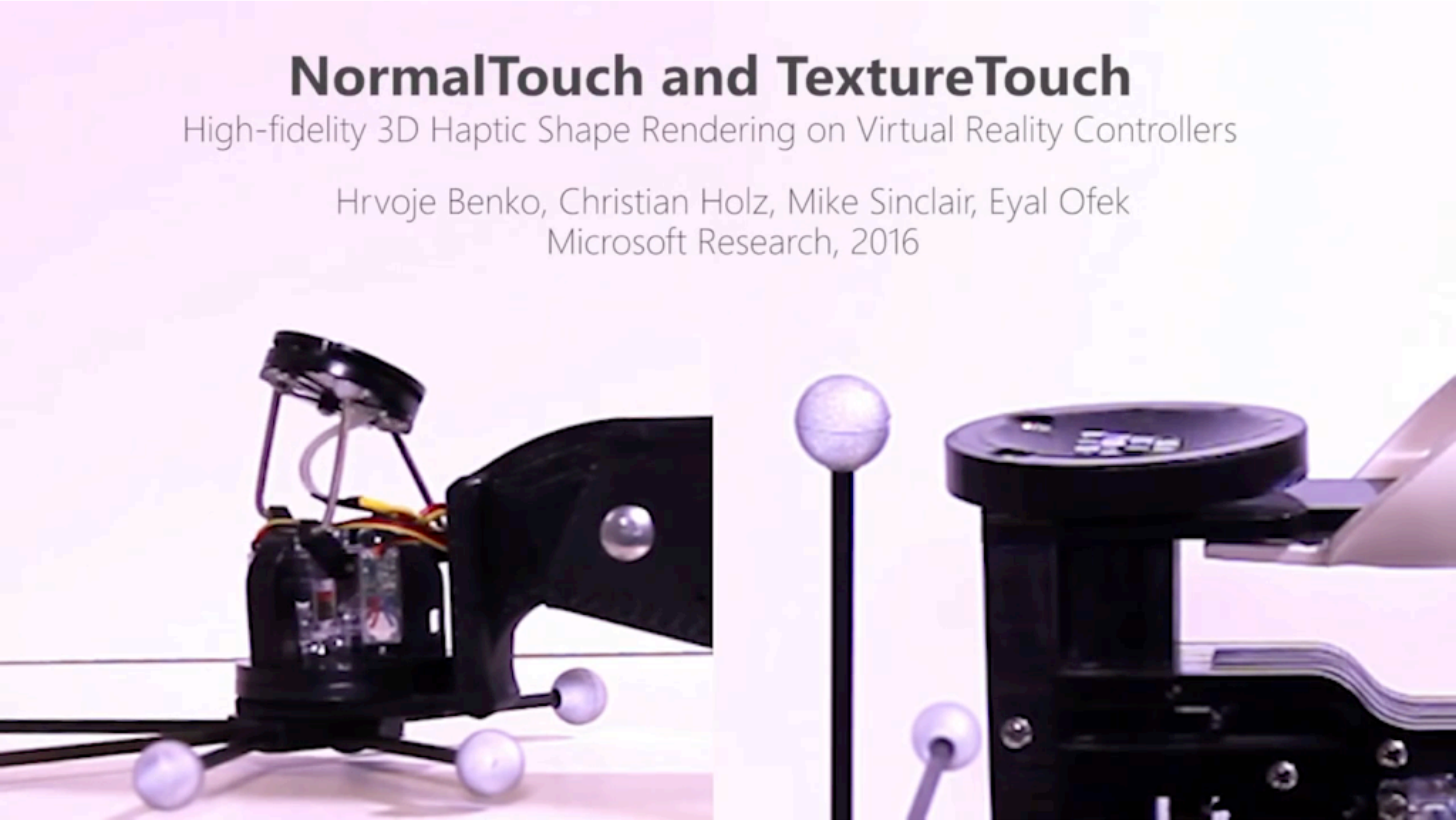


Figure 1. TouchMover co-locates immersive 3D stereo visualization, direct touch and touch force sensing with a robotically actuated display.

either have the haptic feedback mechanism co-located with the display, but are incapable of rendering large forces or displacement necessary for simulating resistance and collision with objects [3,12,15,23]. Alternatively, others can render medium forces, but those are perceived through an actuated proxy device (e.g., stylus, thimble) whose tip is sensed and actuated in up to three dimensions [10,11,21]. Such proxy-based solutions make it difficult to interact in a freehand manner typical of touchscreen interactions. The PHANToM's [21] maximum sustainable force is 6.4N, sufficient only for smaller forces (e.g., moving light objects), the base can also be handheld…



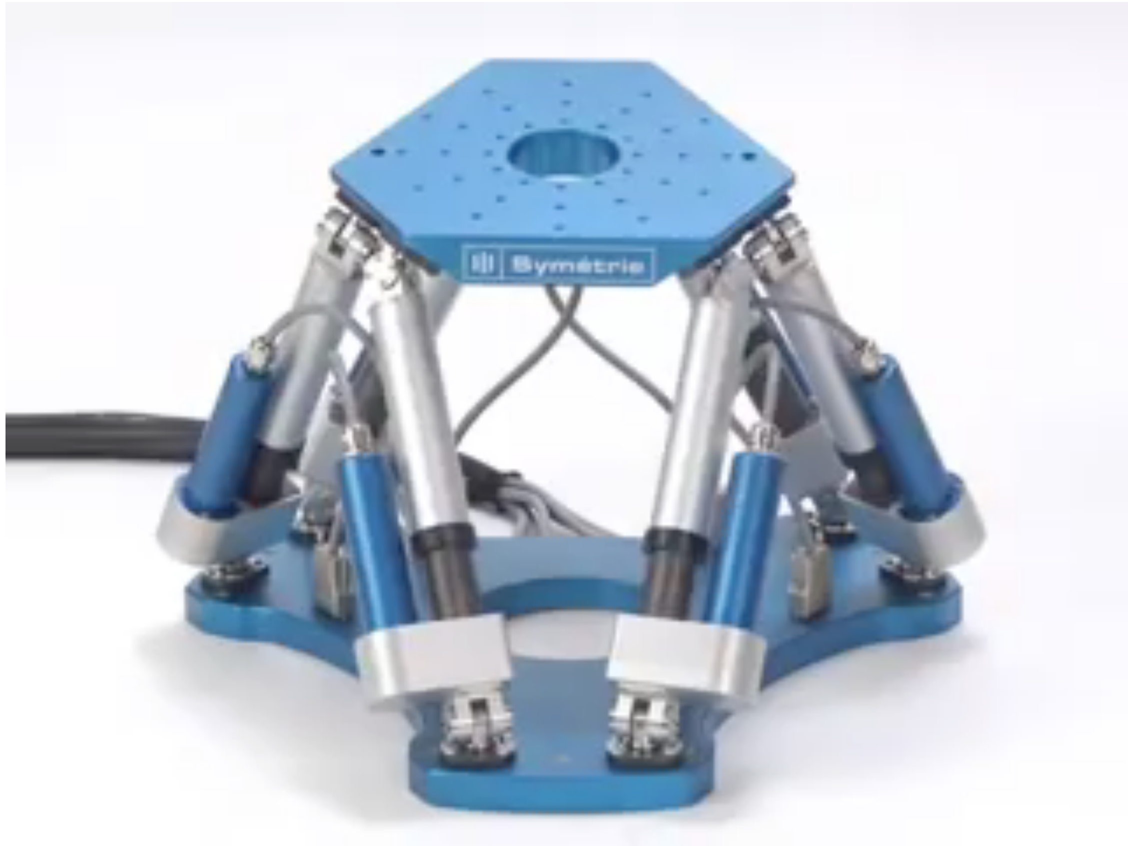
2016: miniaturizing the base

Stewart platform

From Wikipedia, the free encyclopedia

A **Gough-Stewart platform** is a type of parallel robot that has six prismatic actuators, commonly hydraulic jacks or electric actuators, attached in pairs to three positions on the platform's baseplate, crossing over to three mounting points on a top plate. Devices placed on the top plate can be moved in the six degrees of freedom in which it is possible for a freely-suspended body to move. These are the three linear movements x, y, z (lateral, longitudinal and vertical), and the three rotations pitch, roll, & yaw. The terms "six-axis" or "6-DoF" (Degrees of Freedom) platform are also used, also "synergistic" (see below).

Contents [hide]



based on a stewart platform

NormalTouch and TextureTouch: High-fidelity 3D Haptic Shape Rendering on Handheld Virtual Reality Controllers

Hrvoje Benko, Christian Holz, Mike Sinclair, Eyal Ofek
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Figure 1: (a) Our 3D haptic shape controllers allow the Virtual Reality user to touch and feel what they would otherwise only see. (b) Our controllers enable users to explore virtual 3D objects with their finger. (c) *NormalTouch* renders the surface height and orientation using a tiltable and height-adjustable platform. (d) *TextureTouch* renders the detailed surface texture of virtual objects using a 4×4 pin array, which users experience on their finger pad.

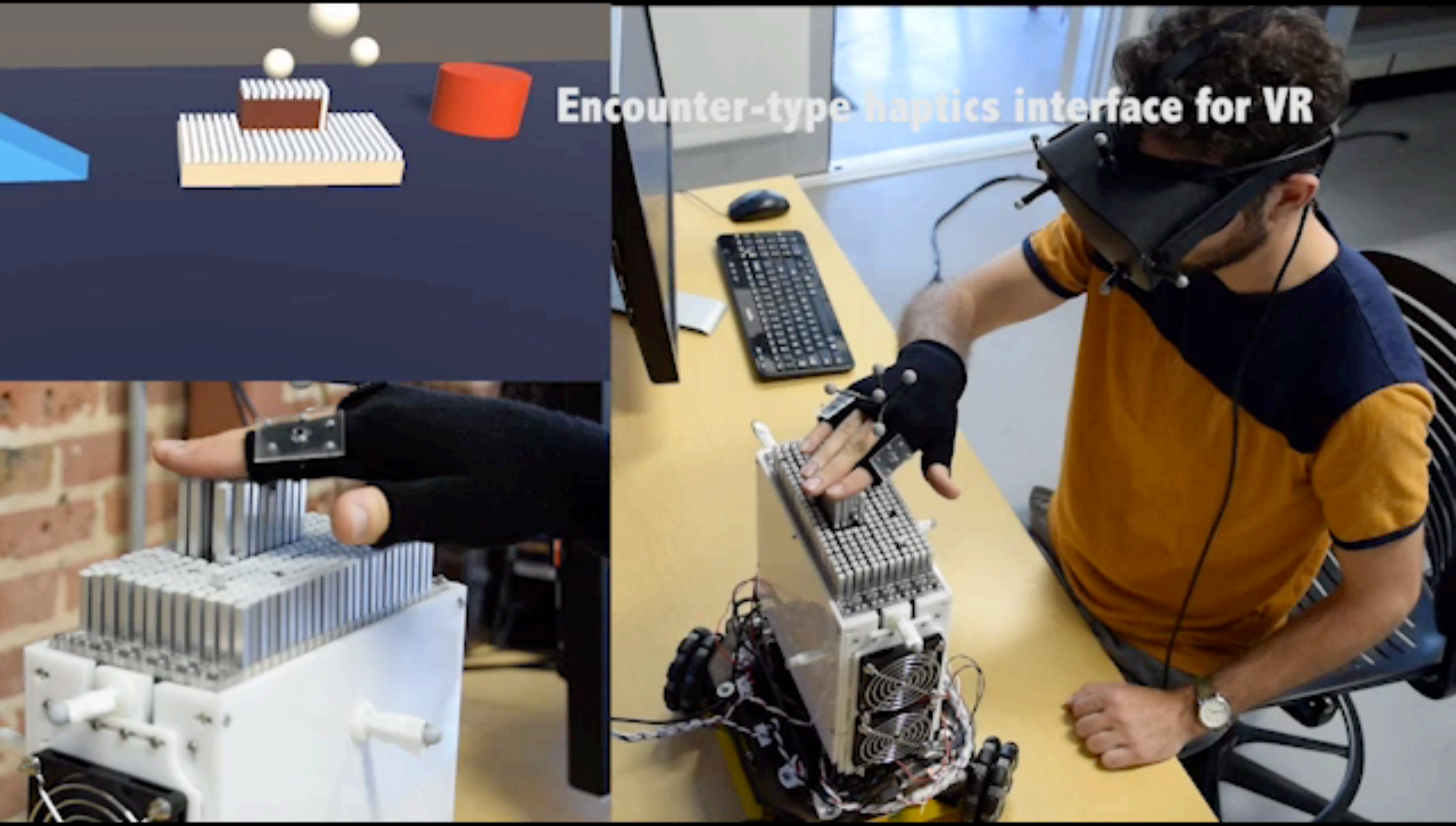
ABSTRACT
We present an investigation of mechanically-actuated handheld controllers that render the shape of virtual objects through physical shape displacement, enabling users to *feel* 3D surfaces, textures, and forces that match the visual rendering. We demonstrate two such controllers, *NormalTouch* and *TextureTouch*. Both controllers are tracked with 6 DOF and produce spatially-registered haptic feedback to a user's finger. NormalTouch haptically renders object *surfaces* and provides force feedback using a tiltable and extrudable platform. TextureTouch renders the shape of virtual objects including detailed surface *structure* through a 4×4 matrix of actuated pins. By moving our controllers around in space while keeping their finger on the actuated platform, users obtain the impression of a much larger 3D shape by cognitively integrating output sensations over time. Our evaluation compares the effectiveness of our controllers with the two de-facto standards in Virtual Reality controllers: device vibration and visual feedback only. We find that haptic feedback significantly increases the accuracy of VR interaction, most

Author Keywords
Haptics; Controller Design; Tactile Display; Virtual Reality.

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
The capabilities of current devices to render meaningful haptics lag far behind their abilities to render highly realistic visual or audio content. In fact, the de-facto standard of haptic output on commodity devices is vibrotactile feedback (e.g., built into mobile devices and game controllers). While ubiquitous and small, these vibrotactile actuators produce haptic sensations by varying the duration and intensity of vibrations. This makes them well suited for user-interface notifications, but fairly limited in conveying a sense of shape, force, or surface structure.

In Virtual Reality (VR), higher fidelity haptic rendering beyond vibrotactile feedback has been extensively explored



and a shape display..

Visuo-Haptic Illusions for Improving the Perceived Performance of Shape Displays

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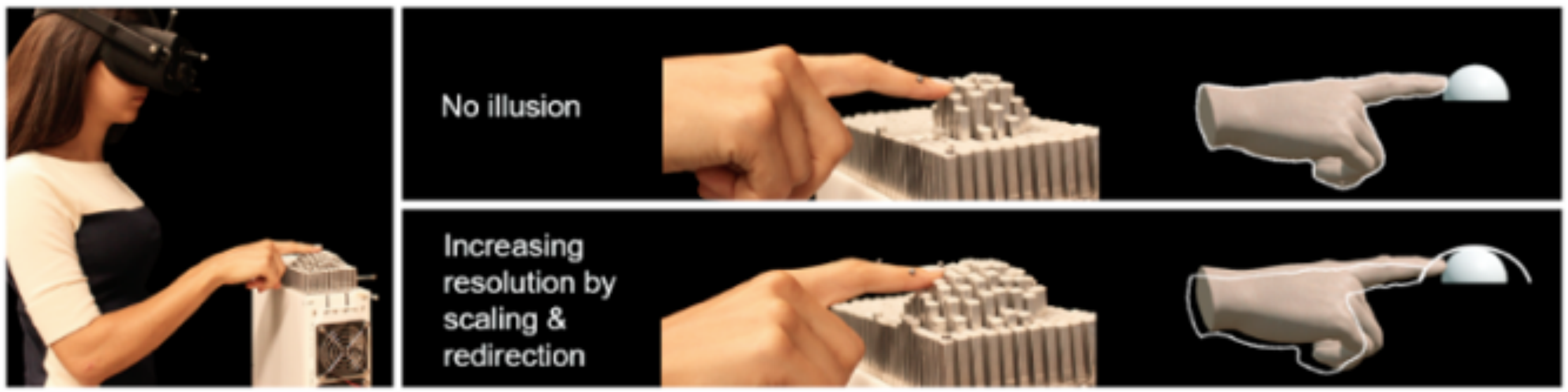


Figure 1. The user wearing a head-mounted display sees a small hemisphere. The tactile feedback is provided with a shape display. Instead of rendering the small hemisphere (top), the shape display renders a larger hemisphere with higher resolution (bottom) that is mapped to the virtual shape by altering the user's perception of scale and redirecting the finger.

ABSTRACT

In this work, we utilize visuo-haptic illusions to improve the perceived performance of encountered-type haptic devices, specifically shape displays, in virtual reality. Shape displays are matrices of actuated pins that travel vertically to render physical shapes; however, they have limitations such as low resolution, small display size, and low pin speed. To address these limitations, we employ illusions such as redirection, scaling, and retargeting that take advantage of the visual dominance effect, the idea that vision often dominates when senses conflict. Our evaluation of these techniques suggests that redirecting sloped lines with angles less than 40° onto a horizontal line is an effective technique for increasing the perceived resolution of the display. Scaling up the virtual object onto the shape display by a factor less than 1.8*x* can also increase the perceived resolution. Finally, using vertical redirection a perceived 3*x* speed increase can be achieved.

Author Keywords

Virtual Reality; Haptics; Illusion; Perception; Shape Displays.

ACM Classification Keywords

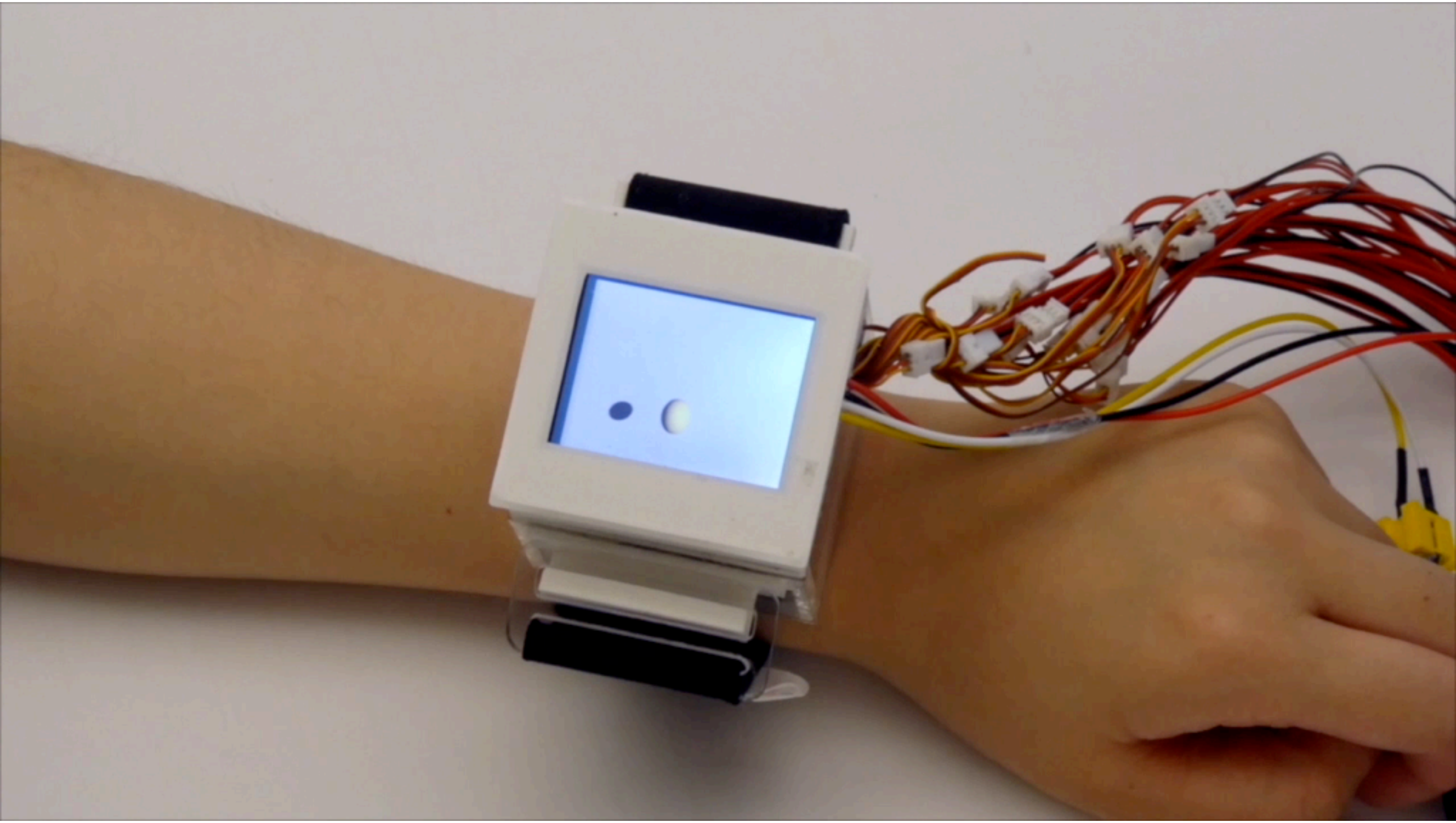
H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial, Augmented, and Virtual Real-

INTRODUCTION

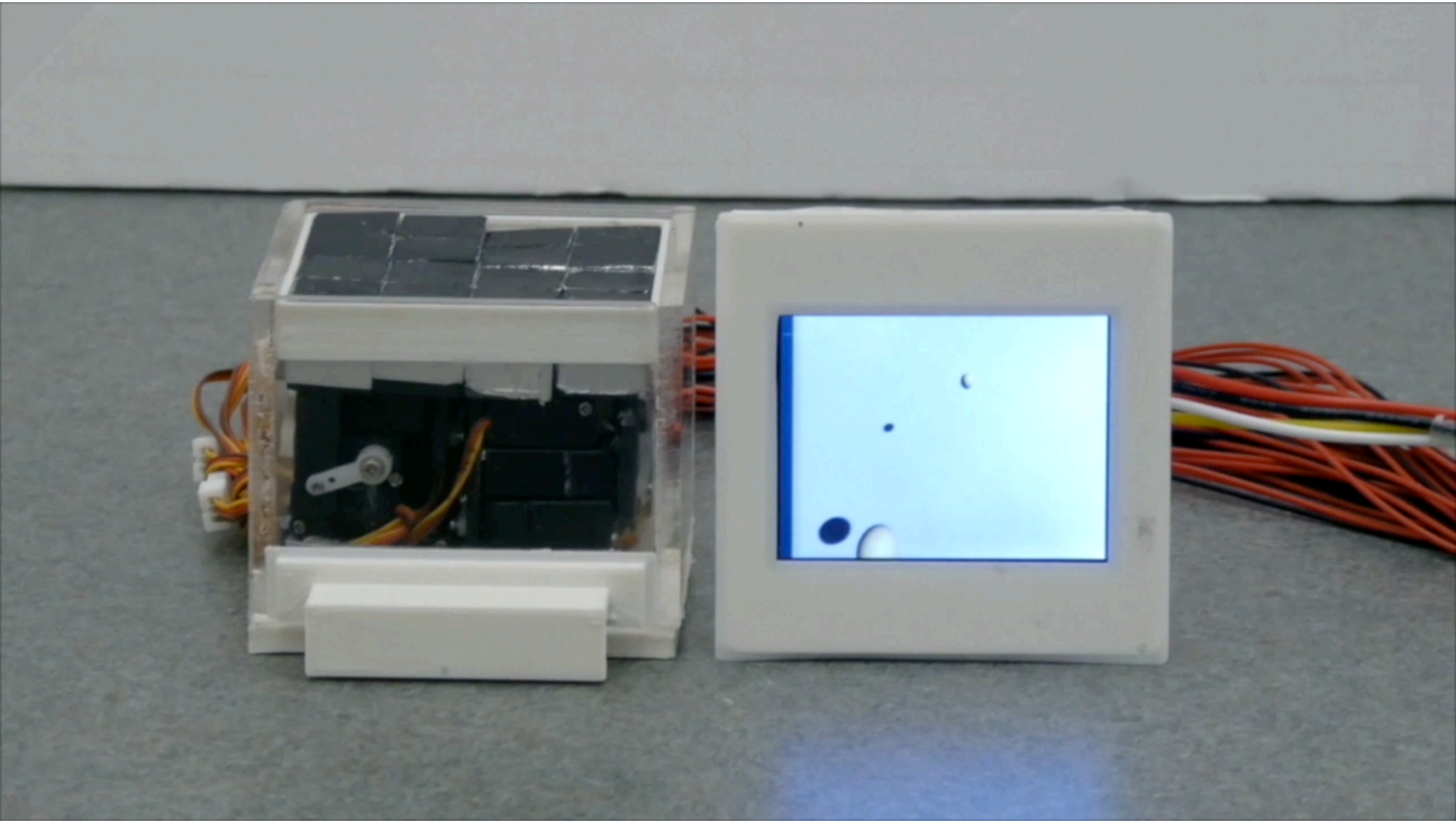
Recent advances in technology have brought Virtual Reality (VR) closer to a visually immersive experience. Haptic feedback technology, however, has not yet reached this level of realism, as users are unable to touch and manipulate virtual objects the same way they interact with real ones. Encountered-type haptic devices, such as shape displays, aim towards bridging this gap by providing a physical object to the user, as opposed to creating the sensation of force or tactile feedback. The advantage of encountered-type haptics over other solutions (externally grounded [34], wearable [9, 40], handheld [7], and mid-air [44, 37]) is that they do not require the user to wear a device or hold a controller. Moreover, they allow haptic exploration of virtual objects not only through a single point or finger tip, but with the entire hand.

Shape displays are matrices of actuated pins that travel vertically and can be used as an encountered-type haptic solution in VR, by rendering various 2.5D geometries [31]. However, the current size and cost of linear actuators and shape display hardware poses some limitations on their use as a haptic device [12]. These limitations include:

… or **wearable…**



2017 wearable shape display



2017 wearable shape display

RetroShape: Leveraging Rear-Surface Shape Displays for 2.5D Interaction on Smartwatches

Da-Yuan Huang[1,2], Ruizhen Guo[1], Jun Gong[1], Jingxian Wang[1,4], John Graham[1], De-Nian Yang[3], Xing-Dong Yang[1]
Dartmouth College[1], NTUST[2], Academia Sinica[3], Carnegie Mellon University[4]
{ruizhen.guo.gr; jun.gong.gr; jack.m.graham.iii.gr; xing-dong.yang}@dartmouth.edu
dayuan.huang@csie.ntust.edu.tw, dnyang@iis.sinica.edu.tw, jingxian@cmu.edu

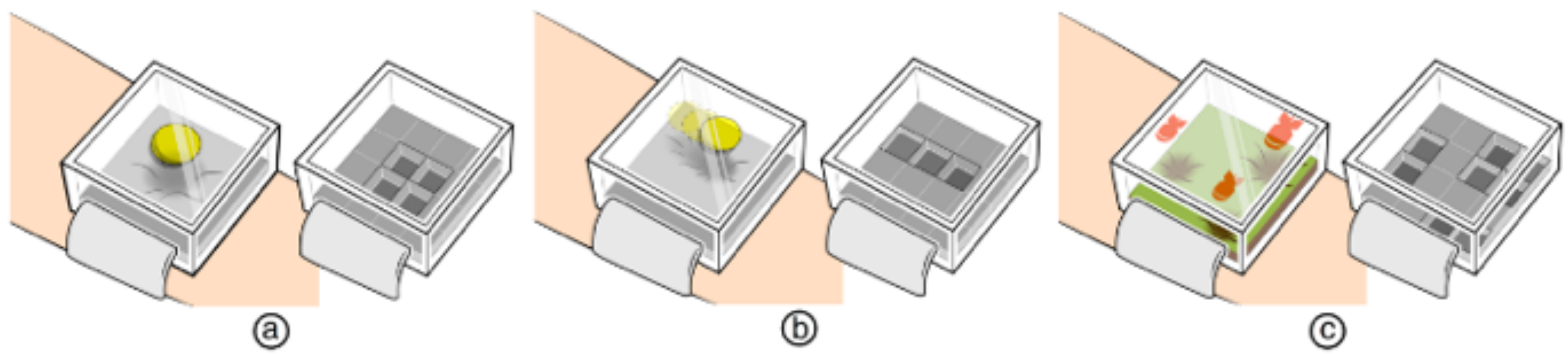


Figure 1. RetroShape aims to extend the visual scene to 2.5D physical space by a deformable display on its rear surface. Our RetroShape prototype equips 4×4 taxels, which can simulate (a) a bouncing ball on an elastic surface, (b) ball rolling, or (c) multiple strikes on the ground.

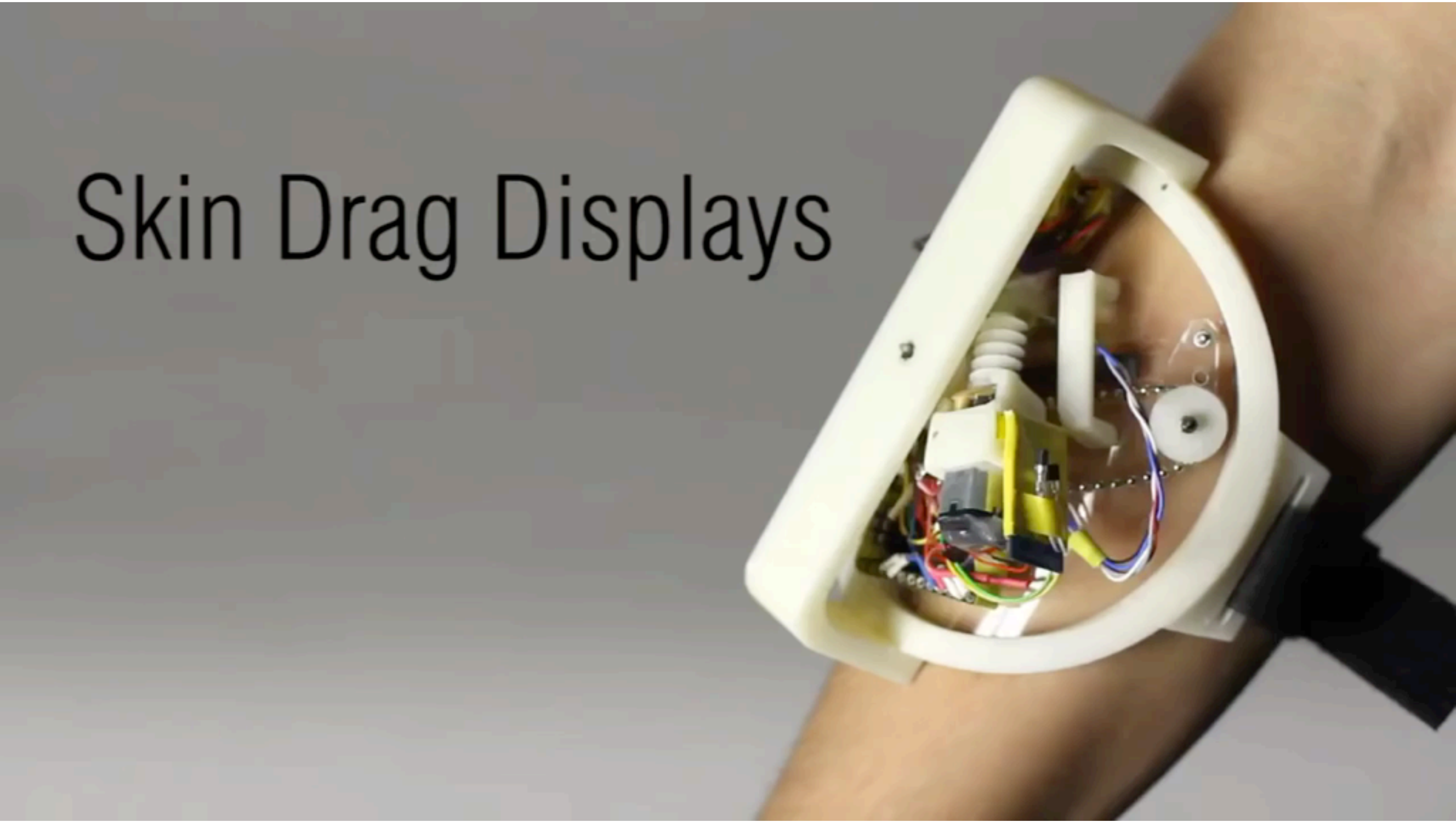
ABSTRACT
The small screen size of a smartwatch limits user experience when watching or interacting with media. We propose a supplementary tactile feedback system to enhance the user experience with a method unique to the smartwatch form factor. Our system has a deformable surface on the back of the watch face, allowing the visual scene on screen to extend into 2.5D physical space. This allows the user to watch and feel virtual objects, such as experiencing a ball bouncing against the wrist. We devised two controlled experiments to analyze the influence of tactile display resolution on the illusion of virtual object presence. Our first study revealed that on average, a taxel can render virtual objects between 70% and 138% of its own size without shattering the illusion. From the second study, we found visual and haptic feedback can be separated by 4.5mm to 16.2mm for the tested taxels. Based on the results, we developed a prototype (called RetroShape) with 4×4 10mm taxels using micro servo motors, and demonstrated its unique capability through a set of

Author Keywords
Mobile haptics; Shape-changing display; Taxel; Smartwatch

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]: User Interfaces – Haptic I/O

INTRODUCTION
Smartwatches provide quick access to short-time entertainment applications, especially when users are on-the-move, e.g. in a bus or train. However, user experience in such applications is limited due to the small screen area and limited input and output options. While smartwatch visual and auditory technologies have improved substantially, the potential of smartwatch-enabled haptics in video and game applications remains to be exploited.

We leverage the user's skin under the watch face for sensing haptic output with collocated visual content. Our approach enhances the viewing experience on a smartwatch using a shape-changing tactile display on the rear surface of the



more than just one spit vibrating!

[SkinDrag Displays 2015]

Skin Drag Displays: Dragging a Physical Tactor across the User's Skin Produces a Stronger Tactile Stimulus than Vibrotactile

Alexandra Ion[1], Edward Wang[2], Patrick Baudisch[1]
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ABSTRACT
We propose a new type of tactile displays that drag a physical tactor across the skin in 2D. We call this *skin drag*. We demonstrate how this allows us to communicate geometric shapes or characters to users. The main benefit of our approach is that it simultaneously produces two types of stimuli, i.e., (1) it moves a tactile stimulus across skin locations and (2) it stretches the user's skin. Skin drag thereby combines the essential stimuli produced by vibrotactile *and* skin stretch. In our study, skin drag allowed participants to recognize tactile shapes significantly better than a vibrotactile array of comparable size. We present two arm-worn prototype devices that implement our concept.

Author Keywords
Haptics; wearable; hands-free; eyes-free.

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]: User Interfaces - Haptic I/O

INTRODUCTION
Tactile devices that are in continuous physical contact with the wearer's skin allow sending simple messages to the user. Devices based on a single vibrotactile actuator [2,7,10], for example, allow pulsing "Morse-like" messages [11].

In order to allow sending more expressive and memorable

cues, i.e., north, south, east, west. The resulting skin stretch triggers the skin's directional sensitivity [9].

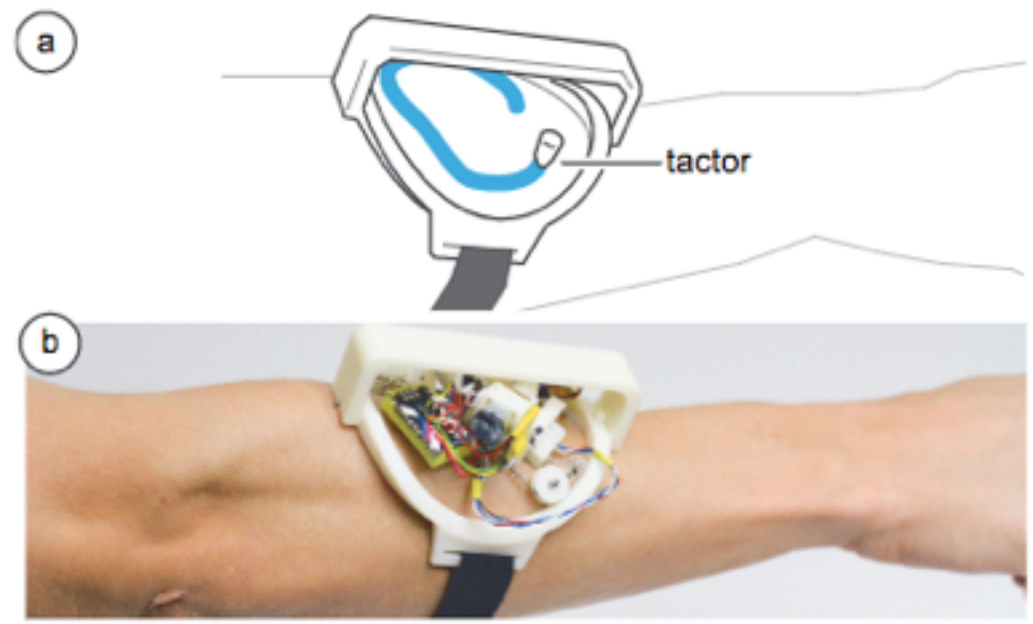


Figure 1: Skin drag displays drag a tactor over the wearer's skin in order to communicate a spatial message, (a) e.g. write a 'C' on the user's arm. (b) Our self-contained prototype.

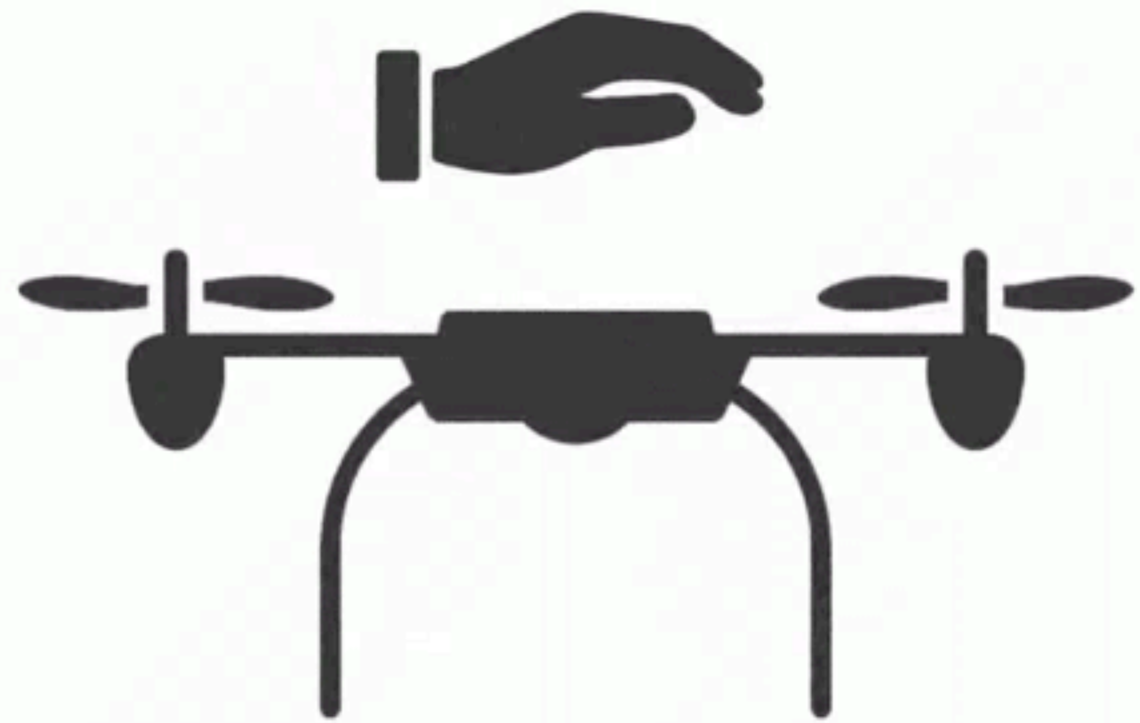
Unfortunately, both approaches are limited since they excite only a subset of tactile receptors. Vibrotactile reaches only fast adapting receptors (Pacinian corpuscles, PC) on a usually larger area, while skin stretch reaches slowly adapting receptors (SA1 and SA2 afferents), however on a small area.

In this paper, we propose combining the benefits of both apthe base can also be flying…

(ungrounded force feedback)

NON-CONTACT MODE

HAND FOLLOWING



2017 HapticDrone

HapticDrone - An Encountered-Type Kinesthetic Haptic Interface with Controllable Force Feedback: Initial Example for 1D Haptic Feedback

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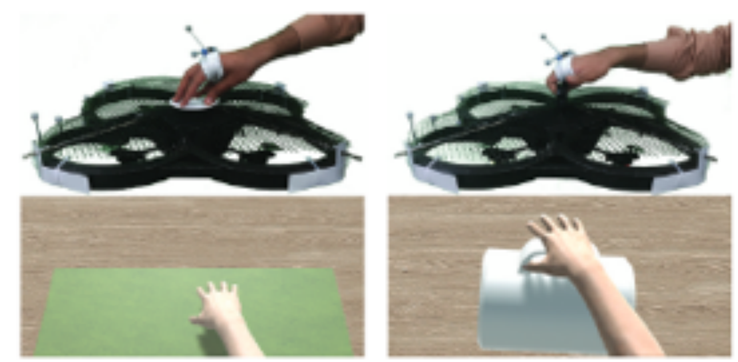
ABSTRACT
We present HapticDrone, a concept to generate controllable and comparable force feedback for direct haptic interaction with a drone. As a proof-of-concept study this paper focuses on creating haptic feedback only in 1D direction. To this end, an encountered-type, safe and un-tethered haptic display is implemented. An overview of the system and details on how to control the force output of drones is provided. Our current prototype generates forces up to 1.53 N upwards and 2.97 N downwards. This concept serves as a first step towards introducing drones as mainstream haptic devices.

ACM Classification Keywords
H.5.2 [User Interfaces]: Haptic I/O

Author Keywords
Haptics; Virtual Reality; Kinesthetic; Encountered; Drone



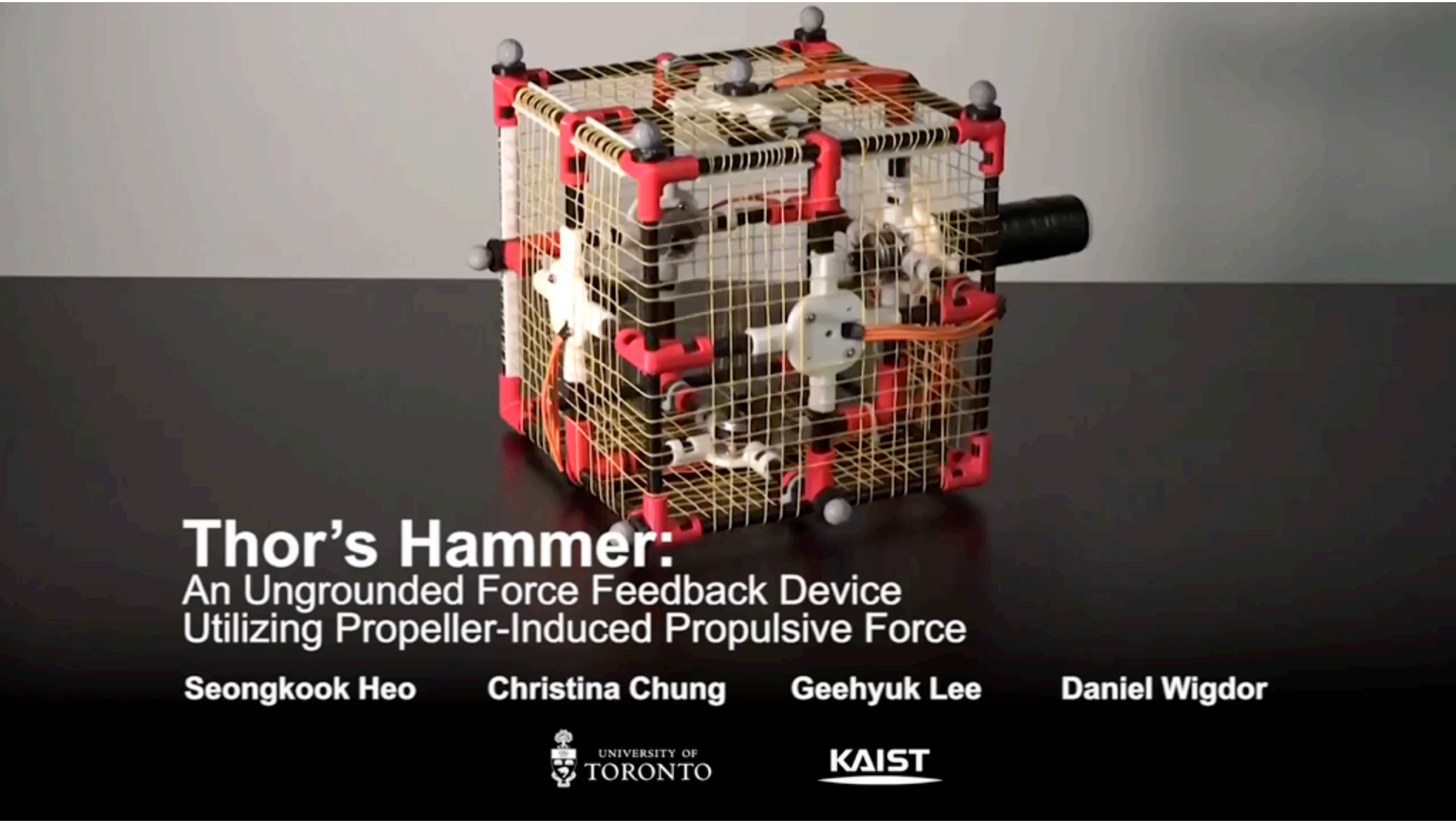
(a) The user experiencing stiffness of a virtual object, the force is rendered in the upward direction.

(b) The user experiences weight sensation by grasping the handle, the force is applied in the downward direction.

Figure 1. The example applications are implemented using the controllable 1D force feedback from the HapticDrone.

INTRODUCTION
Haptic interfaces allow people to perceive virtual objects through kinesthetic and tactile cues. Generally, haptic devices are classified into either grounded or ungrounded category based on the grounding of the feedback forces. Haptic interfaces that use the ground or earth as a counterpart of the action-reaction principle [6] are considered “grounded”. The workspace of these devices is limited to their grounding location. On the other hand, ungrounded haptic interfaces are commonly attached to the user’s body, exploiting a body part as a reaction support [1]. In this case, they remain in perpetual contact with the user and only “relative-force” among body parts can be generated. Encountered type devices are a subset of haptic devices that come in both the grounded and ungrounded format [8]. They follow the user’s movement and only engage contact when a virtual object is touched. Recently a new wave of grounded devices providing midair haptic feedback are being introduced. They use ultrasonic waves [2] or air [7] to create mid-air haptic displays. These devices generate small amounts of force for tactile stimulation.

Drones have recently been introduced into encountered type haptics to overcome the challenges of classical haptic devices. They are capable of generating considerable force in all directions of movement. Thus can constitute a haptic device with multiple degrees of freedom. Research in the area was started by BitDrones [4], where the user experiences basic touch feedback and interacts with flying “catoms”. Kenierim et al. [5] also demonstrated tactile feedback utilizing the impact force of small drones. In [9], Yamaguchi et al. used a drone as an encountered-type haptic device. A flexible sheet of paper was attached to the drone’s side, which becomes stiffer due to air flow from the rotors. A user touches the sheet using a stick to feel the force. The main limitations are that the rendered force cannot be accurately controlled and the maximum force is very low (0.118 N) since the rotor’s airflow is a fraction of the drone’s capabilities.



2018 Thor's Hammer

Thor's Hammer: An Ungrounded Force Feedback Device Utilizing Propeller-Induced Propulsive Force

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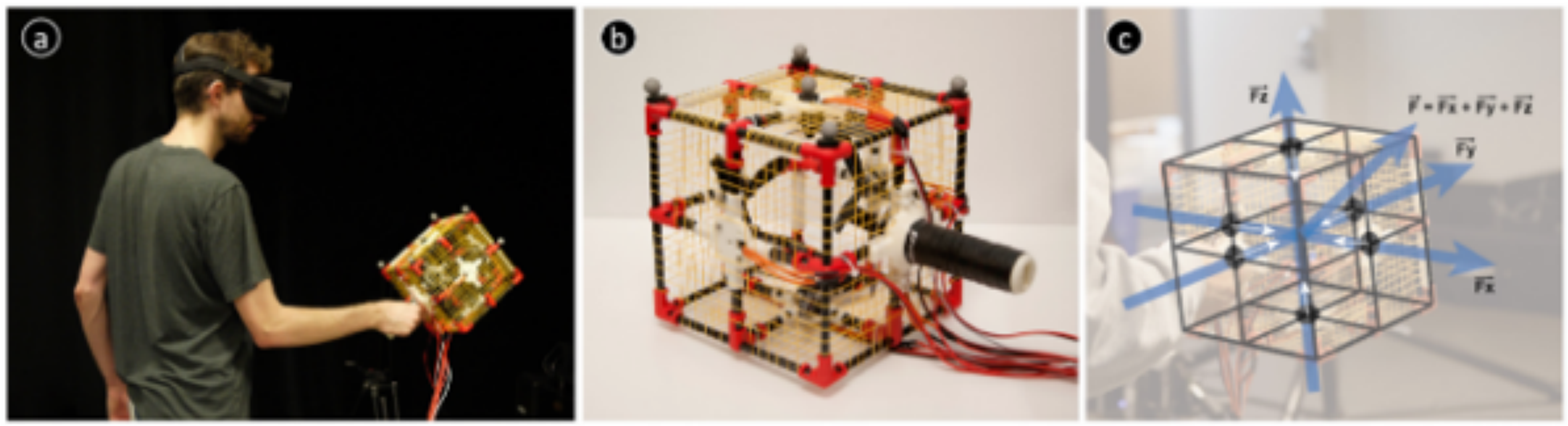


Figure 1. (a) Thor's Hammer held in a user's hand and (b) a close-up of the hammer. (c) The design of Thor's Hammer enables six motors and propellers to create 3-DOF force feedback of up to 4 N without grounding.

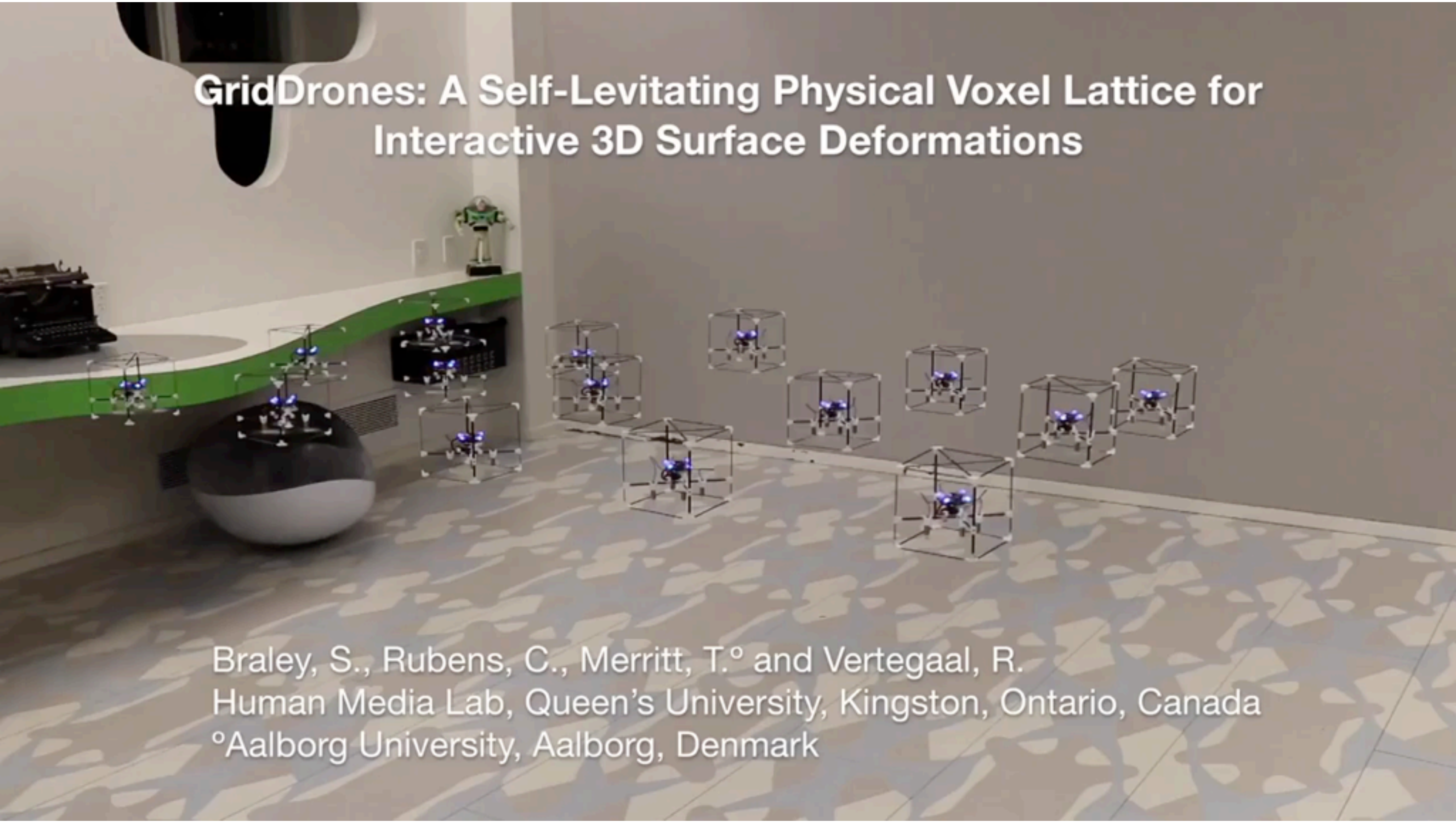
ABSTRACT
We present a new handheld haptic device, Thor's Hammer, which uses propeller propulsion to generate ungrounded, 3-DOF force feedback. Thor's Hammer has six motors and propellers that generates strong thrusts of air without the need for physical grounding or heavy air compressors. With its location and orientation tracked by an optimal tracking system, the system can exert forces in arbitrary directions regardless of the device's orientation. Our technical evaluation shows that Thor's Hammer can apply up to 4 N of force in arbitrary directions with less than 0.11 N and 3.9° of average magnitude and orientation errors. We also present virtual reality applications that can benefit from the force feedback provided by Thor's Hammer. Using these applications, we conducted a preliminary user study and participants felt the experience more realistic and immersive with the force feedback.

Author Keywords
Haptic feedback; ungrounded force feedback; virtual reality; propeller-based feedback.

ACM Classification Keywords
H.5.2. [User Interfaces]: Haptic I/O.

INTRODUCTION
Virtual reality (VR) allows users to engage with compelling experiences in ways that are otherwise not possible. Advances in graphical processing, displays, IMU integration, and other technologies have enabled highly compelling visual and audio experiences in commodity hardware, even on mobile devices. Despite these recent improvements in visual and auditory output, haptic feedback has yet to see the same degree of adoption. While some VR technologies use vibrotactile actuators to induce tactile haptic feedback, these technologies fail to elicit the experience of continuous force, such as feeling an object's weight or an otherwise tugging of the hand. This feeling of the continuous force is sensed through a kinesthetic sensation, and the classes of haptic devices that can simulate continuous forces are generally referred to as *force feedback* or *kinesthetic* haptic devices.

While there has been extensive research on developing force feedback devices, enabling force feedback in immersive VR environments is still challenging. This is because most force feedback devices require grounding, i.e., they need to be attached to a heavy object or otherwise fixed in place in order to be able to produce the forces needed and withstand reciprocal kickback [18,37,42,43]. Approaches to grounded force feedback include the use of mechanical joints [5,9,12,42,43], wires that are pulled [3,18], air jet actuators [30,31,34] or electromagnets [35,37]. While such methods



2018 Grid Drones

GridDrones: A Self-Levitating Physical Voxel Lattice for Interactive 3D Surface Deformations

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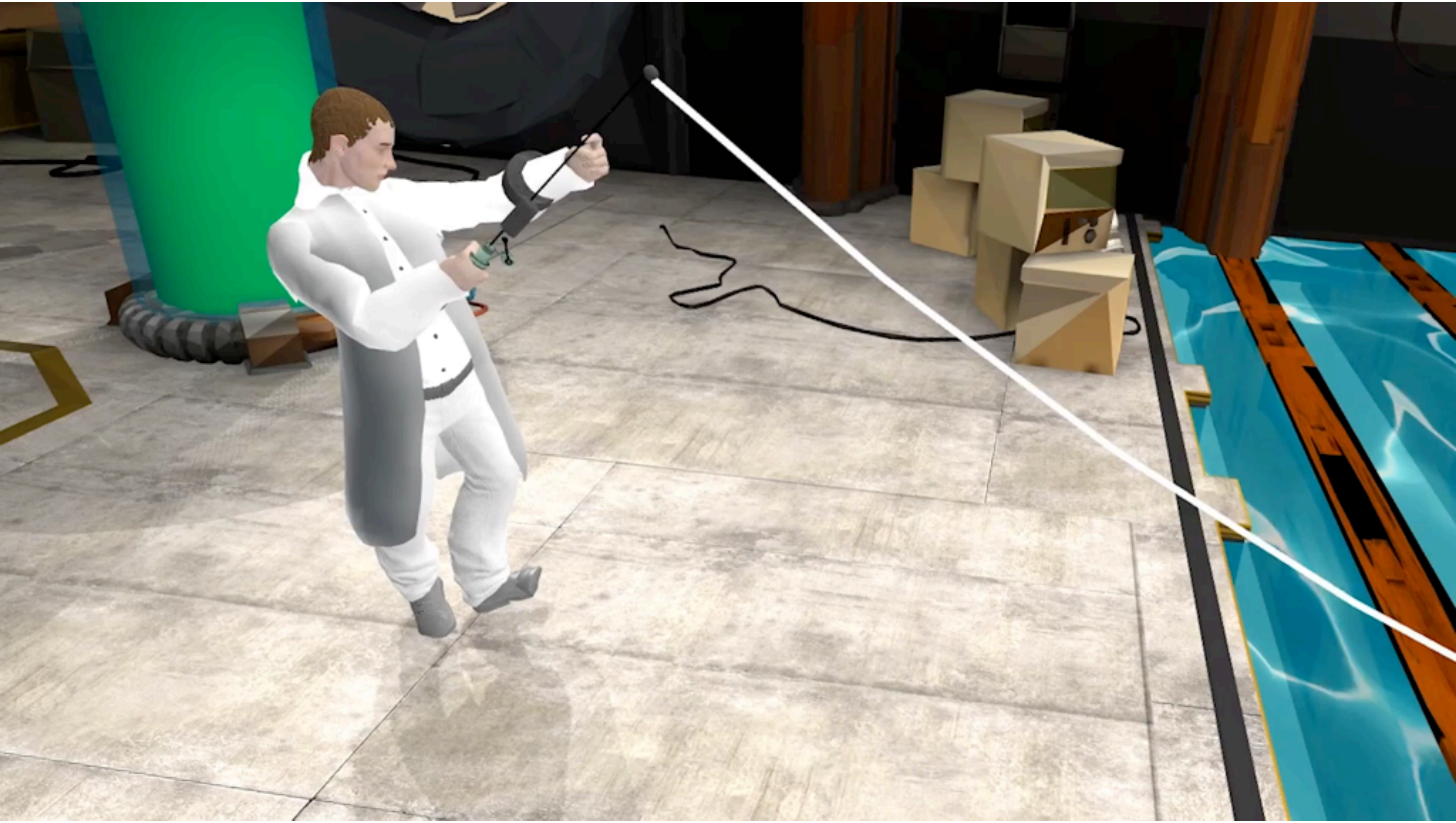
ABSTRACT
We present GridDrones, a self-levitating programmable matter platform that can be used for representing 2.5D voxel grid relief maps capable of rendering unsupported structures and 3D transformations. GridDrones consists of cube-shaped nanocopters that can be placed in a volumetric 1x*n*x*n* mid-air grid, which is demonstrated here with 15 voxels. The number of voxels and scale is only limited by the size of the room and budget. Grid deformations can be applied interactively to this voxel lattice by manually selecting a set of voxels, then assigning a continuous topological relationship between voxel sets that determines how voxels move in relation to each other and manually drawing out selected voxels from the lattice structure. Using this simple technique, it is possible to create unsupported structures that can be translated and oriented freely in 3D. Shape transformations can also be recorded to allow for simple physical shape morphing animations. This work extends previous work on selection and editing techniques for 3D user interfaces.

Author Keywords
Organic User Interfaces; Claytronics; Radical Atoms; Programmable Matter; Swarm User Interfaces.

INTRODUCTION
The creation of bi-directional tangible interfaces has been an enduring research goal [18]. Sutherland [41] envisioned early on that the ultimate form of Virtual Reality (VR) would entail the rendering of physical matter in lieu of virtual pixels. There are two main reasons for this: 1) Physical matter provides haptic feedback that is difficult to simulate in VR; and 2) to achieve symmetry between the ability for physical objects to control software, and software to control physical representations [19]. Toffoli and Margolus [42] coined the term "programmable matter", refining the concept to pertain to massively parallel arrays of physical cellular automata capable of rendering 3D geometric shapes that, someday, would be of sufficient resolution to be indistinguishable from actual physical objects. The effort towards interactive programmable matter is continuing today, within user interface paradigms such as *Claytronics* [12], *Organic User Interfaces* [32,43], and *Radical Atoms* [19] and studied in related fields such as reconfigurable [25], modular [24,34] and swarm robotics [14,36]. These interfaces are capable of representing physical 3D objects via synchronous movement of large quantities of miniature robots dubbed *Catoms* (Claytronic Atoms) [23]. However, one of the problems with existing programmable matter prototypes is that it is challenging to position Catoms in 3D, especially in the vertical (z) dimension [13,35]. This is because Catoms need to overcome gravity in order to move in the vertical dimension, and because structures need to always remain structurally stable under gravity during deformation. Indeed, when we examine prior work in programmable matter prototypes, such as Kilobots [36], or

Figure 1. GridDrones system with an array of self-levitating physical voxels represented by small quadcopters.

the ‘mounted’ base
can also be a friend!



2017 Mutual Human Actuation

Mutual Human Actuation

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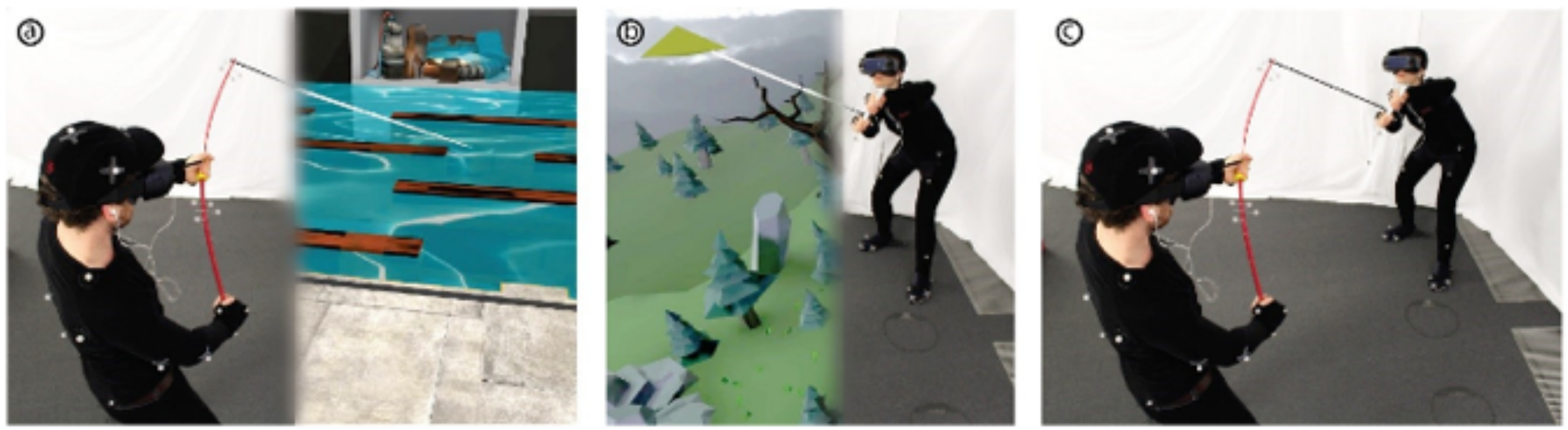

Figure 1: (a) This user, alone in his virtual world, is trying to pull a huge creature out of the water. He feels how the creature is struggling and pulling on his fishing rod. (b) At the same time, this other user, also alone in her virtual world, is struggling to control her kite during a heavy storm, 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

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

2014 Haptic Turk

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

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

INTRODUCTION

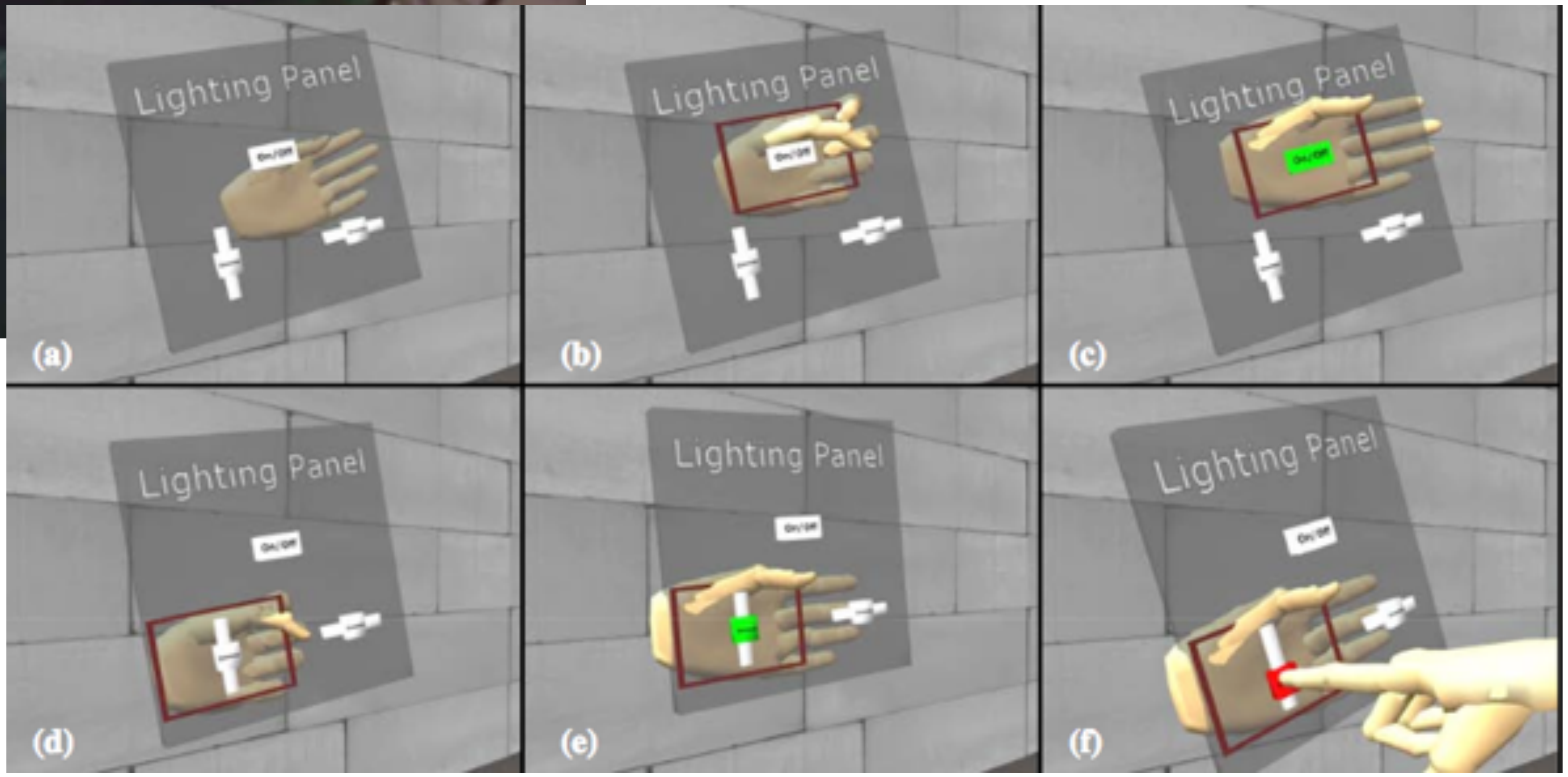
For a long time, the key to immersion in interactive experience and games was sought in photorealistic graphics [8],

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 the mounted base can also be **your own body…**



2005: haptic hand

The Haptic Hand: Providing User Interface Feedback with the Non-Dominant Hand in Virtual Environments

Luv Kohli Mary Whitton

Department of Computer Science
The University of North Carolina at Chapel Hill

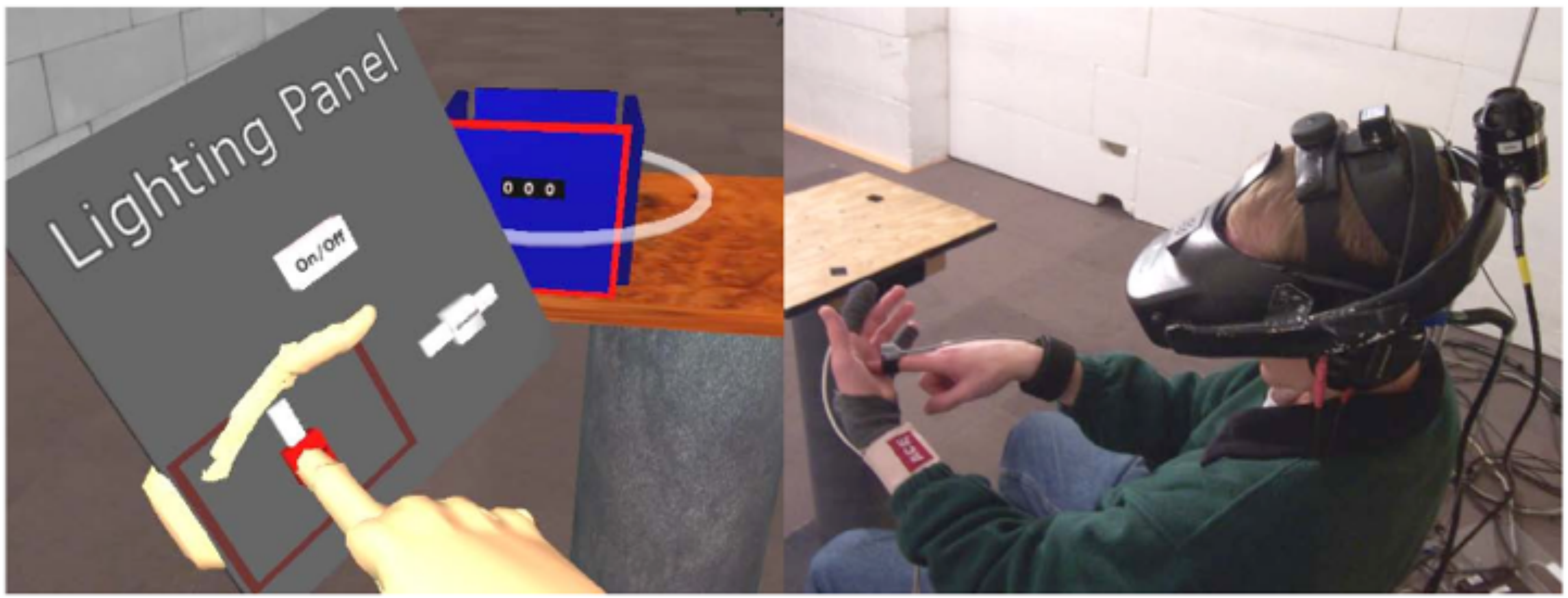


Figure 1 - A user interacts with a virtual interface panel by touching his non-dominant hand.

Abstract

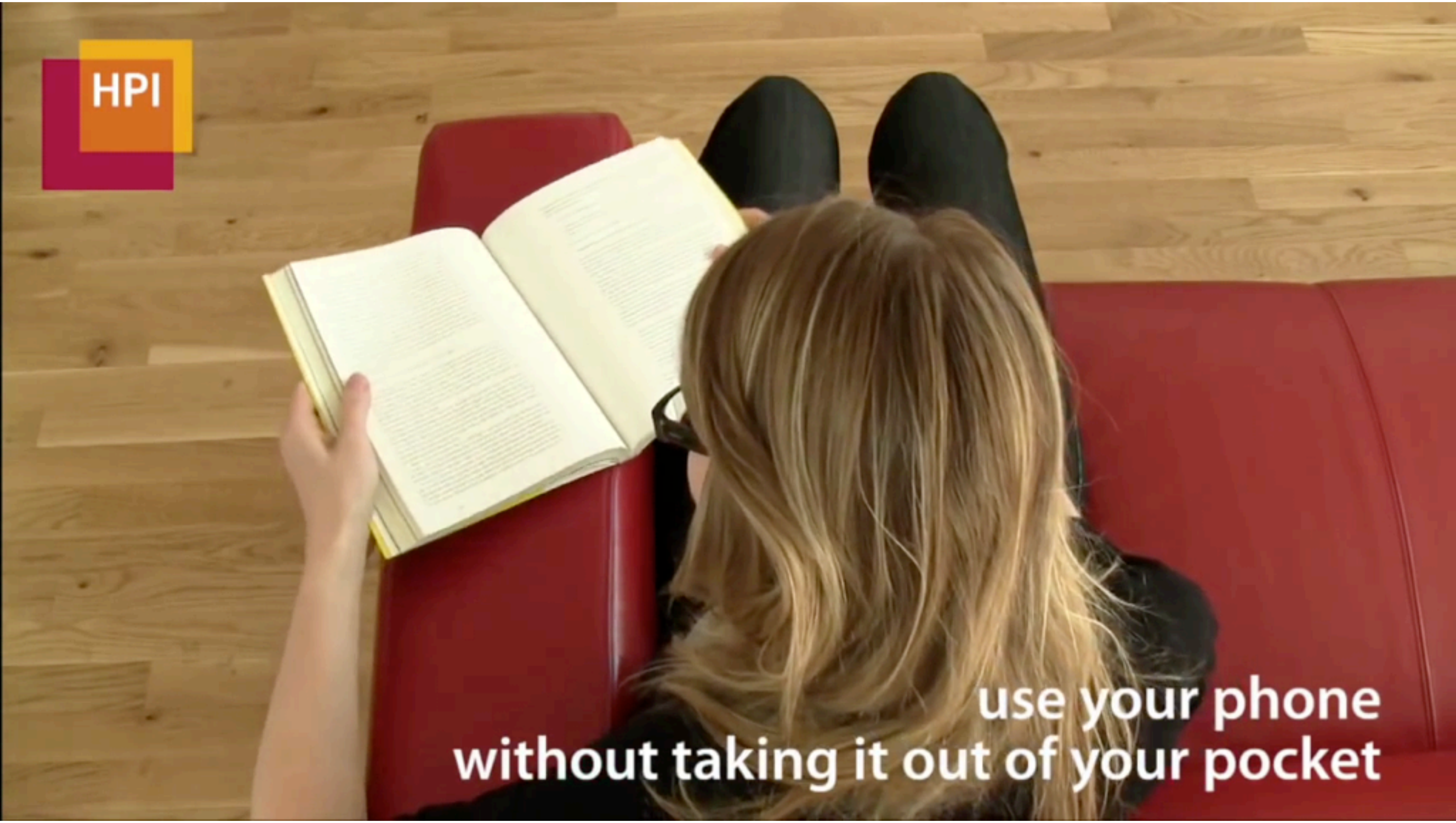
We present a user interface for virtual environments that utilizes the non-dominant hand to provide haptic feedback to the dominant hand while it interacts with widgets on a virtual control panel. We believe this technique improves on existing prop-based methods of providing haptic feedback. To gauge the interface's effectiveness, we performed a usability study. We do not present a formal comparison with prior techniques here. The goal of this study was to determine the feasibility of using the non-dominant hand for haptic feedback, and to obtain subjective data about usability.

user's sense of presence—the user's feeling that she is actually in the VE—as well as the user's spatial memory of the VE [10].

Haptic feedback is especially important for fine manipulation of real objects. Without the sense of touch, it is difficult to interact precisely with objects in VEs because there is nothing to steady the user's hands [13].

Guiard studied the distribution of work between the dominant and the non-dominant hands and classified tasks as *unimanual* (e.g., one-handed throwing), *bimanual symmetric* (identical actions performed by each hand), and *bimanual asymmetric* (both hands

2011: hand as phone



2011: hand as phone

Imaginary Phone: Learning Imaginary Interfaces by Transferring Spatial Memory from a Familiar Device

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ABSTRACT

We propose a method for learning how to use an imaginary interface (i.e., a spatial non-visual interface) that we call "transfer learning". By using a physical device (e.g. an iPhone) a user inadvertently learns the interface and can then transfer that knowledge to an imaginary interface. We illustrate this concept with our *Imaginary Phone* prototype. With it users interact by mimicking the use of a physical iPhone by tapping and sliding on their empty non-dominant hand without visual feedback. Pointing on the hand is tracked using a depth camera and touch events are sent wirelessly to an actual iPhone, where they invoke the corresponding actions. Our prototype allows the user to perform everyday task such as picking up a phone call or launching the timer app and setting an alarm. Imaginary Phone thereby serves as a shortcut that frees users from the necessity of retrieving the actual physical device.

We present two user studies that validate the three assumptions underlying the transfer learning method. (1) Users build up spatial memory automatically while using a physical device: participants knew the correct location of 68% of their own iPhone home screen apps by heart. (2) Spatial memory transfers from a physical to an imaginary interface: participants recalled 61% of their home screen apps when recalling app location on the palm of their hand. (3) Palm interaction is precise enough to operate a typical

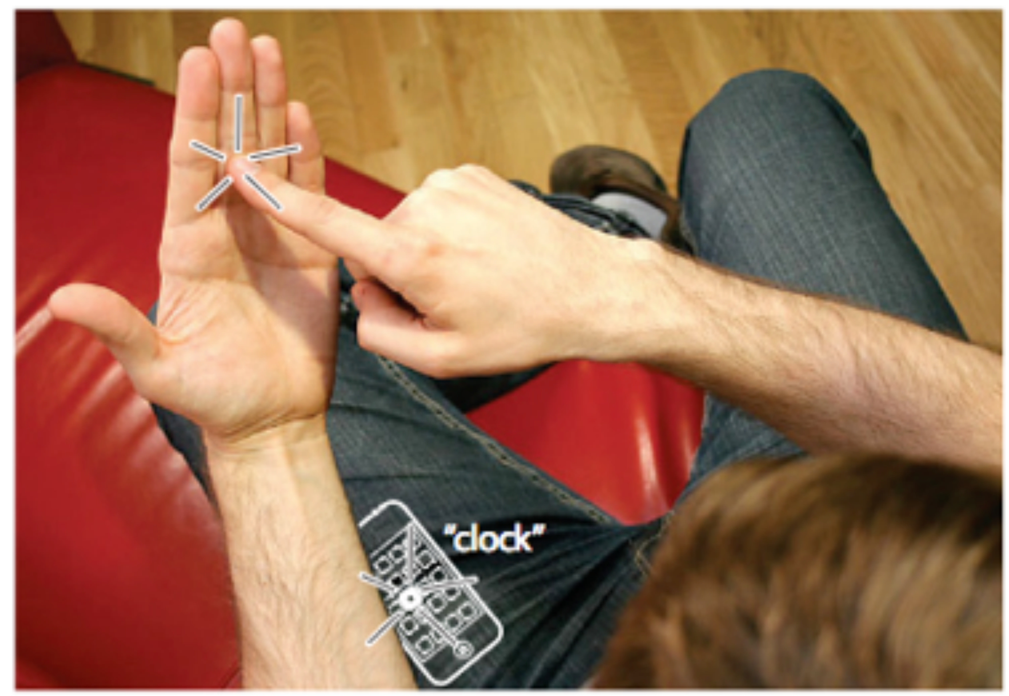

Figure 1: This user operates his mobile phone in his pocket by *mimicking* the interaction on the palm of his non-dominant hand. The palm becomes an *Imaginary Phone* that can be used in place of the actual phone. The interaction is tracked and sent to the actual physical device where it triggers the corresponding function. The user thus leverages spatial memory built up while using the screen device. We call this *transfer learning*.

INTRODUCTION

Imaginary interfaces were proposed as a means for enabling pointing input on screen-less mobile devices [5]

the ‘mounted’ base
can also be a **passive prop…**

2018 Turning Passive Haptics into Active Haptics

iTurk: Turning Passive Haptics into Active Haptics by Making Users Reconfigure Props in Virtual Reality

Lung-Pan Cheng[1], **Li Chang**[12], **Sebastian Marwecki**[1], **Patrick Baudisch**[1]
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Figure 1: (a) As the user launches a plasma ball into the reactor, she feels the physical impact of hitting the prop. (b) The haptic feedback comes from a physical prop on a pendulum. The user's hit, however, also sets the pendulum in motion. (c) When the user later fends off a group of flying droids, the system renders each one of them using one period of the swinging pendulum. Every one of the user's hits is not only a haptic experience, but also provides the impulse for the next attack. As a result, the experience feels alive, even though the user is the only animate entity in it.

ABSTRACT
We present a system that complements virtual reality experiences with passive props, yet still allows modifying the virtual world at runtime. The main contribution of our system is that it does not require any actuators; instead, our system employs *the user* to reconfigure and actuate otherwise passive props. We demonstrate a foldable prop that users reconfigure to represent a suitcase, a fuse cabinet, a railing, and a seat. A second prop, suspended from a long pendulum, not only stands in for inanimate objects, but also for objects that move and demonstrate proactive behavior, such as a group of flying droids that physically attack the user. Our approach conveys a sense of a living, animate world, when in reality the user is the only animate entity present in the system, complemented with only one or two physical props. In our study, participants rated their experience as more enjoyable and realistic than a corresponding no-haptics condition.

Author Keywords
Human actuation; Haptics; Virtual Reality; Immersion;

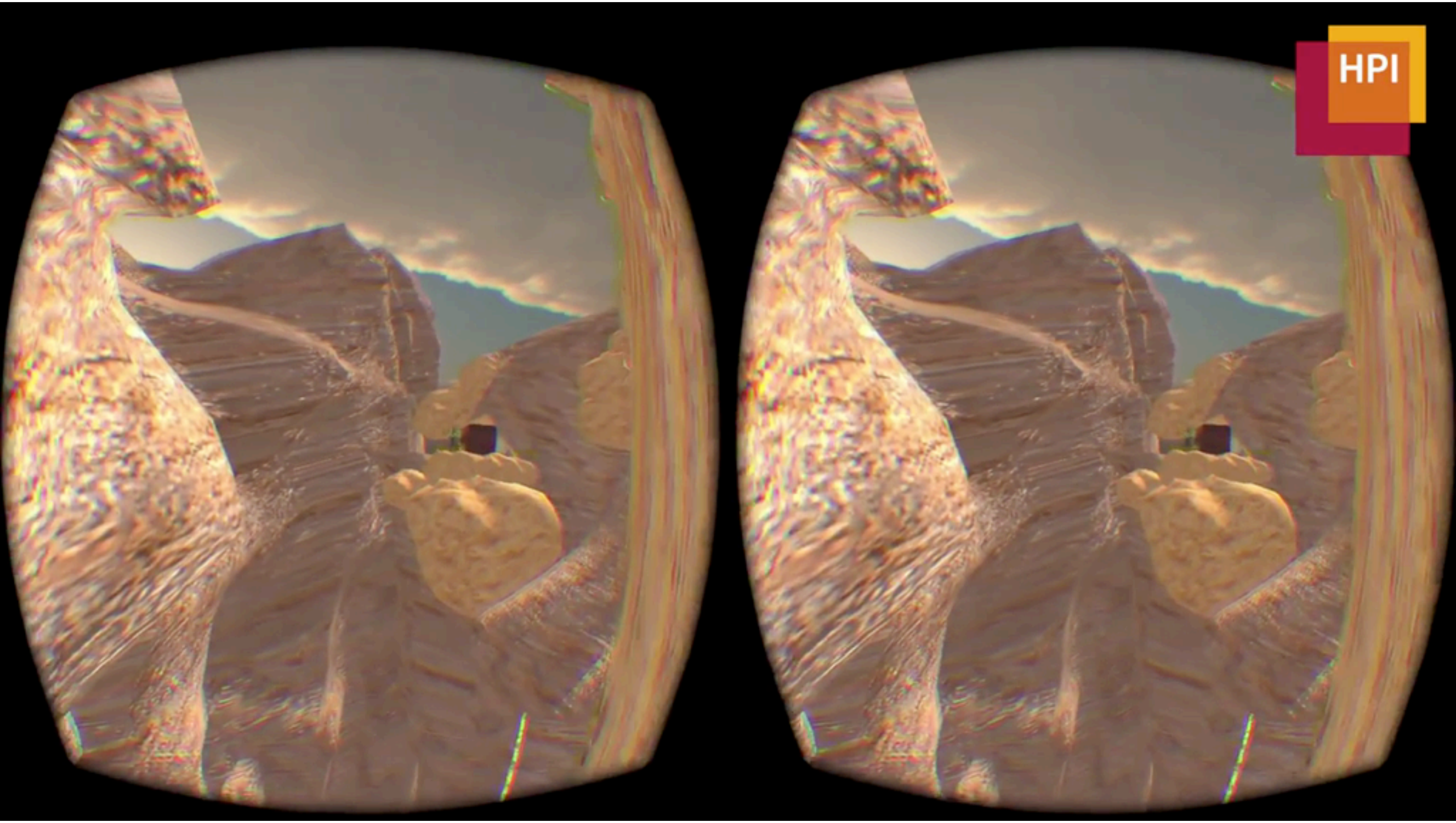
ACM Classification Keywords
H.5.2 [User Interfaces]: Haptic I/O.

INTRODUCTION
Ever since the conception of the virtual reality headset in 1968 [4], many researchers have argued that the next step in virtual reality has to be to allow users to not only see and hear, but also *feel* virtual worlds [5].

One main approach towards this revolves around the use of physical props, also known as *passive haptics* [21,28]. While simple prop-based systems require users to be mostly stationary [23], more elaborate systems allow users to move around freely in a space filled with physical props. Some systems achieved this effect based on projection [15]; others used head-mounted displays [14].

Unfortunately, the increased level of immersion provided by passive haptics is subject to limitations. First, a room filled with physical props tends to match only one specific virtual

the ‘mounted’ base
can also be **dynamically assembled…**



2015 TurkDeck

TurkDeck: Physical Virtual Reality Based on People

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Patrick Schmidt, Robert Kovacs, Johannes Jasper, Jonas Kemper, and Patrick Baudisch
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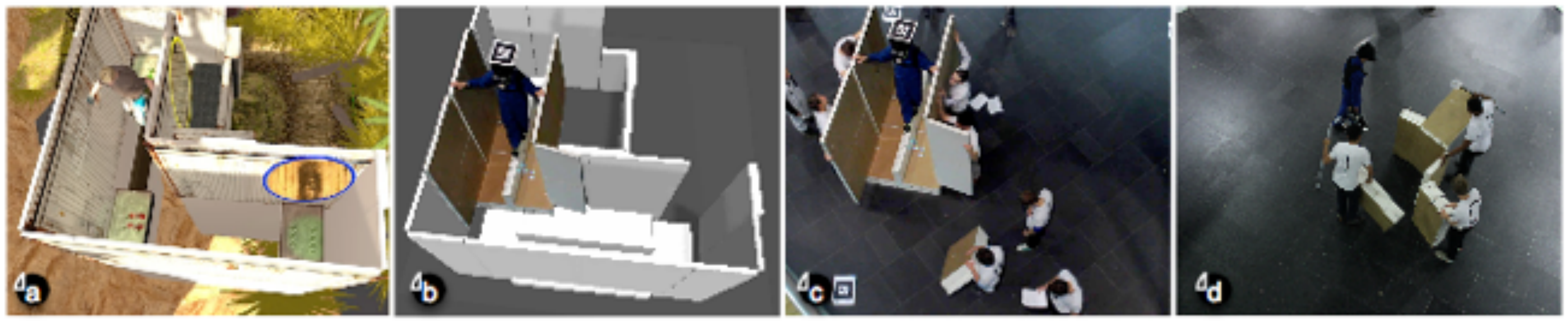


Figure 1: TurkDeck is a prop-based virtual reality system that let's users not only (a) see and hear a virtual world, but also (b) feel it. Conceptually, the user is in a fully populated physical world. (c) In reality, however, TurkDeck's physical room is almost empty. "Human actuators" present and operate props only when and where the user can actually reach them. (d) By reusing generic props, TurkDeck minimizes the required props to what human actuators can carry, still allows producing virtual worlds of arbitrary size.

ABSTRACT

TurkDeck is an immersive virtual reality system that reproduces not only what users see and hear, but also what users feel. TurkDeck produces the haptic sensation using props, i.e., when users touch or manipulate an object in the virtual world, they simultaneously also touch or manipulate a corresponding object in the physical world. Unlike previous work on prop-based virtual reality, however, TurkDeck allows creating arbitrarily large virtual worlds in finite space and using a finite set of physical props. The key idea behind TurkDeck is that it creates these physical representations on the fly by making a group of human workers present and operate the props only when and where the user can actually reach them. TurkDeck manages these so-called "human actuators" by displaying visual instructions that tell the human actuators when and where to place props and how to actuate them. We demonstrate TurkDeck at the example of an immersive $300m^2$ experience in $25m^2$ physical space. We show how to simulate a wide range of physical objects and effects, including walls, doors, ledges, steps, beams, switches, stompers, portals, zip lines, and wind. In a user study, participants rated the realism/immersion of TurkDeck higher than a traditional prop-less baseline condition (4.9 vs. 3.6 on 7 item Likert).

Author Keywords

Prop-based virtual reality; passive virtual reality.

ACM Classification Keywords

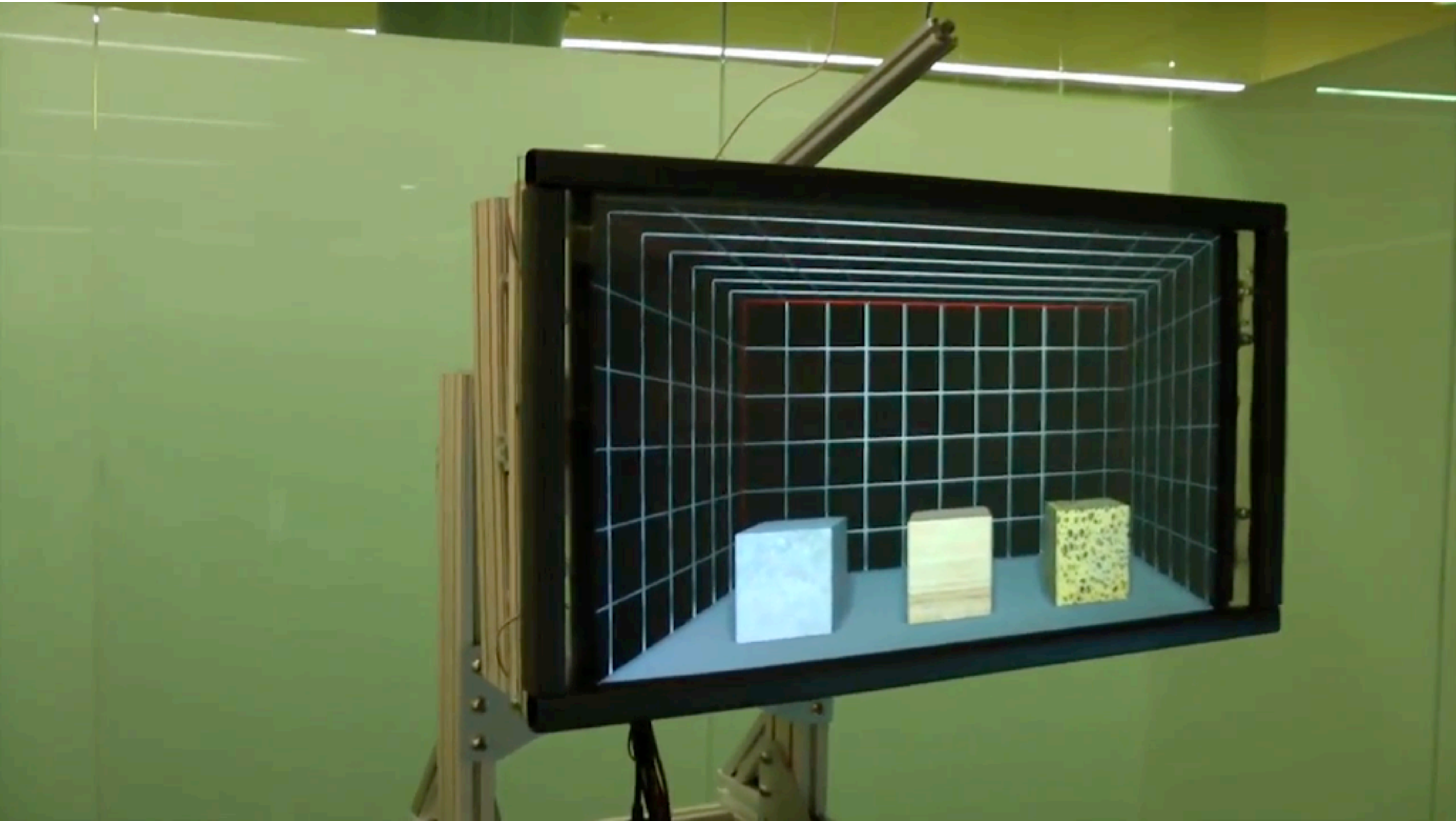
INTRODUCTION

Ever since its conception in the 1960's, head-mounted virtual reality systems have been primarily concerned with the user's visual senses [28] and optionally spatial audio [1]. As the next step towards realism and immersion, however, many researchers argue that the next sense such a system should support is the haptic sense, in order to convey the physicality of the virtual world [3,4].

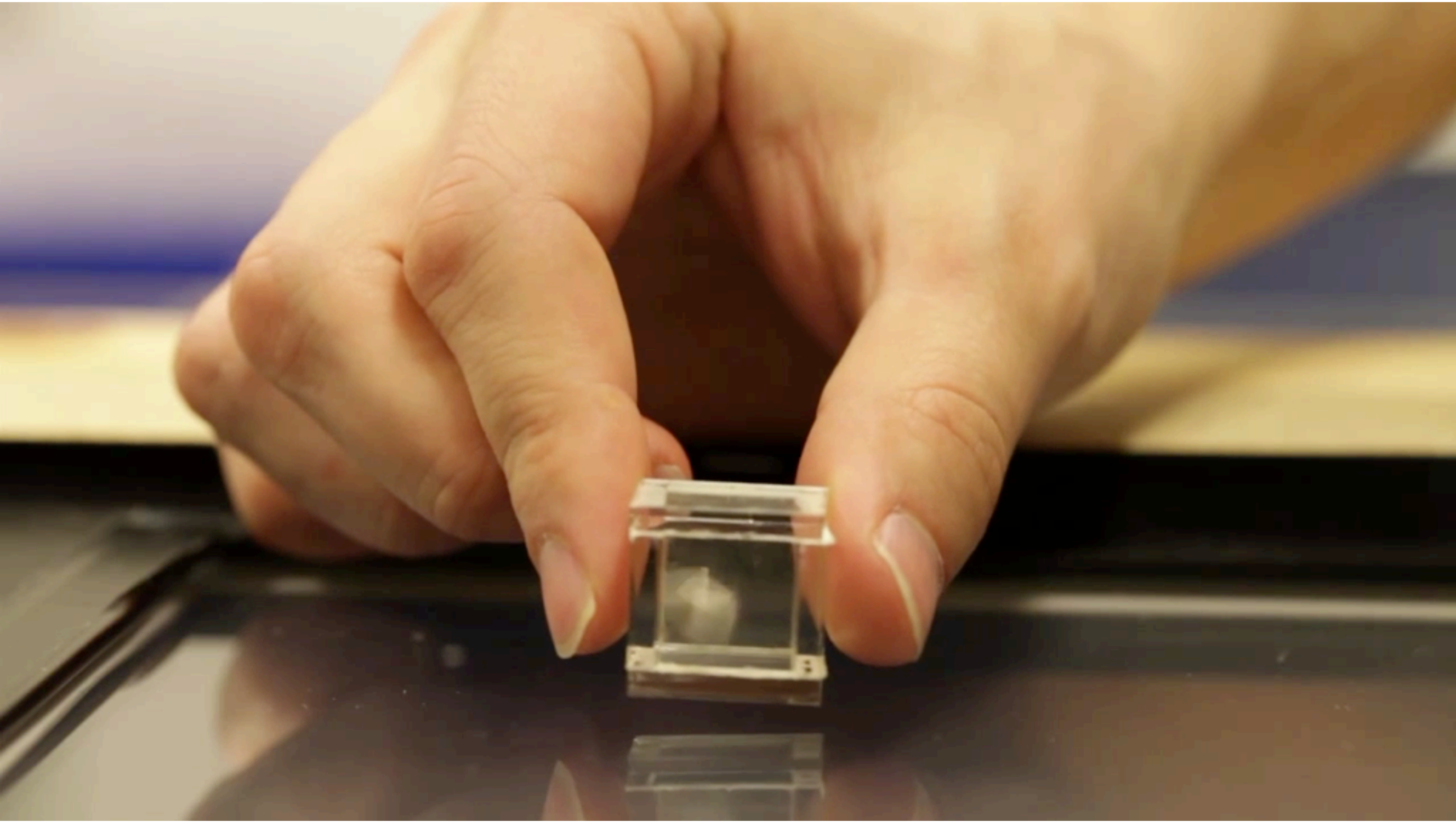
In the past, researchers have pursued two different approaches. On the one hand, researchers use mechanical machinery, such as motion platforms [27] and exoskeletons [3] to apply forces to the user. While these approaches have been very successful at giving users the experience of walking, they are not well suited for recreating the experience of touching objects, such as grabbing a door handle or slamming against a wall.

Researchers therefore proposed using physical props. Simple prop-based systems used a single hand-held prop (Ortega et al [19]). The more elaborate systems supported "real walking" [30] in a space where all walls were physical (with projection [14] or head-mounted displays [10]) allowing users to experience the full physicality of the room.

Unfortunately, simulating one room worth of a virtual world using the prop-based approach requires one room worth of physical space, as even redirected walking allows reusing only isolated props [13]. This makes prop-based force feedback can be implemented in many different ways…



mechanical



magnetic

FingerFlux: Near-surface Haptic Feedback on Tabletops

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ABSTRACT

We introduce FingerFlux, an output technique to generate near-surface haptic feedback on interactive tabletops. Our system combines electromagnetic actuation with permanent magnets attached to the user's hand. FingerFlux lets users feel the interface before touching, and can create both attracting and repelling forces. This enables applications such as reducing drifting, adding physical constraints to virtual controls, and guiding the user without visual output. We show that users can feel vibration patterns up to 35 mm above our table, and that FingerFlux can significantly reduce drifting when operating on-screen buttons without looking.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces.—Haptic I/O.

General terms: Design, Human Factors, Experimentation

Keywords: Haptic feedback, Magnets, Actuation, Interactive Tabletops

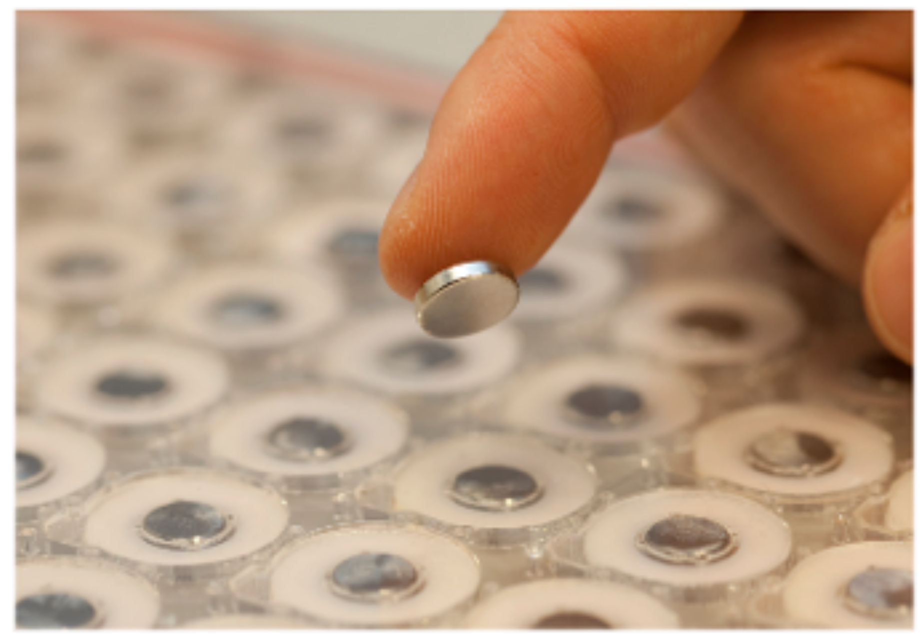


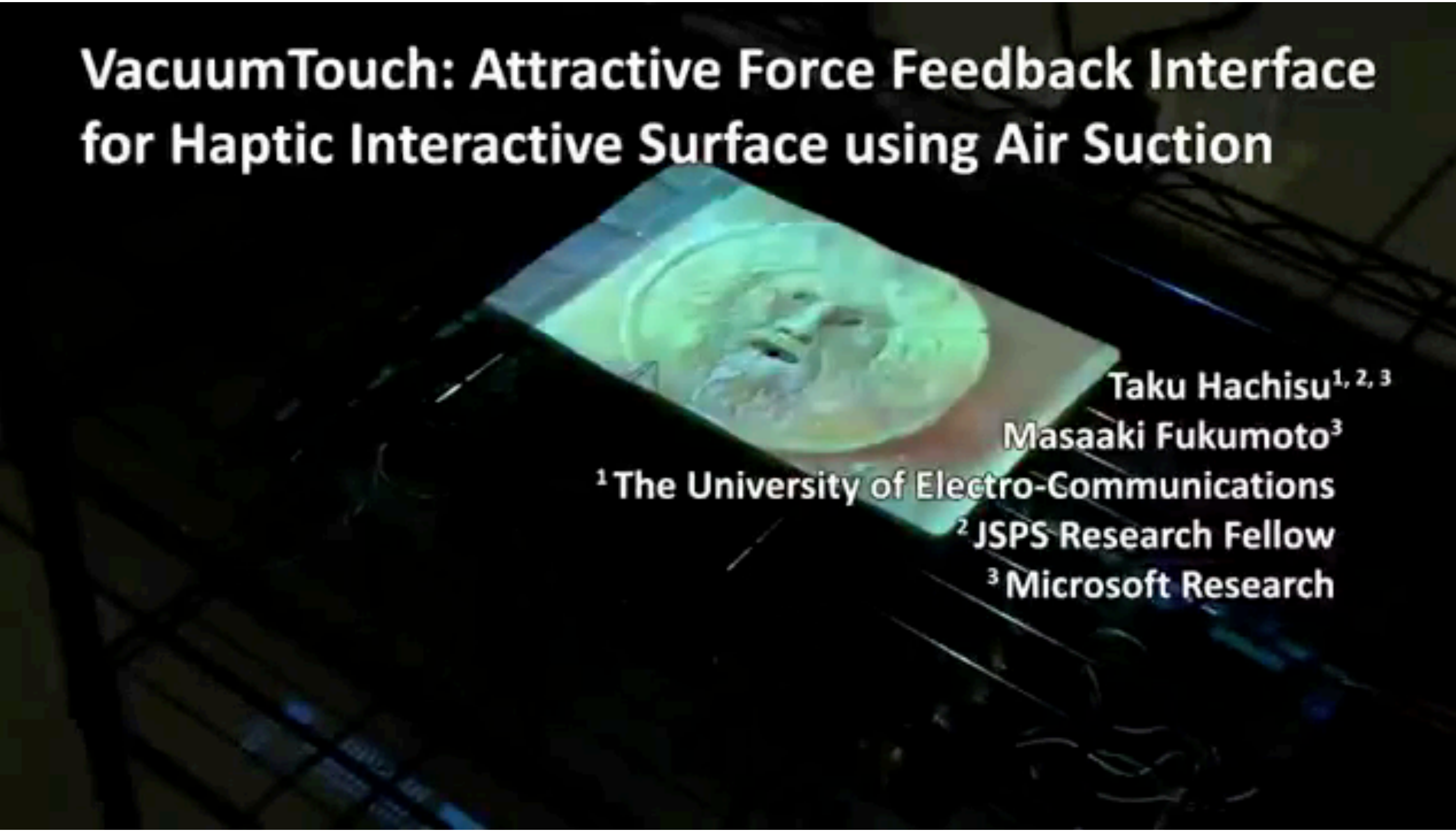
Figure 1: FingerFlux provides attraction, repulsion, vibration, and directional haptic feedback on and near the surface using electromagnets in the table and a permanent magnet attached to the user's finger.

INTRODUCTION

Touchscreens allow users to directly manipulate objects on the screen with their fingers. This interaction heavily depends on the user's visual perception of the hand [8] and visual feedback from the screen [27]. Yet, there are situations in which vision is not available, such as entering text on a

if the user is drifting too much, e.g., beyond the boundaries of a control she wants to press, there is no haptic feedback to realign her fingers anymore.

In this paper, we present a system that allows users to feel haptic feedback when hovering above the table, i.e., *before* they touch the surface. Our system is based on electromag-


VacuumTouch: Attractive Force Feedback Interface for Haptic Interactive Surface using Air Suction
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[1] The University of Electro-Communications
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pneumatic

VacuumTouch: Attractive Force Feedback Interface for Haptic Interactive Surface using Air Suction

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ABSTRACT
We present VacuumTouch, a novel haptic interface architecture for touch screens that provides attractive force feedback to the user's finger. VacuumTouch consists of an air pump and solenoid air valves that connect to the surface of the touch screen and suck the air above the surface where the user's finger makes contact. VacuumTouch does not require the user to hold or attach additional devices to provide the attractive force, which allows for easy interaction with the surface. This paper introduces the implementation of the VacuumTouch architecture and some applications for enhancement of the graphical user interface, namely a suction button, a suction slider, and a suction dial. The quantitative evaluation was conducted with the suction dial and showed that the attractive force provided by VacuumTouch improved the performance of the dial menu interface and its potential effects. At the end of this paper, we discuss the current prototype's advantages and limitations, as well as possible improvements and potential capabilities.

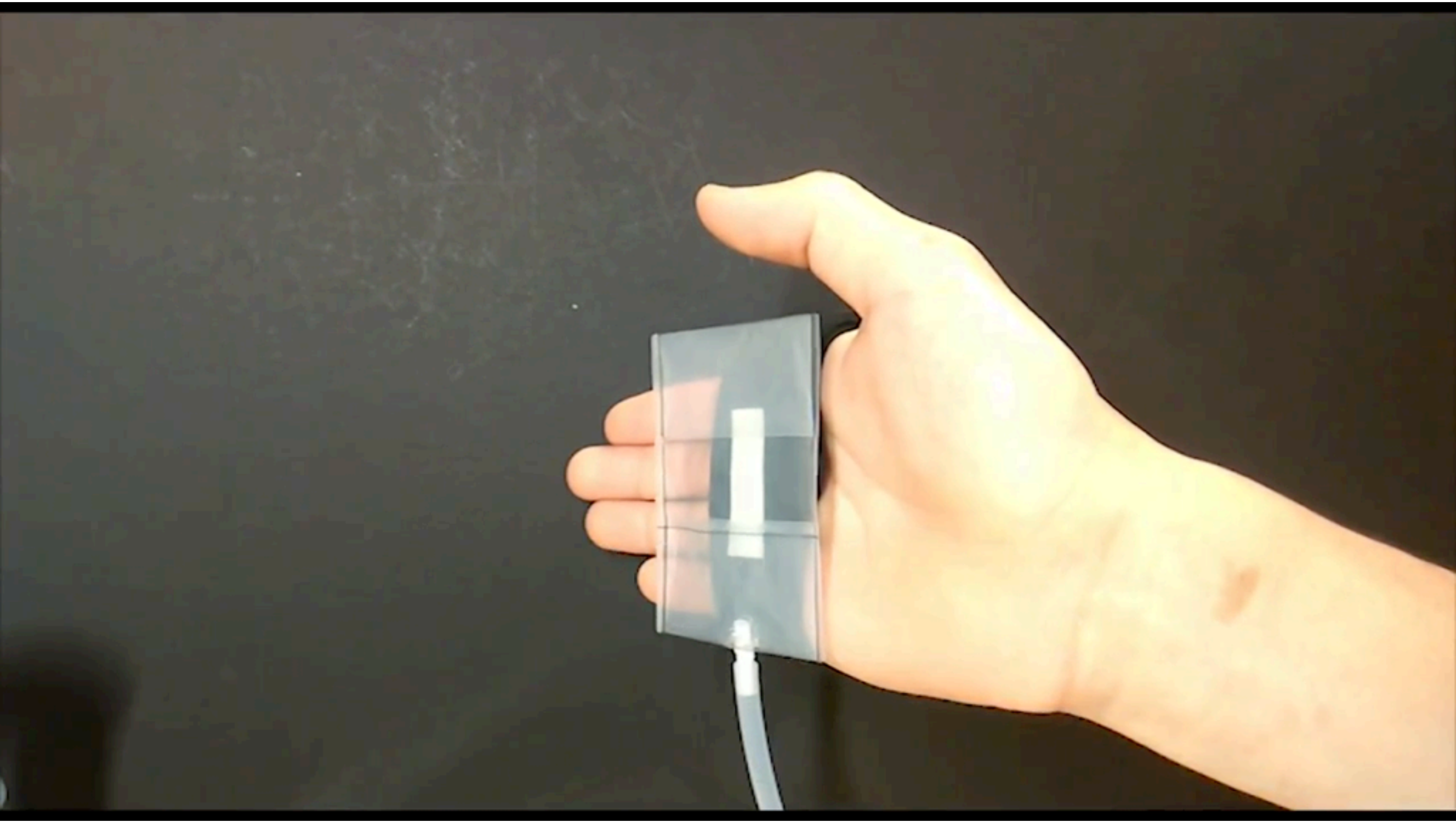
Author Keywords
Air suction; attractive force; interactive surface; haptic interface; VacuumTouch.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]: User

a user is able to perceive the texture or material of an image [3, 12]. Many techniques and systems that offer a variety of realistic haptic sensations have been explored.

The haptic sensation induced by the interface can be divided into two categories, namely tactile or force. Tactile sensation is usually induced by mechanical skin deformation that fires the cutaneous receptors. Vibratory sensation that is included in one of the tactile sensations is often used for haptic interactions on a touch screen. Force sensation is most often induced by the tension on the muscle, tendons and joints. Using force sensation as feedback for a touch screen can guide the user's hand to the desired position and assure manipulation.

Furthermore, force sensation falls into three categories in terms of direction of actuation from the surface to the finger, namely lateral, repulsive, or attractive. Systems that offer lateral direction force feedback have previously been established [28, 34]. Saga and Deguchi, for example, developed a lateral-force-based haptic interface for touch screens, employing motors and wire strings that pull the user's finger from the corners of the screen [28]. A repulsive sensation is induced by a force whose direction is from the surface toward the finger. It is often used for simulating mechanical button clicking on the surface [9, 27]. An attractive force is induced by a force whose direction is



pneumatic

PuPoP: Pop-up Prop on Palm for Virtual Reality [paper]

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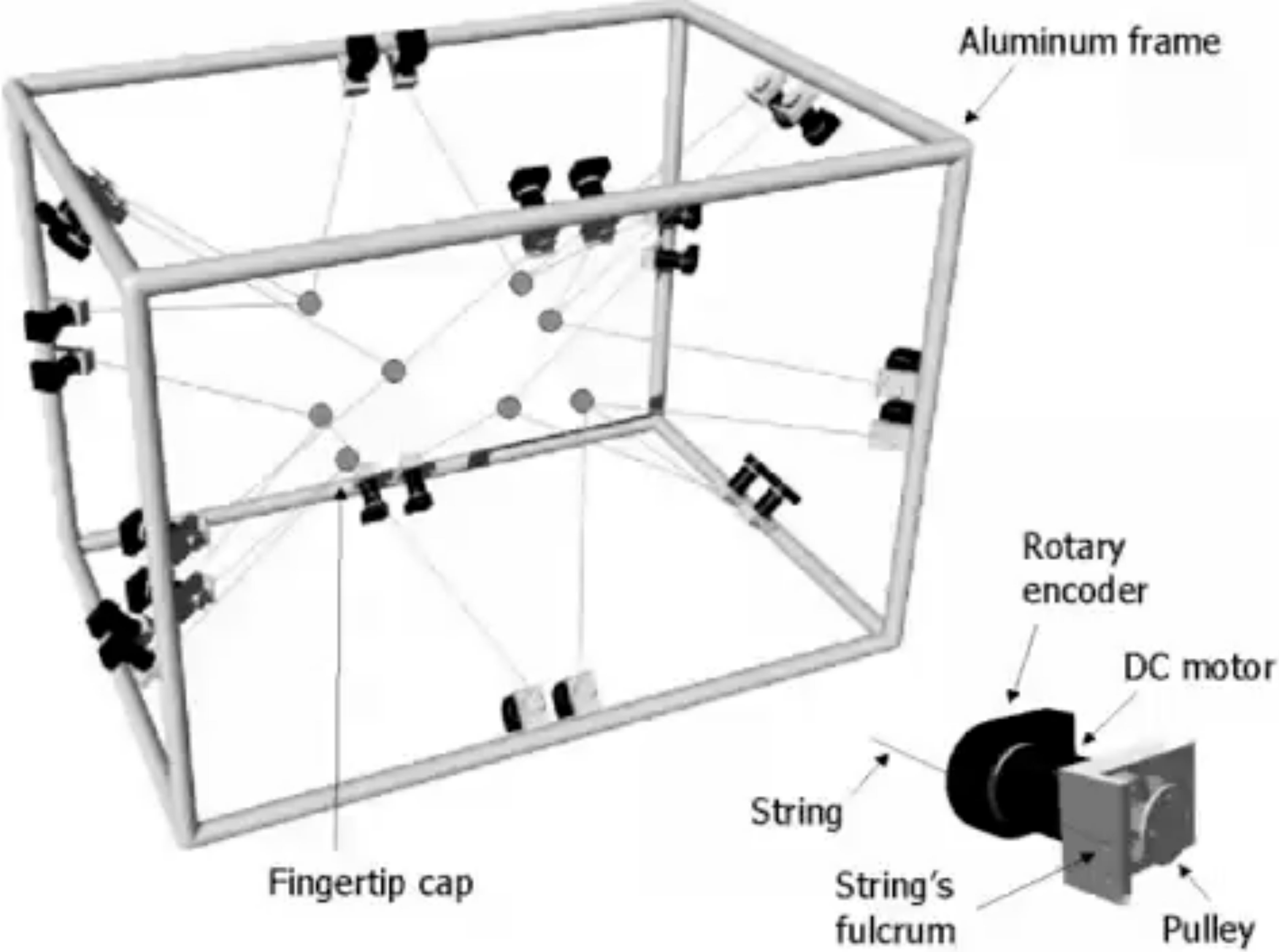
Tzu-Sheng Kuo, National Taiwan University
Chi Wang, National Taiwan University of Science and Technology
Chi-Huan Chiang, National Taiwan University
Da-Yuan Huang, National Chiao Tung University
Liwei Chan, National Chiao Tung University
Bing-Yu Chen, National Taiwan University

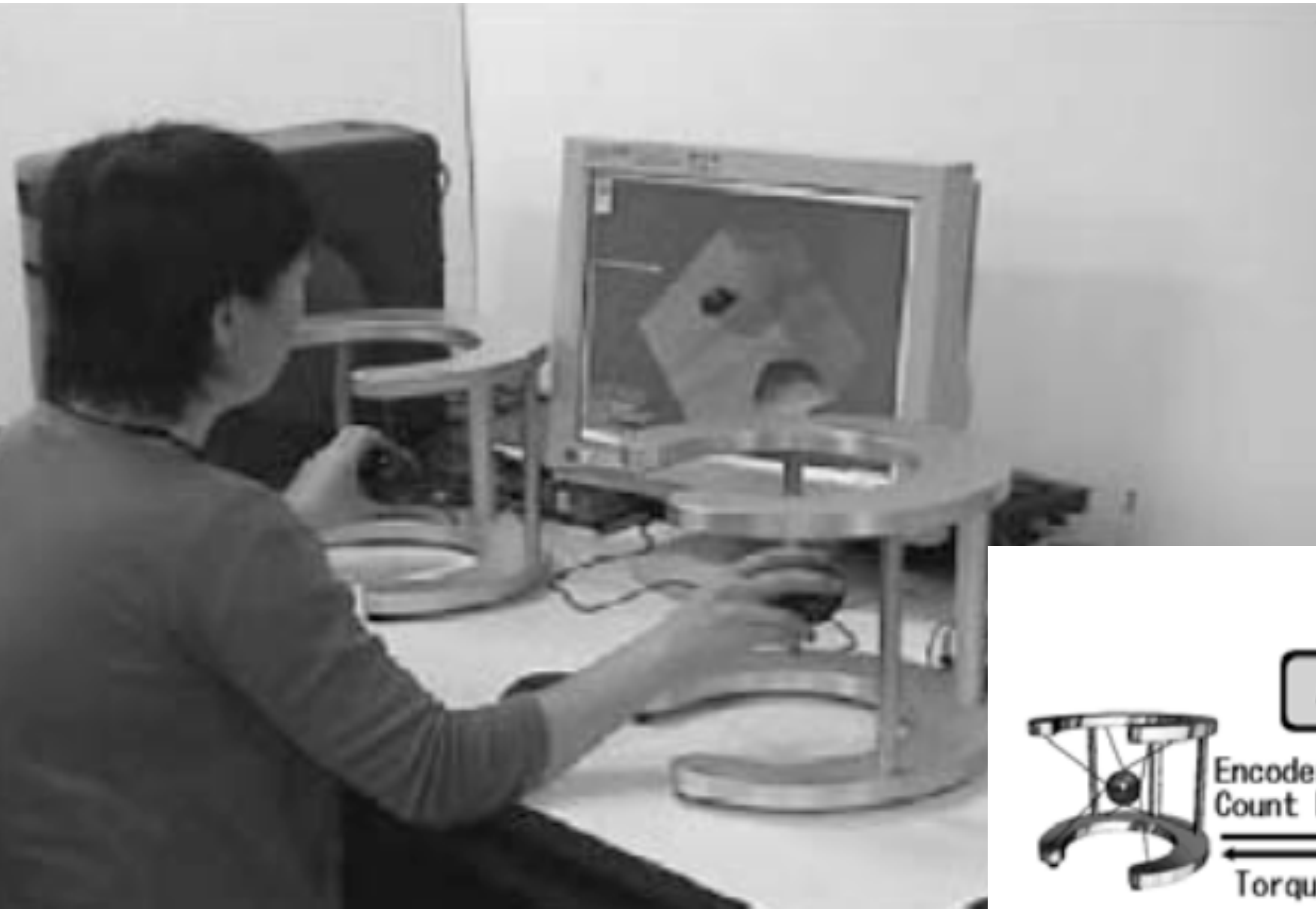
The sensation of being able to feel the shape of an object when grasping it in Virtual Reality (VR) enhances a sense of presence and the ease of object manipulation. Though most prior works focus on force feedback on fingers, the haptic emulation of grasping a 3D shape requires the sensation of touch 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.

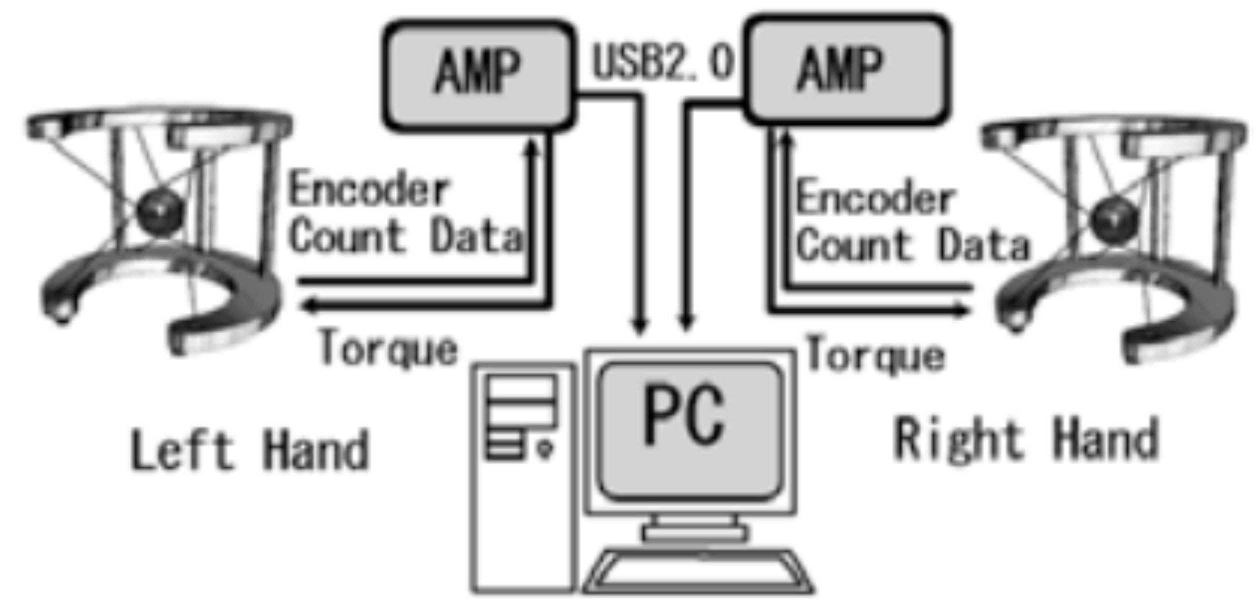
Haptics, Virtual Reality, Airbag, Shape-Proxy

solution 2:
pull the hand from a frame



2002: SPIDAR-8 (SPace Interface for Artificial Reality)





2004: SPIDAR G&G

Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

SPIDAR G&G: A Two-Handed Haptic Interface for Bimanual VR Interaction

Jun Murayama[1], Laroussi Bougrila[2], YanLin Luo[3] Katsuhito Akahane[1], Shoichi Hasegawa[1], Béat Hirsbrunner[2], and Makoto Sato[1]

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Abstract. In this paper, we propose a new haptic interface for tasks requiring two-handed manipulation. The system, named "SPIDAR-G&G", consists of a pair of string-based 6DOF haptic device called "SPIDAR-G". By grasping a special grip provided by each device, user can interact with virtual objects using both hands and accomplish life-like bimanual tasks in an intuitive manner. furthermore, the interface imparts user with the ability to feel different kind of force feedback. The system was evaluated by measuring "completion time" of a 3D pointing task, and shown to enhance interactivity for bimanual works.

1 Introduction

Most of the tasks that we perform in our daily life, involve the use of both hands for a wide variety of purposes ranging from a simple pickup tasks to a more complex and fine manipulation such as surgery tasks. However, both hands work all the time in concert with each other and in a seamless and spontaneous manner to acomplish desired tasks. Keeping such skillful interaction within virtual environemnet will be of great interest to many applications that require the use of both hands such as mechanical assembling, medical surgery, free form modering

this was force feedback,
let’s look at tactile stimulation

<u>types of haptics</u>

(1) force feedback

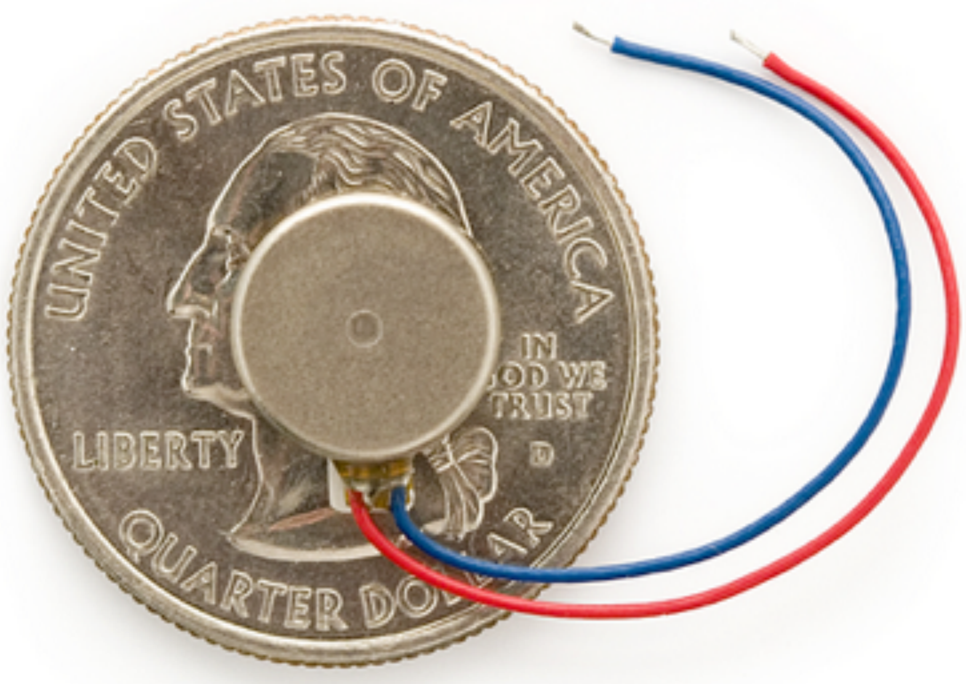
(2) tactile feedback

(vibration, sound, air, lasers)

tactile feedback:

vibration motors

HOME / PRODUCT CATEGORIES / OTHER MOTORS / VIBRATION MOTOR



Vibration Motor

ROB-08449 ROHS✔

★★★★☆ 9

$4.95

Volume sales pricing

- 1 + **ADD TO CART**

Quantity discounts available

DESCRIPTION DOCUMENTS

A vibration motor! This itty-bitty, shaftless vibratory motor is perfect for non-audible indicators. Use in any number of applications to indicate to the wearer when a status has changed. All moving parts are protected within the housing. With a 2-3.6V operating range, these units shake crazily at 3V. Once anchored to a PCB or within a pocket, the unit vibrates softly but noticeably. This high quality unit comes with a 3M adhesive backing and reinforced connection wires.

easy to design and implement

drawback: not very expressive

tactons (vs. icons, earcons):

- vibrotactile messages
- communicate non-verbal messages
- using different rhythms and amplitudes of vibration

Tactons: Structured Tactile Messages for Non-Visual Information Display

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Abstract

Tactile displays are now becoming available in a form that can be easily used in a user interface. This paper describes a new form of tactile output. *Tactons*, or tactile icons, are structured, abstract messages that can be used to communicate messages non-visually. A range of different parameters can be used for Tacton construction including: frequency, amplitude and duration of a tactile pulse, plus other parameters such as rhythm and location. Tactons have the potential to improve interaction in a range of different areas, particularly where the visual display is overloaded, limited in size or not available, such as interfaces for blind people or in mobile and wearable devices. This paper describes Tactons, the parameters used to construct them and some possible ways to design them. Examples of where Tactons might prove useful in user interfaces are given.

Keywords: Tactons, tactile displays, multimodal interaction, non-visual cues.

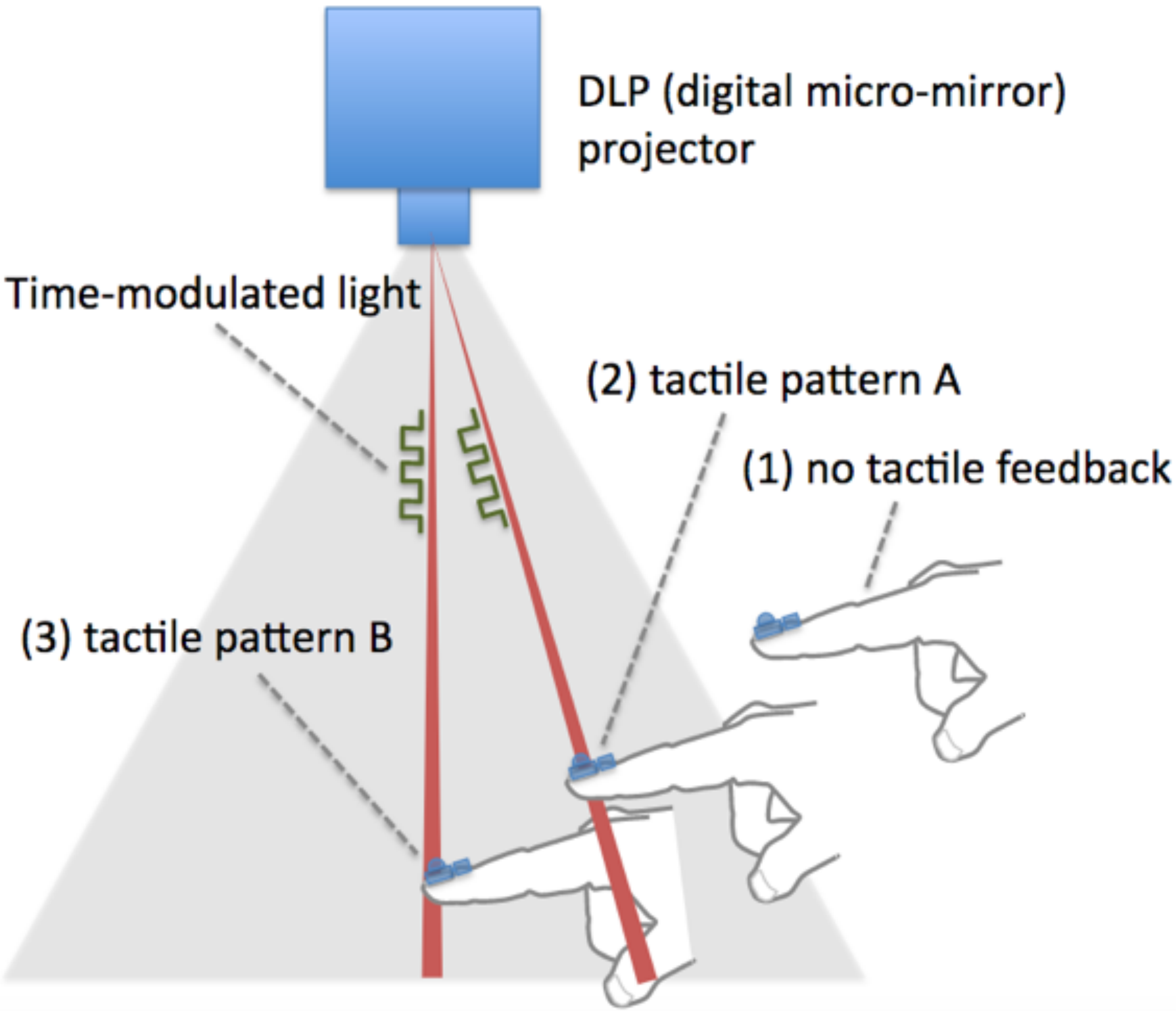
1 Introduction

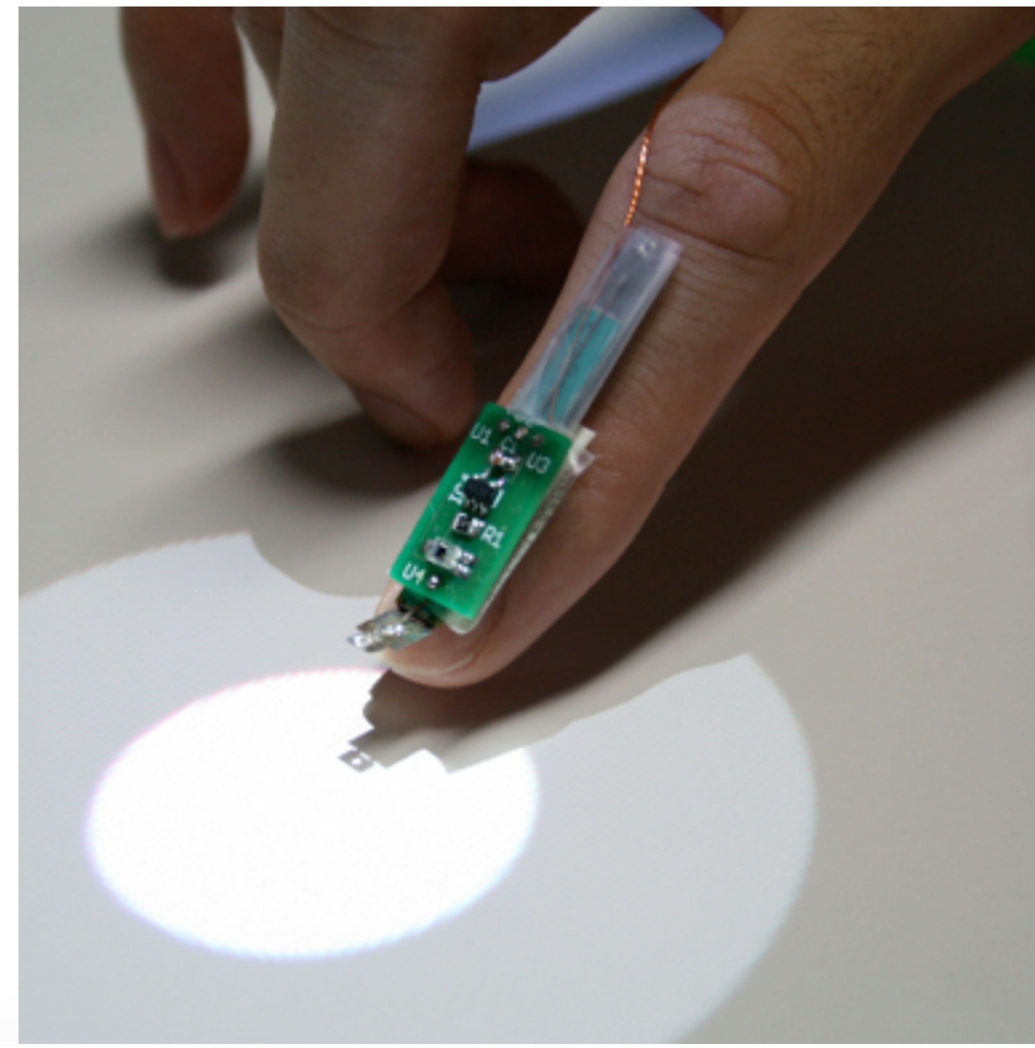
The area of haptic (touch-based) human computer interaction (HCI) has grown rapidly over the last few years. A range of new applications has become possible now that touch can be used as an interaction technique (Wall et al., 2002). However, most current haptic devices have scant applications (Kaczmarek et al., 1991). They have been used in areas such as tele-operation or displays for blind people to provide sensory substitution – where one sense is used to receive information normally received by another (Kaczmarek et al.). Most of the development of these devices has taken place in robotics or engineering labs and has focused on the challenges inherent in building low cost, high-resolution devices with realistic size, power and safety performance. Little research has gone into how they might actually be used at the user interface. Devices are now available that allow the use of tactile displays so the time is right to think about how they might be used to improve interaction.

In this paper the concept of *Tactons,* or tactile icons, is introduced as a new communication method to complement graphical and auditory feedback at the user interface. Tactons are structured, abstract messages that can be used to communicate messages non-visually. Conveying structured messages through touch will be very useful in areas such as wearable computing where screens are limited. The paper gives some background to the perception and use of tactile stimuli and then describes the design of Tactons. It finishes with examples of potential uses for Tactons.

2 Background and previous work

The skin is the largest organ in the body, about 2 m^2 in





2009: extra-senses: photoresistor + piezo ‘feel the light’

SenseableRays: Opto-Haptic Substitution for Touch-Enhanced Interactive Spaces

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CHI 2009, April 4 – 9, 2009, Boston, MA, USA
ACM 978-1-60558-247-4/09/04.

Abstract
This paper proposes a new haptic interaction system based on optical-haptic substitution. This system combines time-modulated structured light emitted to the workspace and a mobile or finger-mounted module consisting of a photo-detector with a tactile actuator. Unlike other tactile feedback systems, it does not require any complicated mechanism for position sensing and tactile actuation. Instead, it directly converts time-modulated structured light into haptic sensations. By sensing this light with a photo detector, users can feel this time-modulated light as haptic sensations. The system can easily add haptic feedback to a wide variety of applications, including surface computing systems and 3D interactive spaces.

Keywords
Haptic interactions, interactive devices, digital micro-mirror device, time-modulated structured light

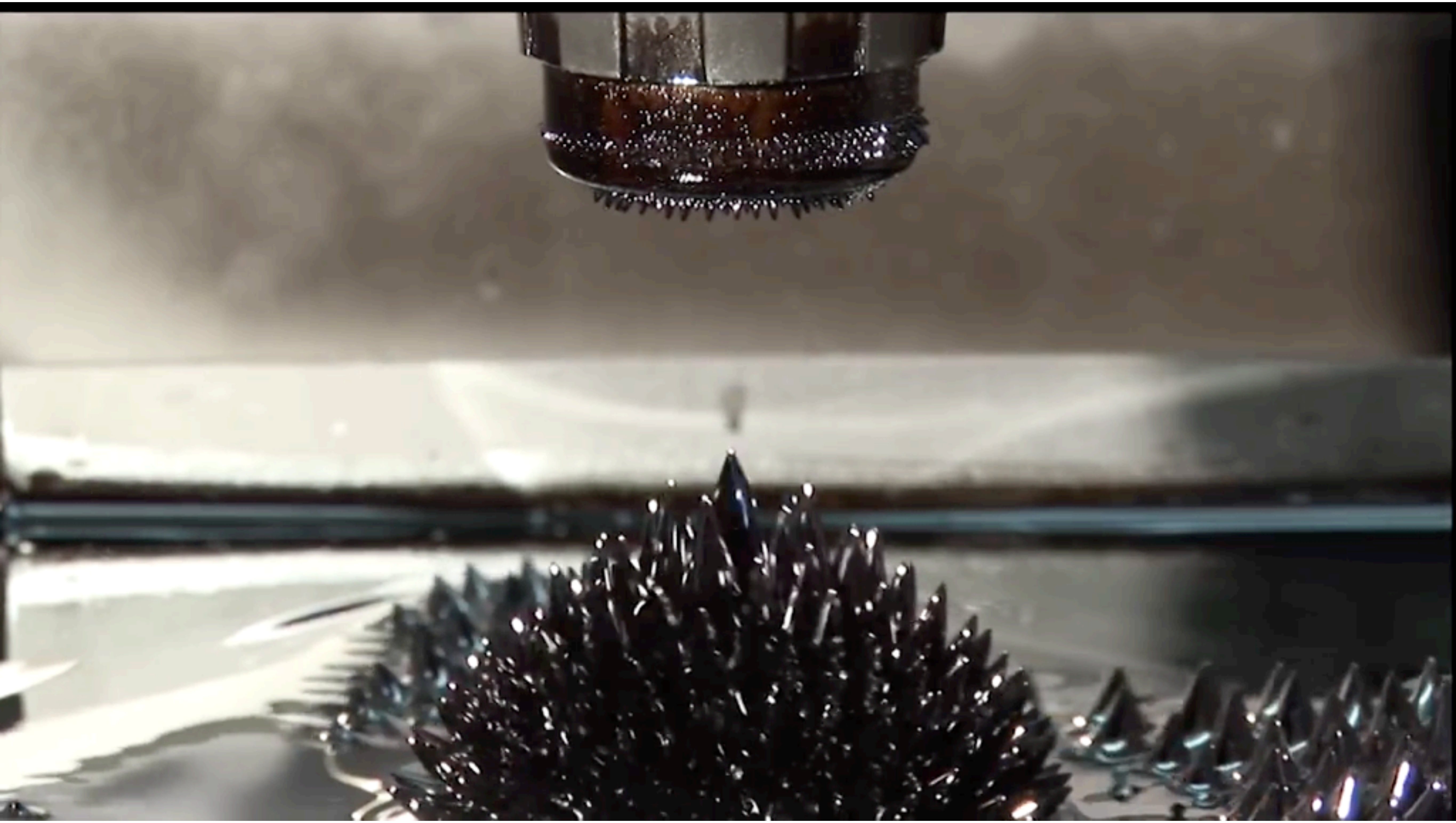
ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces.

Introduction
Haptic sensations play a very important role in physical interactions among persons in that the sense of touch

tactile feedback:

magnetic / electric fluids

using liquids that deform
when **magnetic** field is present

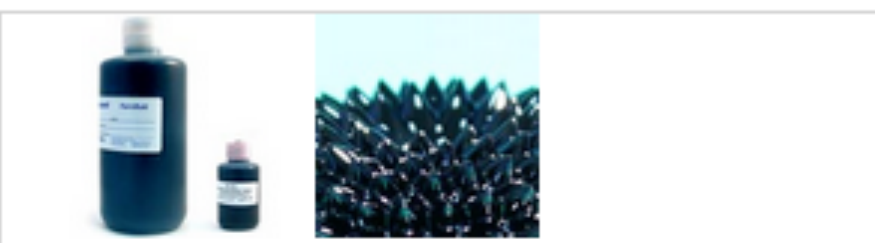


ferrofluids: magnetic fluid

ferrofluids: magnetic fluid

Bulk Ferrofluid (100 ml)

Zoom



GRADES 5-8 GRADES 9-12 COLLEGE SAFETY

Bulk Ferrofluid (100 ml)

$39.95
80 points (Points accrued: 0)
Item #: FF-310

Qty. 1
Learn about Extra Credit Points

ADD TO CART

Items You May Also Need:

Bulk Ferrofluid (1000ml)

$220.00
440 points (Points accrued: 0)
Item #: FF-350

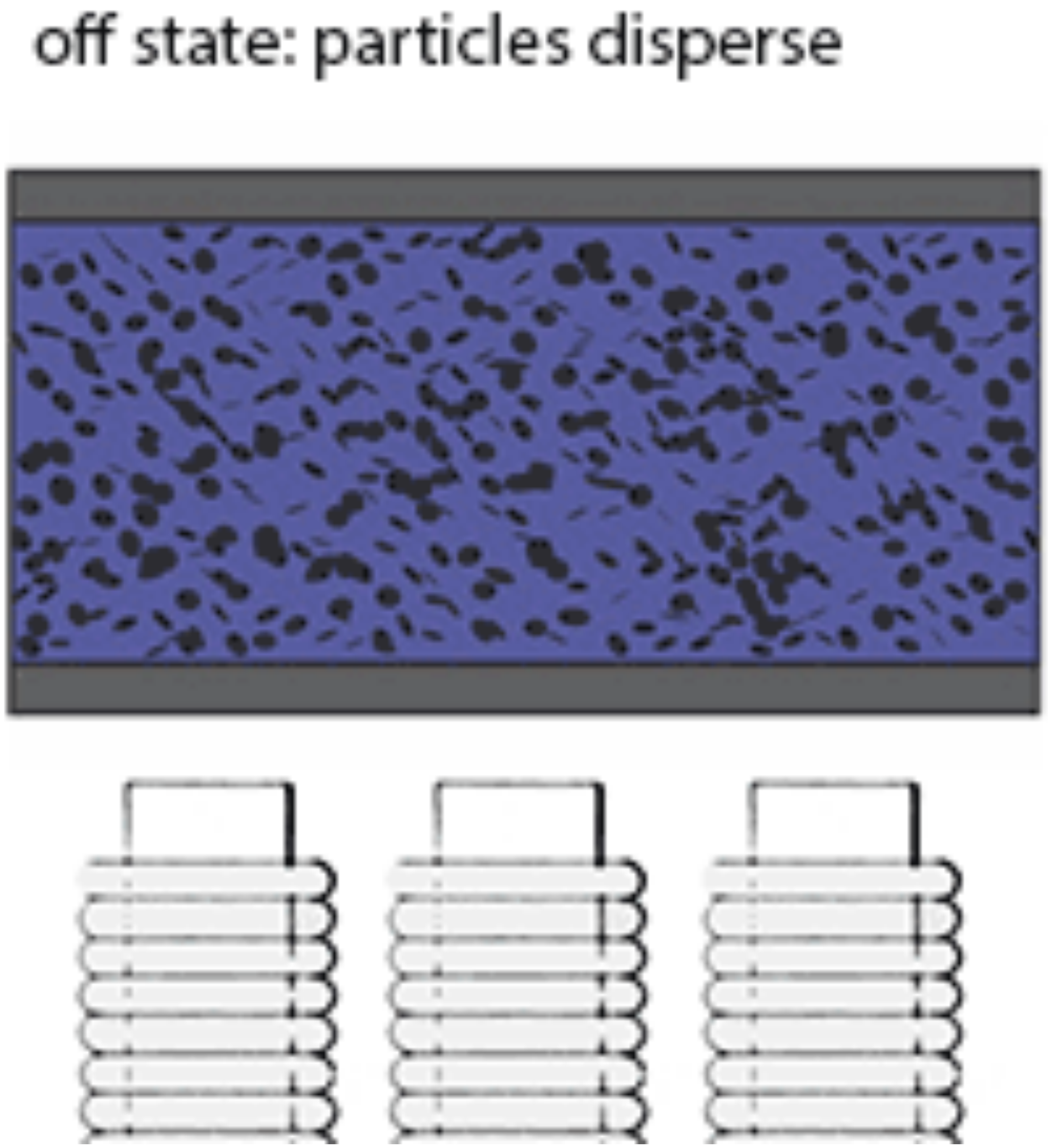
Qty. 1
Learn about Extra Credit Points

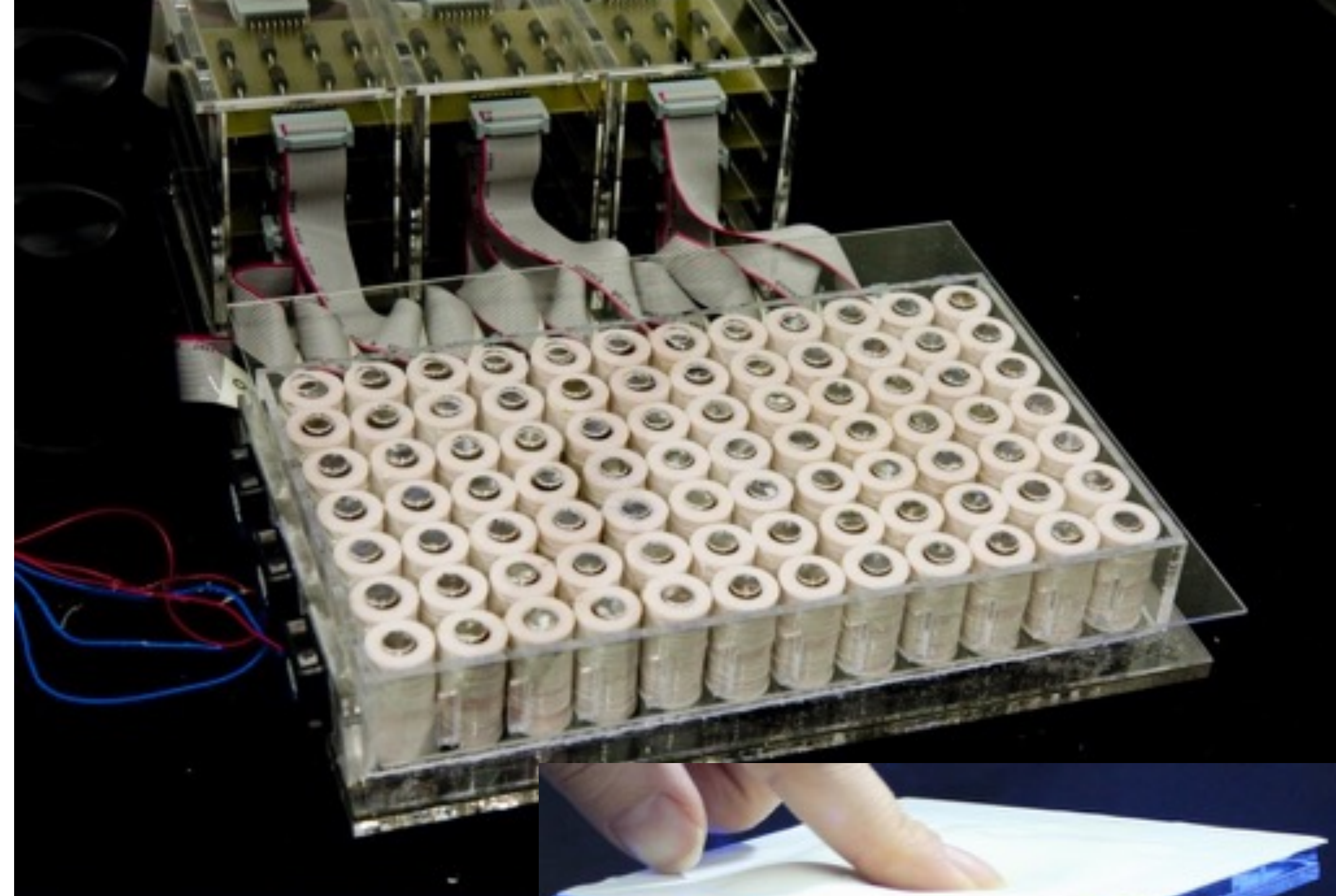
ADD TO CART

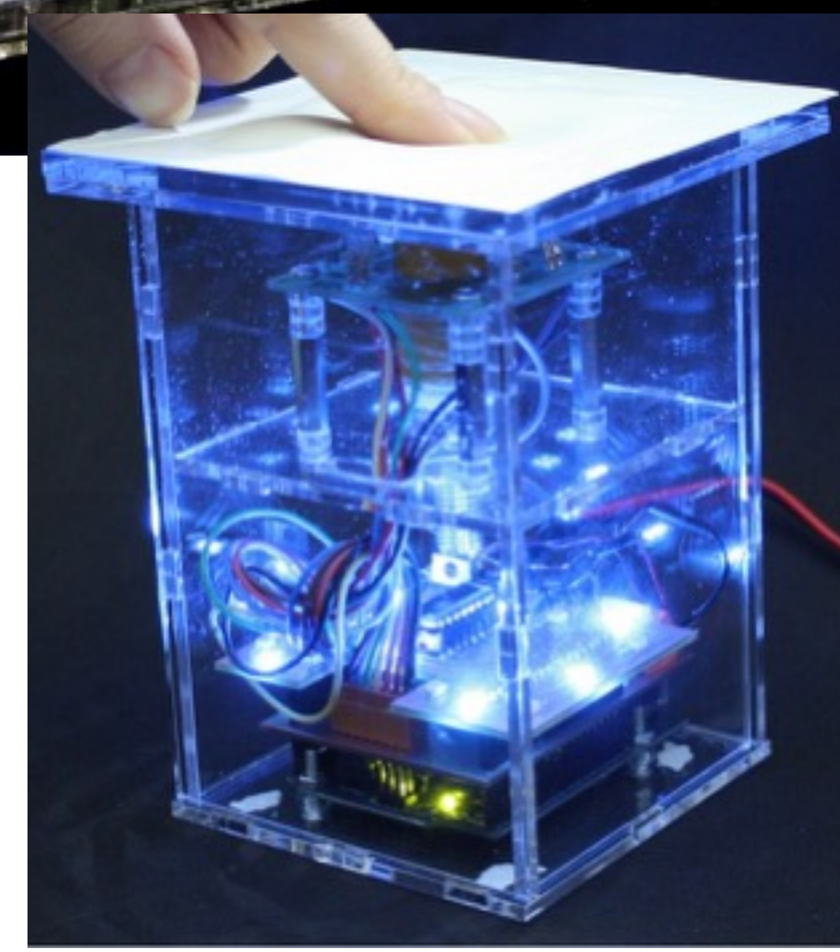
Tweet Save Like 0

ferrofluids: magnetic fluid

ferrofluids: magnetic fluid







2010: Mudpad: haptics with ferrofluids

MudPad: Localized Tactile Feedback on Touch Surfaces

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ABSTRACT
We present MudPad, a system that is capable of localized active haptic feedback on multitouch surfaces. An array of electromagnets locally actuates a tablet-sized overlay containing magnetorheological (MR) fluid. The reaction time of the fluid is fast enough for realtime feedback ranging from static levels of surface softness to a broad set of dynamically changeable textures. As each area can be addressed individually, the entire visual interface can be enriched with a multi-touch haptic layer that conveys semantic information as the appropriate counterpart to multi-touch input.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Haptic I/O.

General terms: Human Factors

Keywords: haptic I/O, tactile feedback, multitouch

INTRODUCTION
Touch screens have become common input devices. While they are intuitive to use, they do not provide tactile feedback for user input. Simple vibration and audio signals can be used to alleviate this problem, but these signals are undirected and do not support complex messages beyond simple acknowledgments. Additionally, fingers touching the surface occlude the visual interface. With MudPad [3], we enrich the entire GUI with a continuous haptic layer. Each display area can be individually controlled to 'display' a distinct tactile feedback pattern, i.e., each graphical UI element or part thereof can be associated with a different tactile sensation. By doing so, we cannot only acknowledge user input but also convey additional semantic information, e.g., about system states and background processes, possibly saving valuable

Figure 1: MudPad is a system that provides localized haptic feedback independently at multiple points.

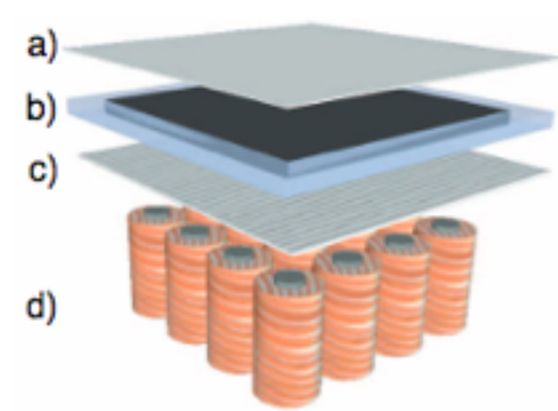


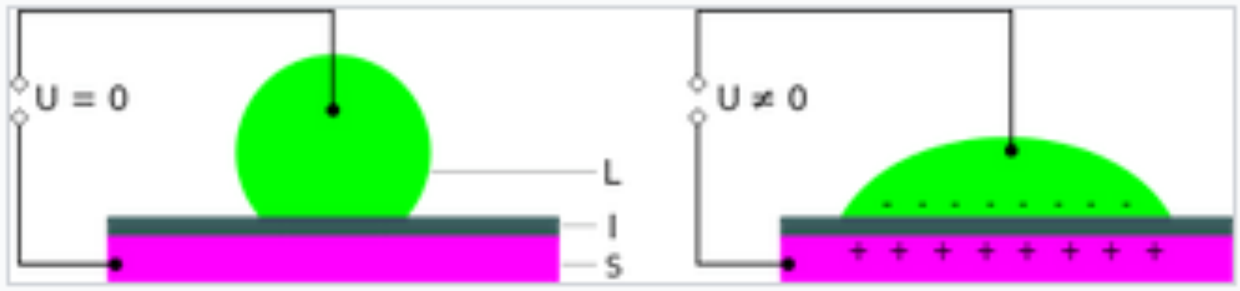
Figure 2: Exploded view of system design: a) latex touch & projection surface, b) MR fluid pouch, c) resistive touch input pad, d) array of electromagnets (projector omitted in this schematic).

Magnetorheological Fluid
MR fluid is a "smart fluid" whose viscosity can be altered

using liquids that deform
when **electric** field is present

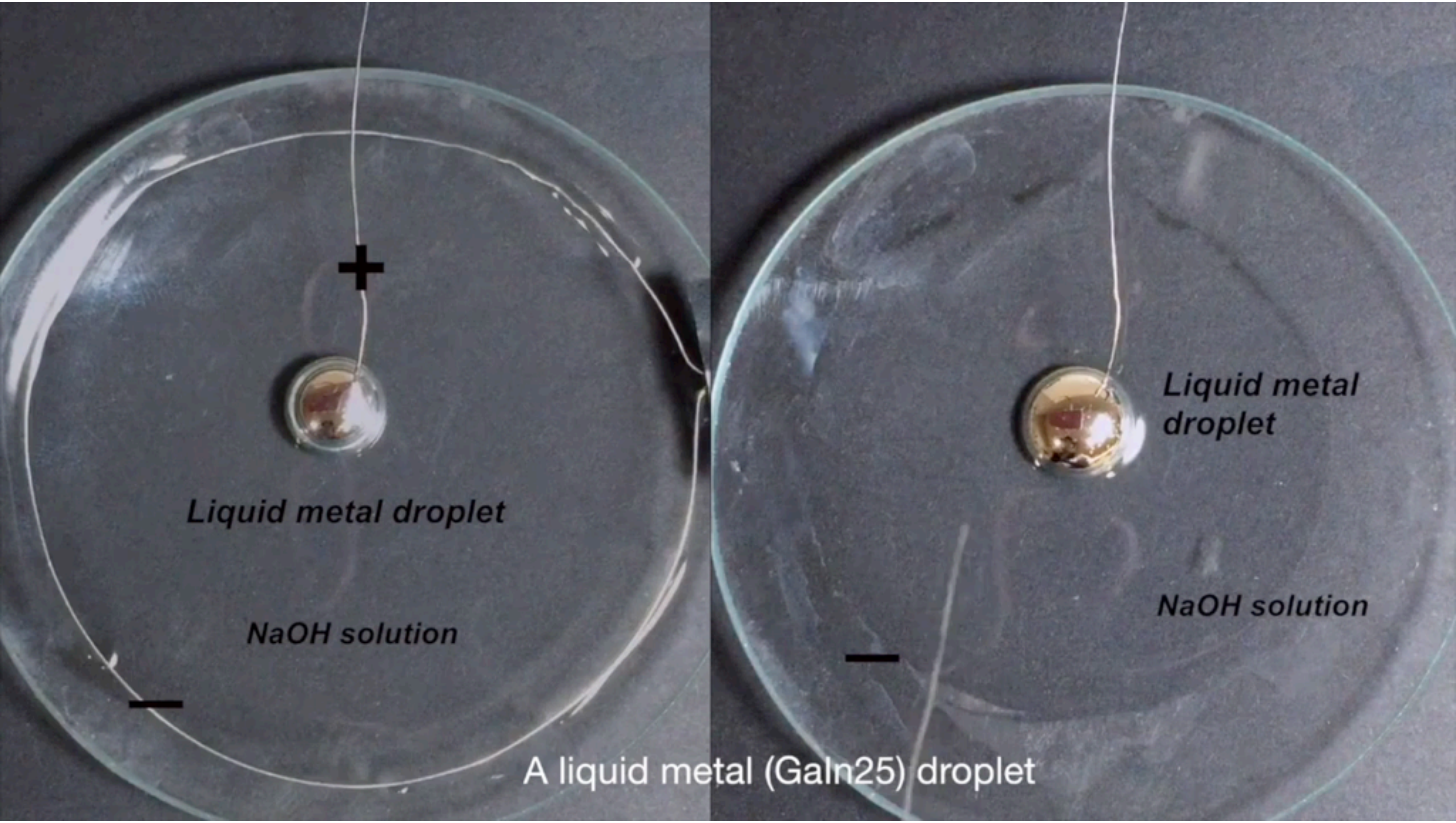
Electro-Wetting:

Electrowetting theory [edit]

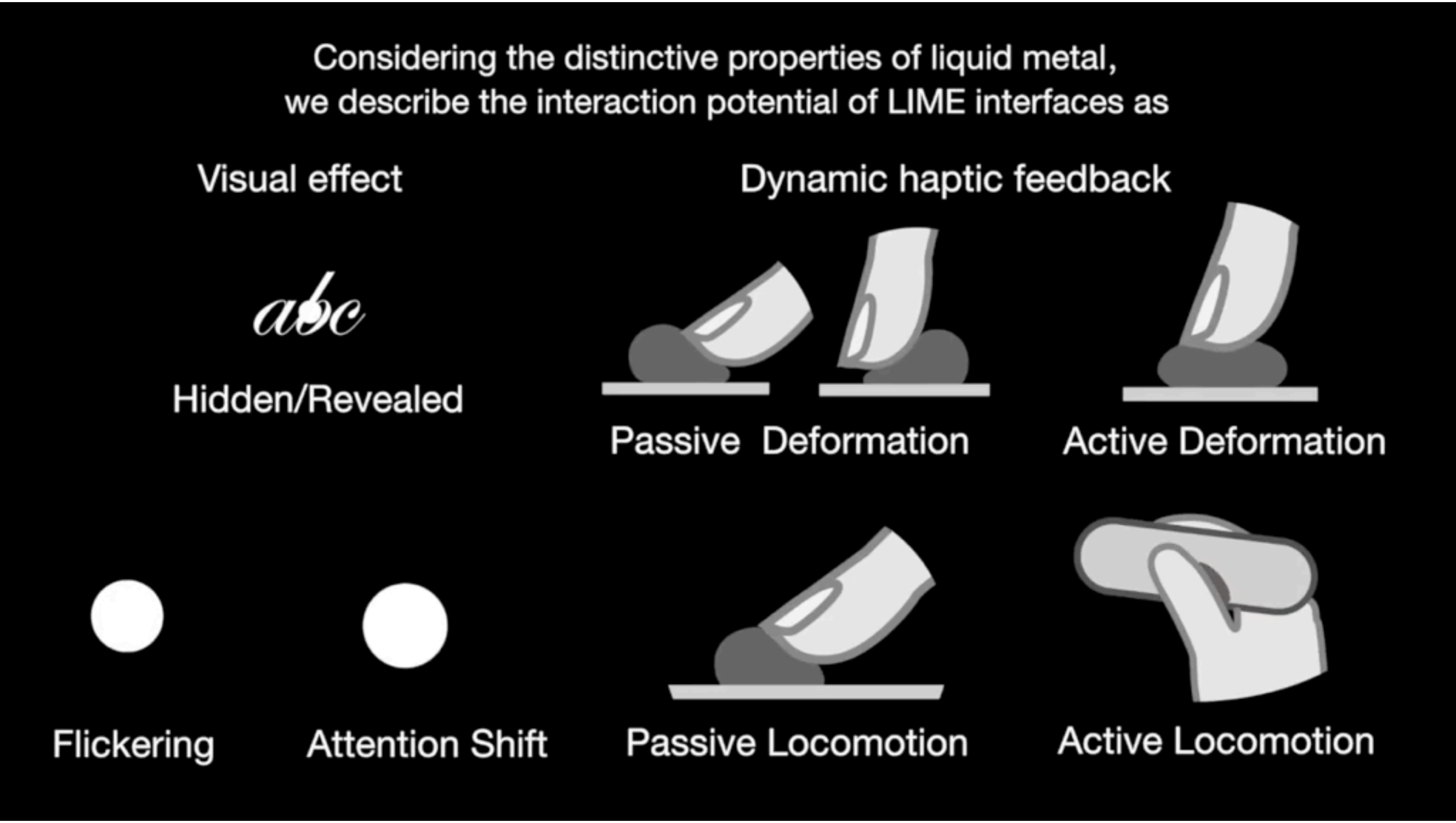


Liquid, Isolator, Substrate

The electrowetting effect has been defined as "the change in solid-electrolyte contact angle due to an applied potential difference between the solid and the electrolyte". The phenomenon of electrowetting can be understood in terms of the forces that result from the applied electric field.[19][20] The fringing field at the corners of the electrolyte droplet tends to pull the droplet down onto the electrode, lowering the macroscopic contact angle and increasing the droplet contact area. Alternatively, electrowetting can be viewed from a thermodynamic perspective. Since the surface tension of an interface is defined as the Helmholtz free energy required to create a certain area of that surface, it contains both chemical and electrical components, and charge becomes a significant term in that equation. The chemical component is just the natural surface tension of the solid/electrolyte interface with no electric field. The electrical component is the energy stored in the capacitor formed between the conductor and the



2016: Liquid Metal Alloy for haptic feedback



2016: Liquid Metal Alloy for haptic feedback

LIME: LIquid MEtal Interfaces for Non-Rigid Interaction

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ABSTRACT
Room-temperature liquid metal GaIn25 (Eutectic Gallium-Indium alloy, 75% gallium and 25% indium) has distinctive properties of reversible deformation and controllable locomotion under an external electric field stimulus. Liquid metal's newly discovered properties imply great possibilities in developing new technique for interface design. In this paper, we present LIME, LIquid MEtal interfaces for non-rigid interaction. We first discuss the interaction potential of LIME interfaces. Then we introduce the development of LIME cells and the design of some LIME widgets.

Author Keywords
Liquid Metal; Shape-Changing; Haptic Feedback; Non-Rigid Interface

ACM Classification Keywords
H.5.2. Information interfaces and presentation: Prototyping

INTRODUCTION
In the field of HCI, researchers have started to investigate smart materials and apply them to design novel interfaces. Smart materials, which are capable of changing their chemical or physical properties while under a certain stimulus [11], have been used to design novel interfaces. Shape memory alloy [1,2,10] and humidity sensitive biological material [13] have been applied to shape-changing interfaces and texture-changing interfaces. Ferromagnetic fluid [6] and thermoresponsive hydrogel [8] have been utilized for stiffness-changing interfaces. Such researches have explored new technique for interface design, enabling new HCI semantics that have been used in manifesting of digital information, offering dynamic affordances, providing haptic feedback, and affording different functionalities [4,5,8,12].

Niiyama et al. have used liquid metal as a medium of mass transfer in interface design. With an extra pump, this work realized a passive transfer of liquid metal [9]. Recently, some unique properties of liquid metal have been revealed. Under external electric field stimuli, liquid metal GaIn25 shows a capability of reversible shape-changing and controllable locomotion [7,14]. This distinctive mechanism inspired us to develop novel interaction techniques.

With our work, we are contributing by introducing the distinctive properties of liquid metal for interface design, discussing interaction potential of LIME interfaces, and presenting the design and development of LIME cells and a number of LIME widgets.

PROPERTIES OF LIQUID METAL
GaIn25 is room temperature liquid metal with a melting point of ~15.5°C and a density of ~6.35g/cm^3 [3]. These physical parameters are adjustable by regulating the proportion of alloys.

A GaIn25 droplet can transform from a sphere to a large thin film and vice versa, under the stimulation of external electric field when in alkaline or acidic electrolyte solution (e.g. NaOH solution). The variation of surface area can reach up to 5 times (Figure 1). Besides, the droplet tends to flow towards the cathode while deforming (Figure 2). The deformation is caused by the change in surface tension. Electrochemical oxide combines on the surface of a liquid metal droplet under an external electric field stimulus, leading to a decline of surface tension from ~500mj/m^2 to near zero. The surface tension reconverts when electric field is removed so that oxide is chemically dissolved by NaOH solution. Furthermore, the oxidation of liquid metal can even be affected by the distribution of the electric field

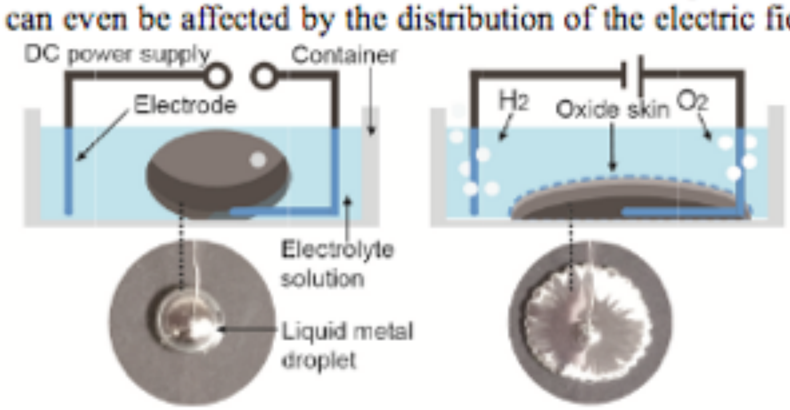
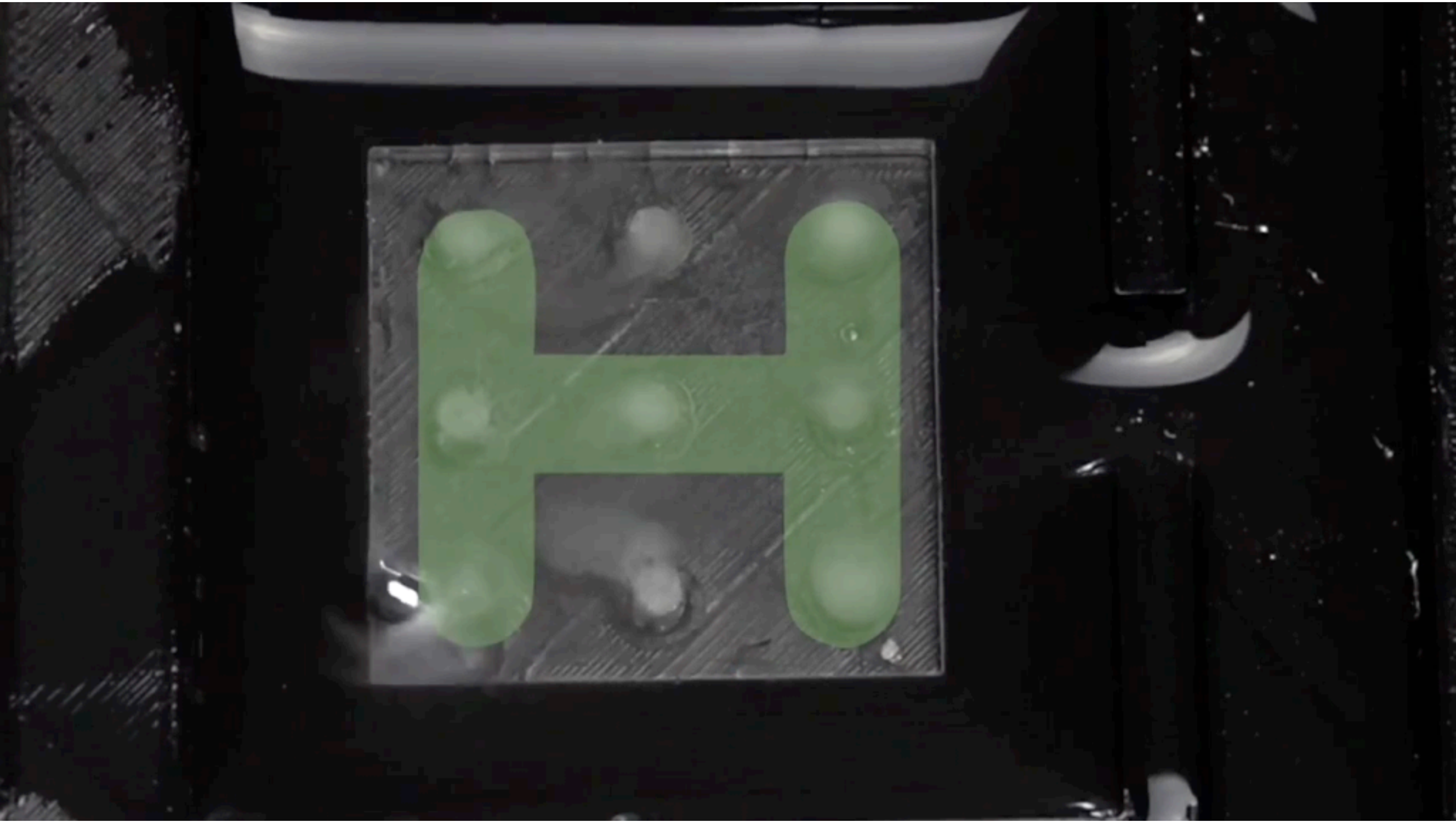
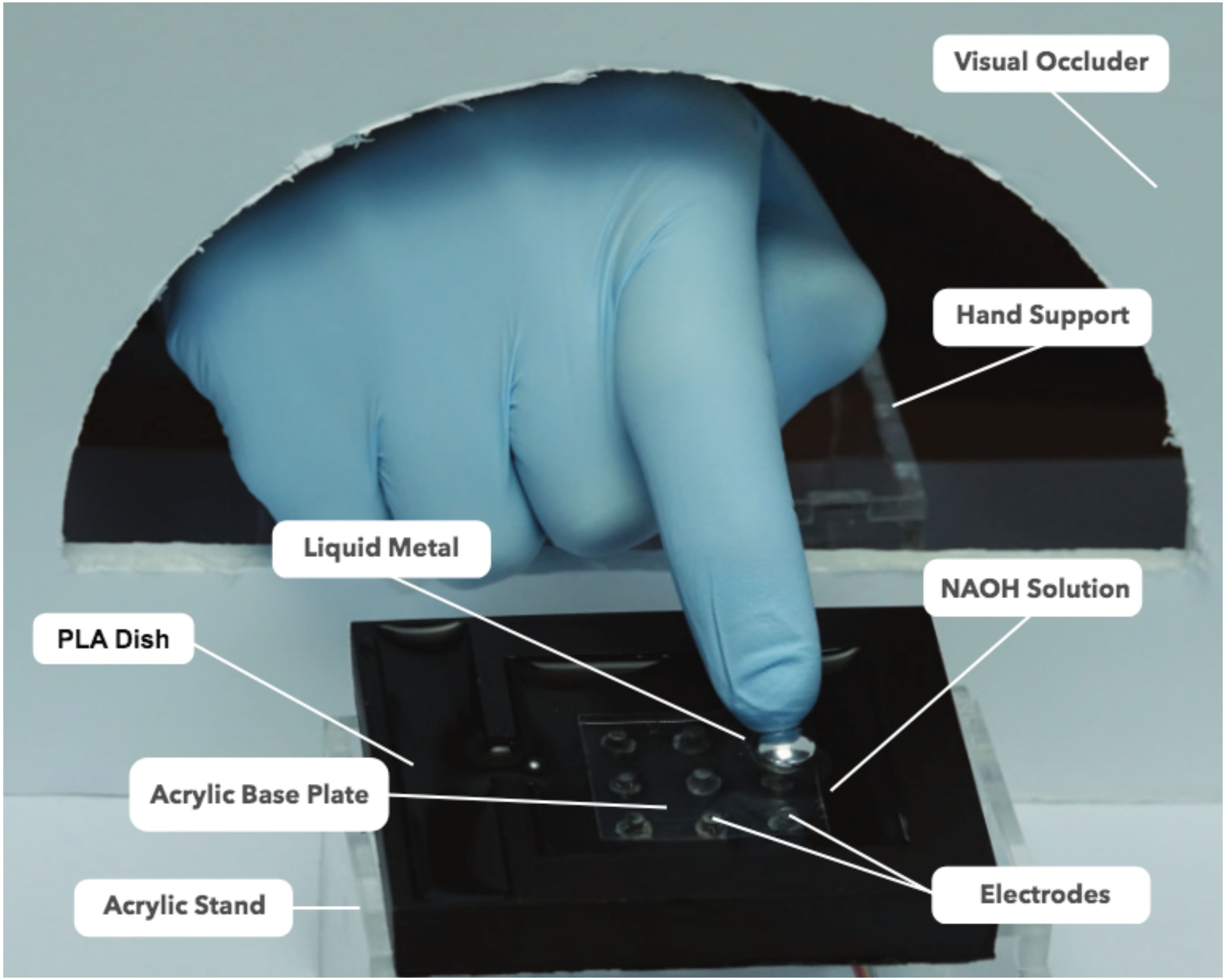


Figure 1. Working mechanism of the liquid metal's



2018: Tangible Drops (Liquid Metal Alloy + Electrodes)


Visual Occluder
Hand Support
Liquid Metal
NAOH Solution
PLA Dish
Acrylic Base Plate
Acrylic Stand
Electrodes

Tangible Drops: A Visio-Tactile Display Using Actuated Liquid-Metal Droplets

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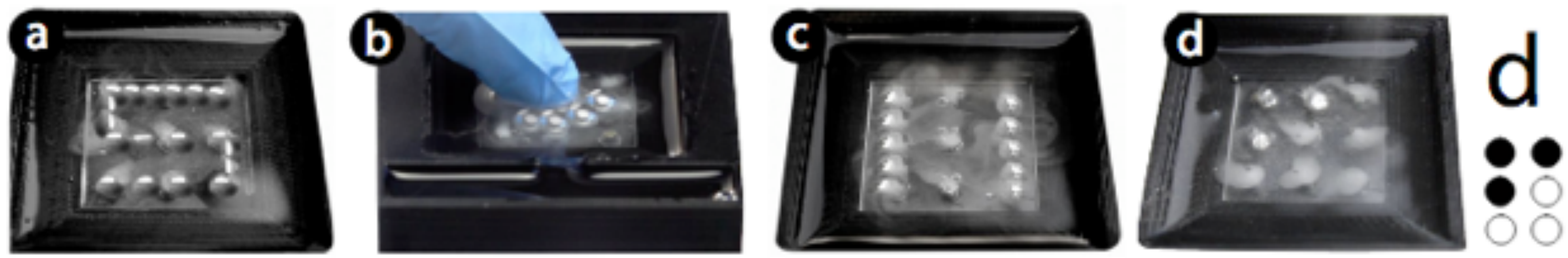

Figure 1. (a) A (timelapsed) visual display showing animated letter "S" using locomotion, and (b) a (timelapsed) tactile display with direction feedback using vibration and locomotion of a liquid metal drop. (c) A timelapsed visio-tactile equalizer widget and (d) a dynamic Braille display.

ABSTRACT
We present Tangible Drops, a visio-tactile display that for the first time provides physical visualization and tactile feedback using a planar liquid interface. It presents digital information interactively by tracing dynamic patterns on horizontal flat surfaces using liquid metal drops on a programmable electrode array. It provides tactile feedback with directional information in the 2D vector plane using linear locomotion and/or vibration of the liquid metal drops. We demonstrate move, oscillate, merge, split and dispense-from-reservoir functions of the liquid metal drops by consuming low power (450 mW per electrode) and low voltage (8–15 V). We report on results of our empirical study with 12 participants on tactile feedback using 8 mm diameter drops, which indicate that Tangible Drops can convey tactile sensations such as changing speed, varying direction and controlled oscillation with no visual feedback. We present the design space and demonstrate the applications of Tangible Drops, and conclude by suggesting potential future applications for the technique.

Author Keywords
Tangible Drops; Liquid Metal; Tactile Feedback; Kinetic Interface; Rheological Interface; Non-Rigid Interface; Programmable Matter

ACM Classification Keywords
H.5.2. User Interfaces: Haptic I/O; Prototyping; User-centered design

INTRODUCTION
Current interactions with mobile devices are largely confined to pressing, swiping and gesturing on flat glass surfaces to manipulate digital content. In comparison to physical interfaces and controls, these high-resolution capacitive touch-screens allow for greater user interface diversity and flexibility, but as a result offer little in the way of tactile feedback, leaving the rich sensory capabilities of our hands and bodies particularly under-utilised. As Bret Victor fittingly describes it, this interaction technique is often little more than "pictures under glass" [54], providing none of the tangibility benefits of physical, tactile interfaces.

Much research of late has aimed to tackle this trade-off between physicality and mutability. The ultimate goal is to develop interfaces that can provide real-time physical feedback, creating truly three-dimensional interfaces, and producing new, more tangible computing experiences. Tangibility and tactile feedback have been shown to offer many benefits over touchscreen user interfaces, such as the reduced need for visual attention [19], and an increased level of task efficiency [53]. Tangible controls—for example on a flight deck or an audio mixing desk—nearly always excel when compared to their touchscreen counterparts [39, 53, 55].

This lack of mutability in tangible interfaces, and the lack of tangibility in digital interfaces, has led to the development of shape-changing interfaces, with an ultimate aim to connect the physical world more directly to the digital content we use and manipulate, as outlined in Ishii's vision of tangible bits [16].

tactile feedback:

mechanical

2016: Rovables

Rovables: Miniature On-Body Robots as Mobile Wearables

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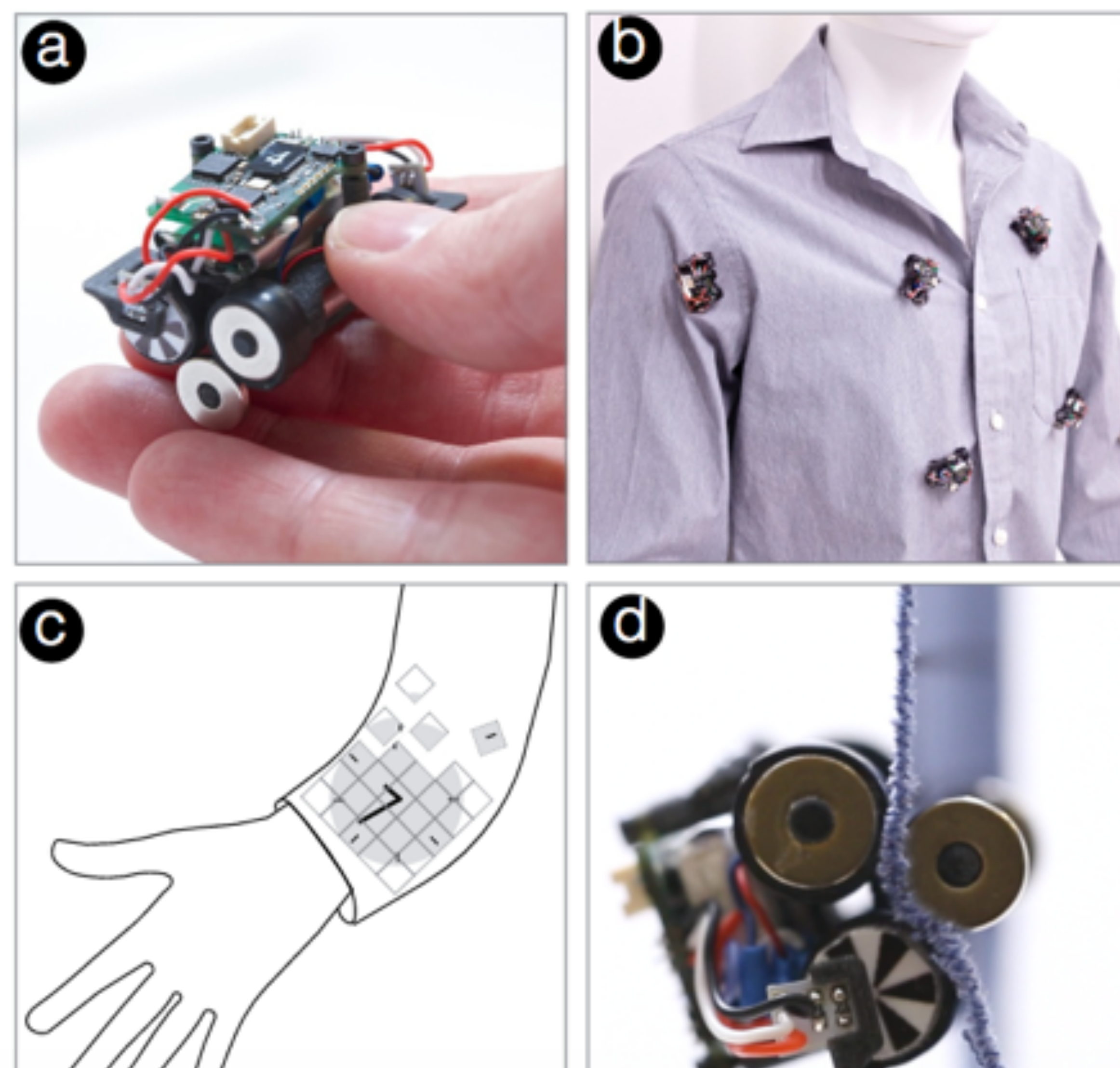
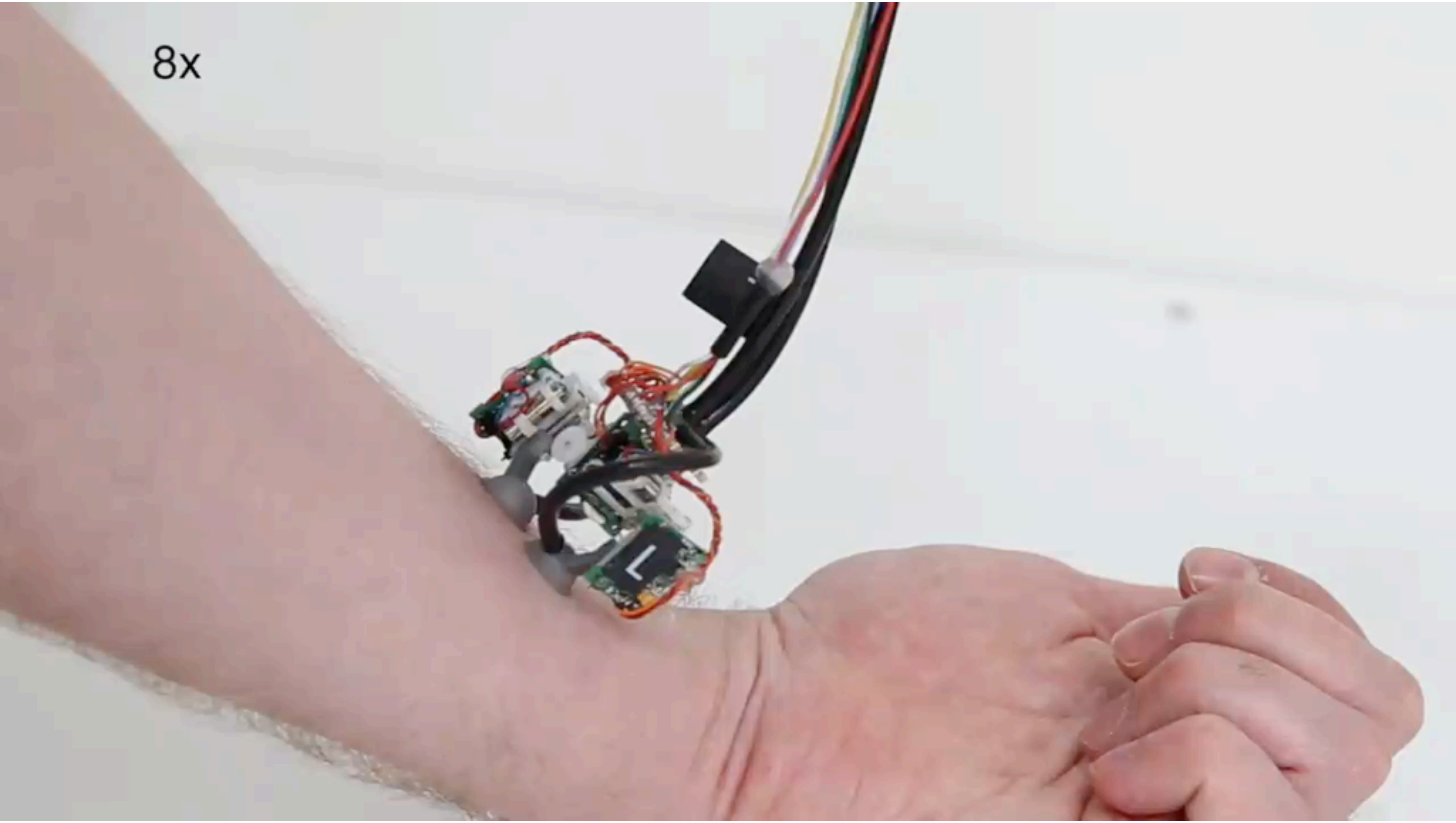
ABSTRACT

We introduce Rovables, a miniature robot that can move freely on unmodified clothing. The robots are held in place by magnetic wheels, and can climb vertically. The robots are untethered and have an onboard battery, microcontroller, and wireless communications. They also contain a low-power localization system that uses wheel encoders and IMU, allowing Rovables to perform limited autonomous navigation on the body. In the technical evaluations, we found that Rovables can operate continuously for 45 minutes and can carry up to 1.5N. We propose an interaction space for mobile on-body devices spanning sensing, actuation, and interfaces, and develop application scenarios in that space. Our applications include on-body sensing, modular displays, tactile feedback and interactive clothing and jewelry.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous.





2017: SkinBot

SkinBot: A Wearable Skin Climbing Robot

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ABSTRACT
We introduce SkinBot; a lightweight robot that moves over the skin surface with a two-legged suction-based locomotion mechanism and that captures a wide range of body parameters with an exchangeable multipurpose sensing module. We believe that robots that live on our skin such as SkinBot will enable a more systematic study of the human body and will offer great opportunities to advance many areas such as telemedicine, human-computer interfaces, body care, and fashion.

Author Keywords
Skin, robotics, wearable devices, telemedicine

ACM Classification Keywords
H.5.m. Information Int. and Presentation: Miscellaneous

INTRODUCTION
Semi-autonomous robots have become a critical tool for the systematic exploration of challenging scenarios such as the rubble of natural disasters, the bottom of the oceans, or distant planets such as Mars. With a similar philosophy in mind but a significant difference in scale, this work proposes using wearable robots to systematically explore the human body.

While there is a large array of instruments and wearables to capture different aspects of the body (e.g., physiology, behavior), many of the devices still require the direct manipulation of an expert practitioner, are usually designed to remain at a specific body location (e.g., chest, wrist), and/or do not have direct access to the skin. To help address these limitations, this work leverages the benefits of such instruments with robotics. In particular, we propose and develop SkinBot; a small wearable semi-autonomous robot that lives on the skin surface and provides objective and systematic digitization of the body. To successfully achieve these goals, SkinBot and similar robots need to satisfy several design considerations such as (1) being lightweight and small, (2) have the ability to move and adhere to the skin, (3) have multimodal sensing and actuation capabilities, and (4) have the ability to communicate with a central control unit or other robots to achieve complex tasks. To the best of our knowledge, this is the first work to show a functional wearable robot that meets the previous design considerations.

PREVIOUS WORK
Developing a small robot that can adhere and move over the skin surface is challenging due to many factors such as the elasticity of the skin and many of its irregularities (e.g., wrinkles, hair). Moreover, the robot needs to be able to adhere irrespective of its orientation and multiple directions of gravitational forces. Existing approaches have devised successful mechanisms for climbing vertical surfaces, such as magnetic wheels and gecko-like adhesives and suction [2, 4, 6, 8, 10], and other studies have explored cloth-climbing robots using fabric pinching [3, 9] and magnetic rollers or needles for adhesion [1, 5]. However, such approaches cannot be easily used on the human skin due to their large size and/or incompatible adhesion methods. In contrast, this work proposes a robot that circumvents many of the previous challenges.

SKINBOT DESIGN
With an iterative design process, we designed and developed SkinBot which consists of two main parts: a 2-legged suction-based locomotion system, and an exchangeable multipurpose sensing module.

Locomotion. To move over the skin surface, we use a suction-based approach which outperformed other considered methods (e.g., sticky pre-gelled wheels, pinching on the clothes) by covering a larger proportion of the body and bet-

all of the previous methods,
required the **user to be in touch with the device**

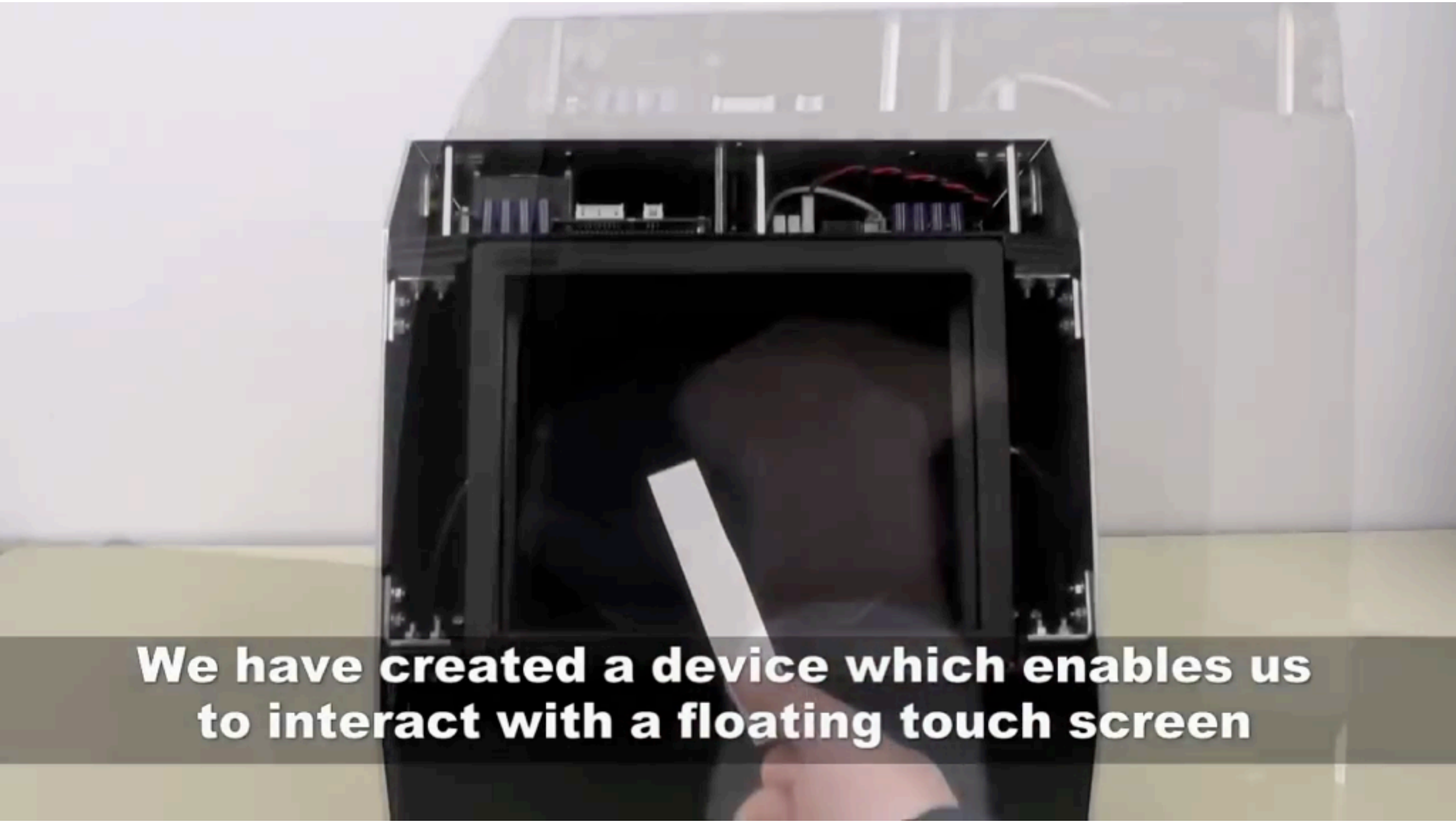
let’s look at some **contact-less methods**

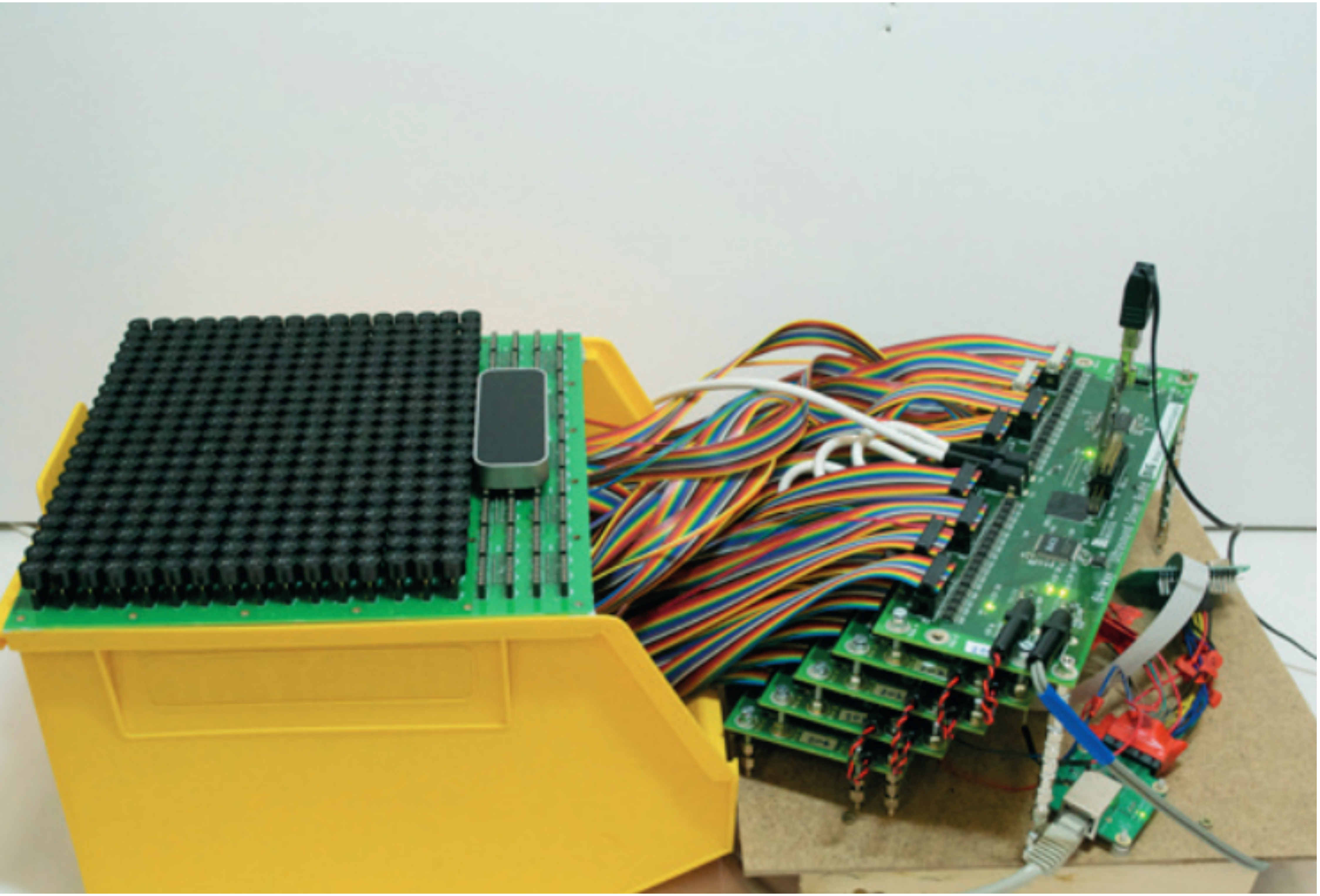
ultra-sound

(contact-less)

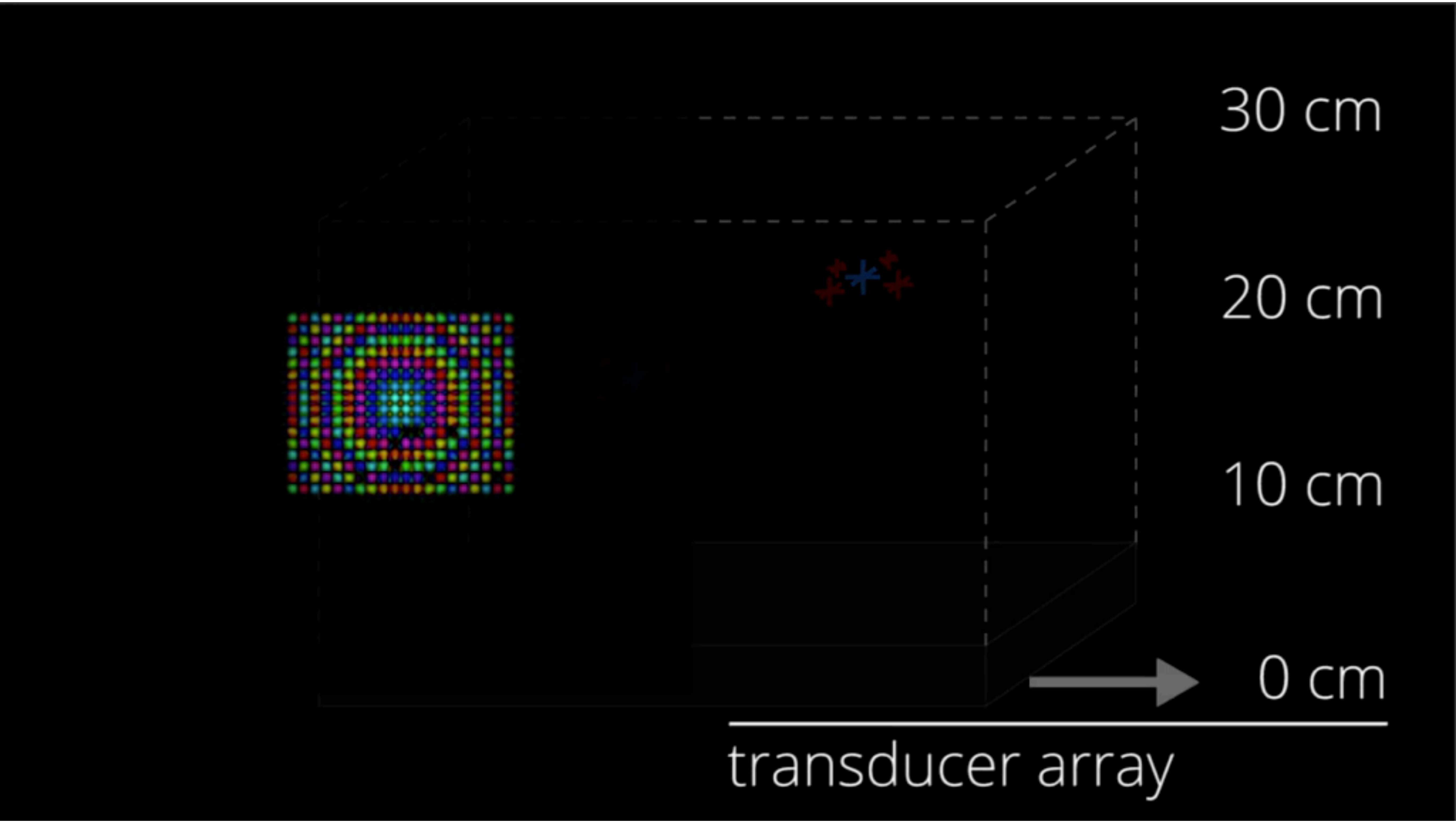
2013: Ultrahaptics ultra-sound

2013: Ultrahaptics ultra-sound


We have created a device which enables us
to interact with a floating touch screen



transducer array: creates an **acoustic field**



- acoustic waves focus at a certain distance

UltraHaptics: Multi-Point Mid-Air Haptic Feedback for Touch Surfaces

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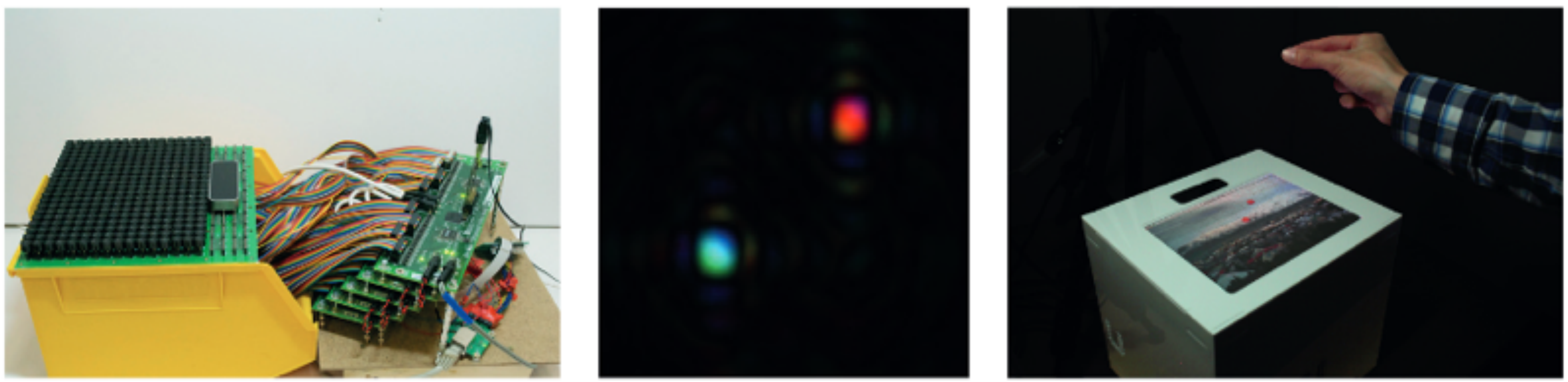
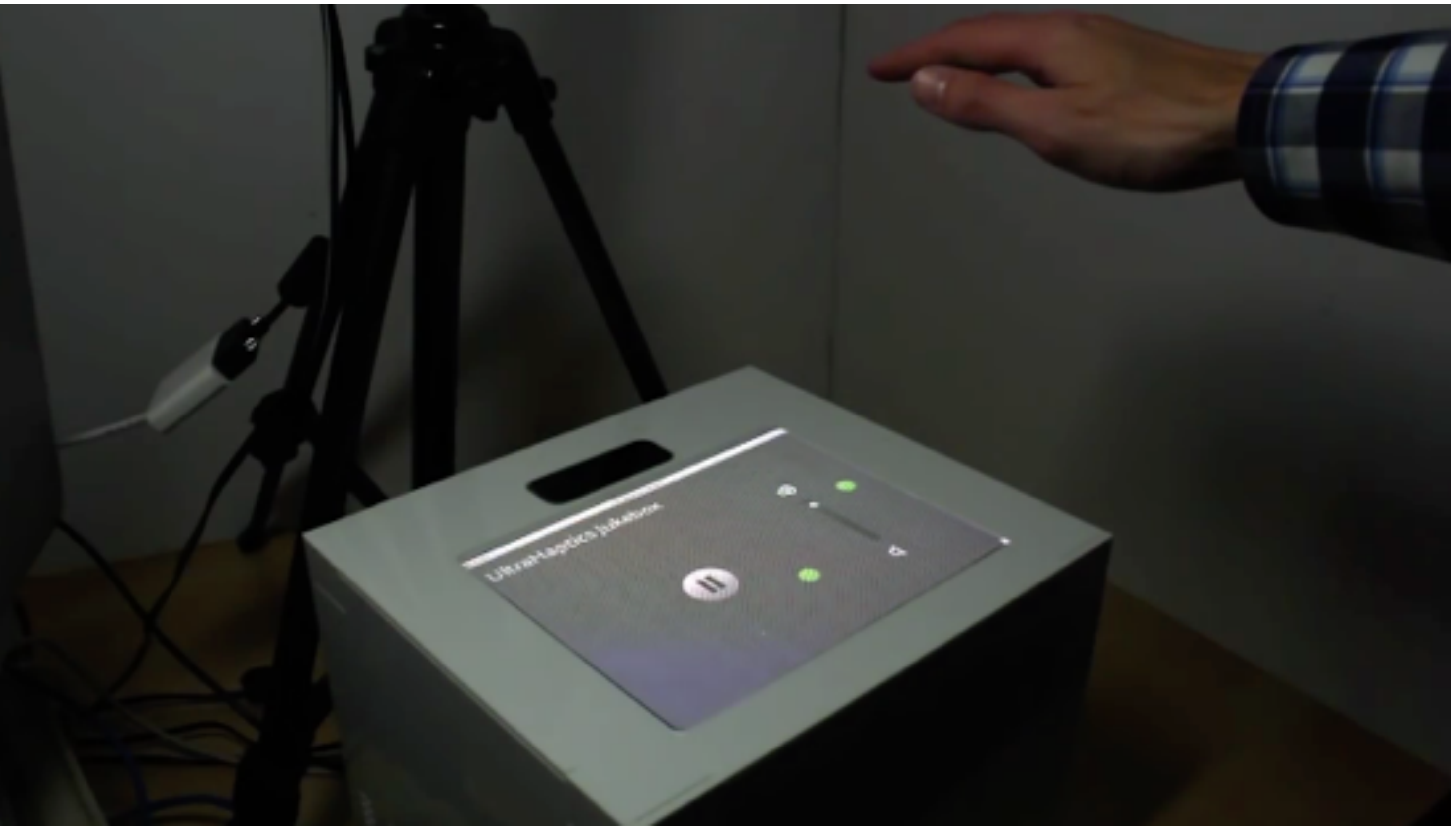
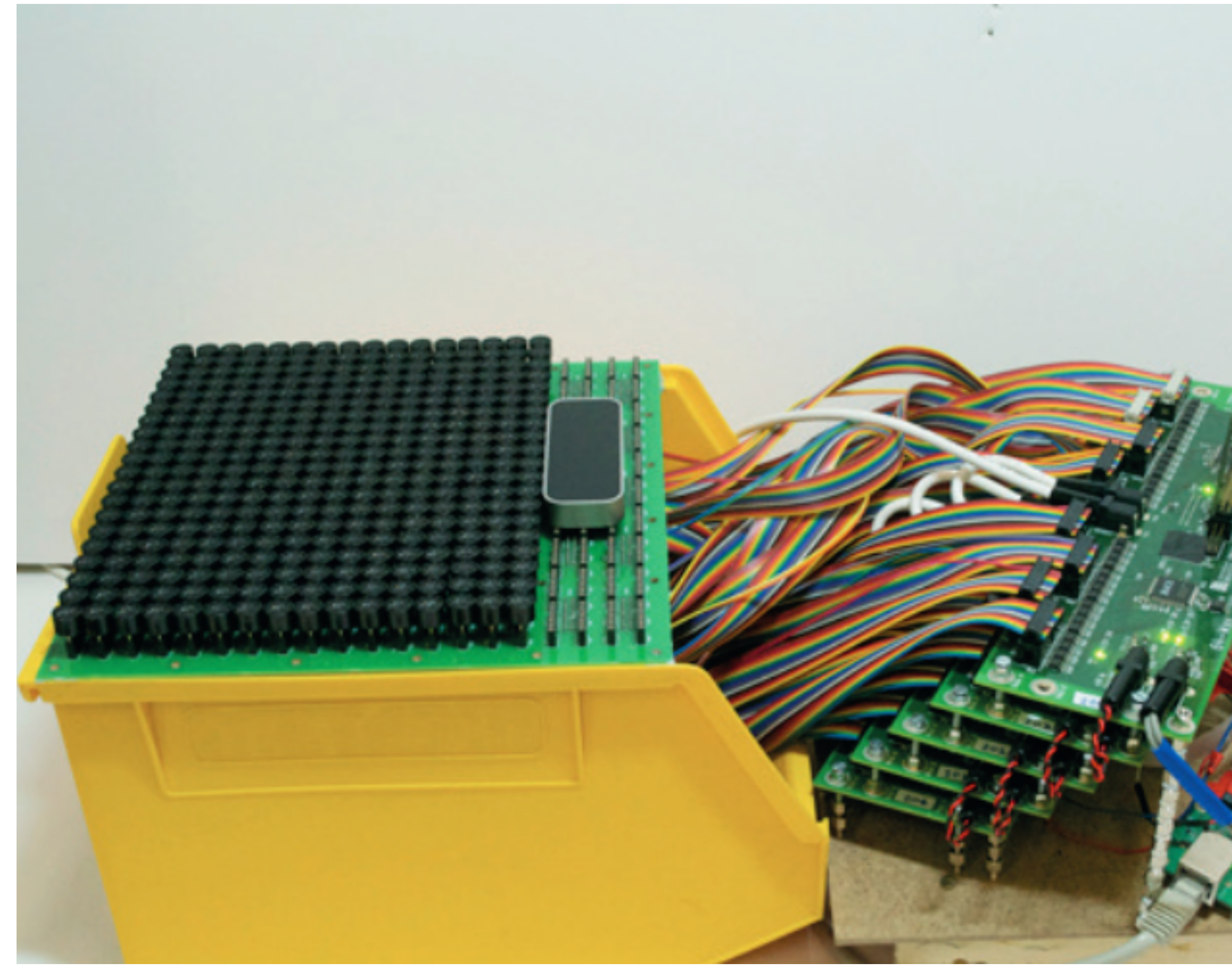


Figure 1: The UltraHaptics system. Left: the hardware. Centre: a simulation of two focal points, with colour representing phase and brightness representing amplitude. Right: receiving two independent points of feedback while performing a pinch gesture.

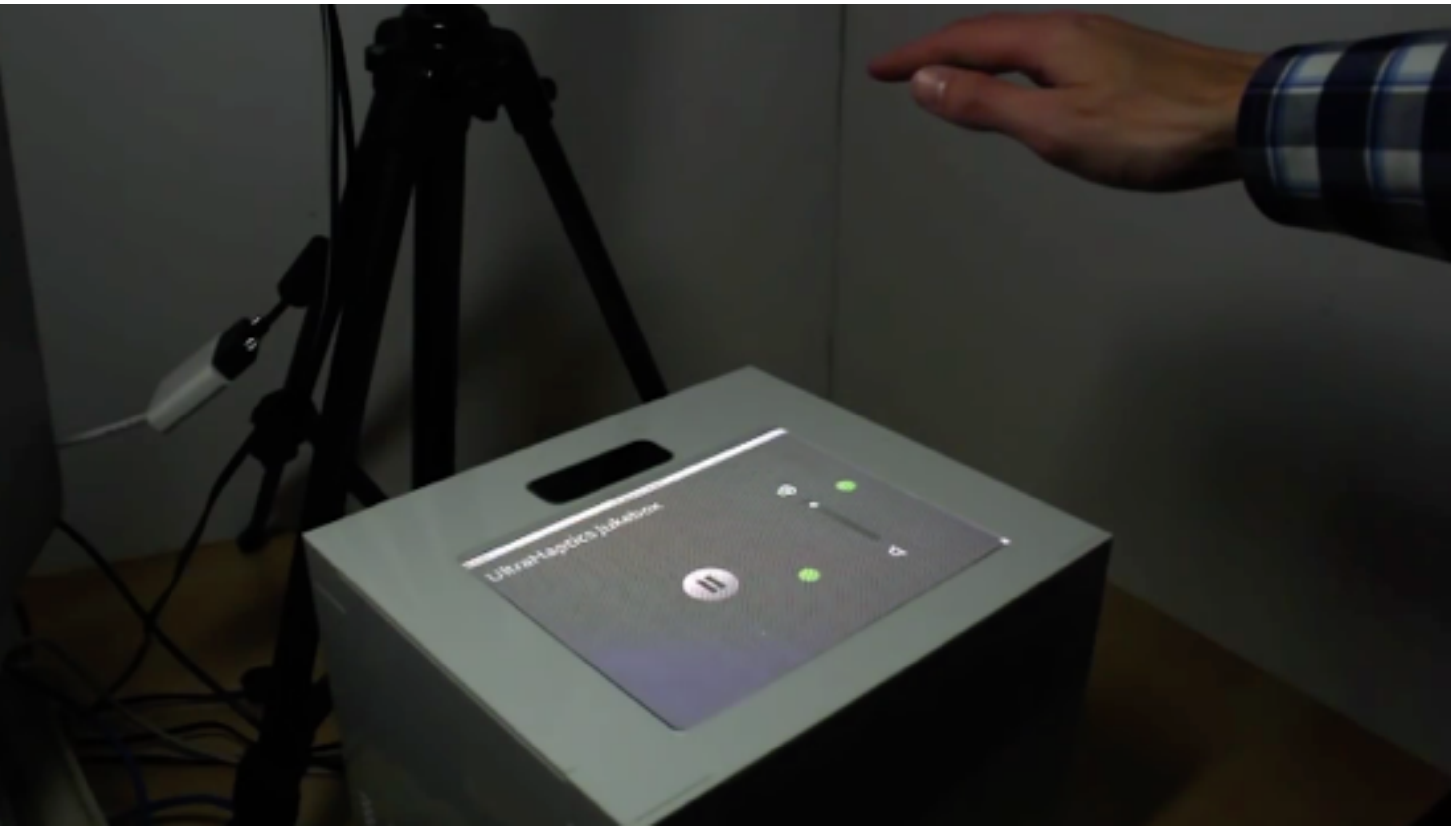
ABSTRACT
We introduce *UltraHaptics*, a system designed to provide multi-point haptic feedback above an interactive surface. *UltraHaptics* employs focused ultrasound to project discrete points of haptic feedback through the display and directly on to users' unadorned hands. We investigate the desirable properties of an acoustically transparent display and demonstrate that the system is capable of creating multiple localised points of feedback in mid-air. Through psychophysical experiments we show that feedback points with different tactile properties can be identified at smaller separations. We also show

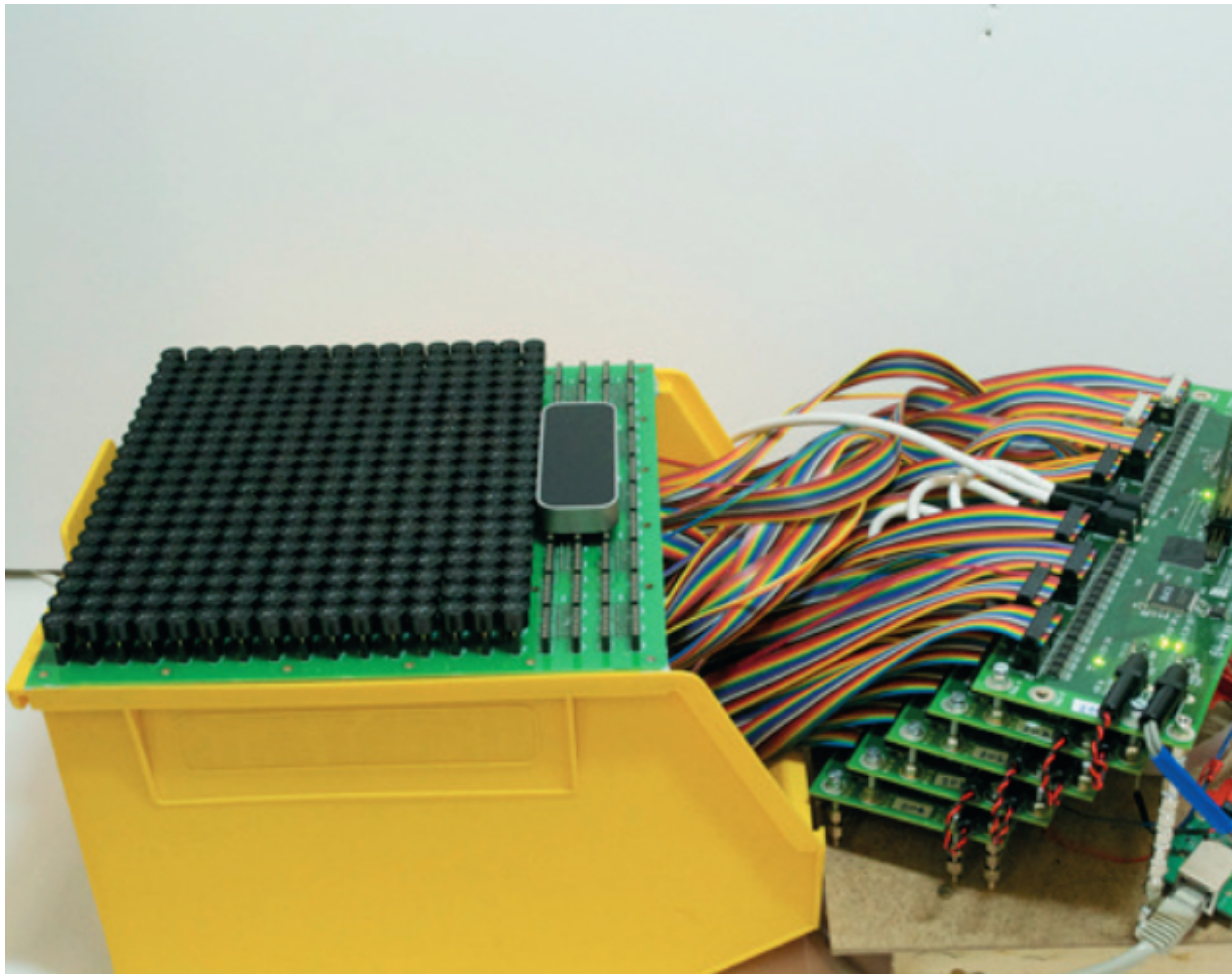
INTRODUCTION
Multi-touch surfaces have become common in public settings, with large displays appearing in hotel lobbies, shopping malls and other high foot traffic areas. These systems are able to dynamically change their interface allowing multiple users to interact at the same time and with very little instruction. This ability to 'walk-up and use' removes barriers to interaction and encourages spontaneous use. However, in return for this flexibility we have sacrificed the tactile feedback afforded by physical controls.





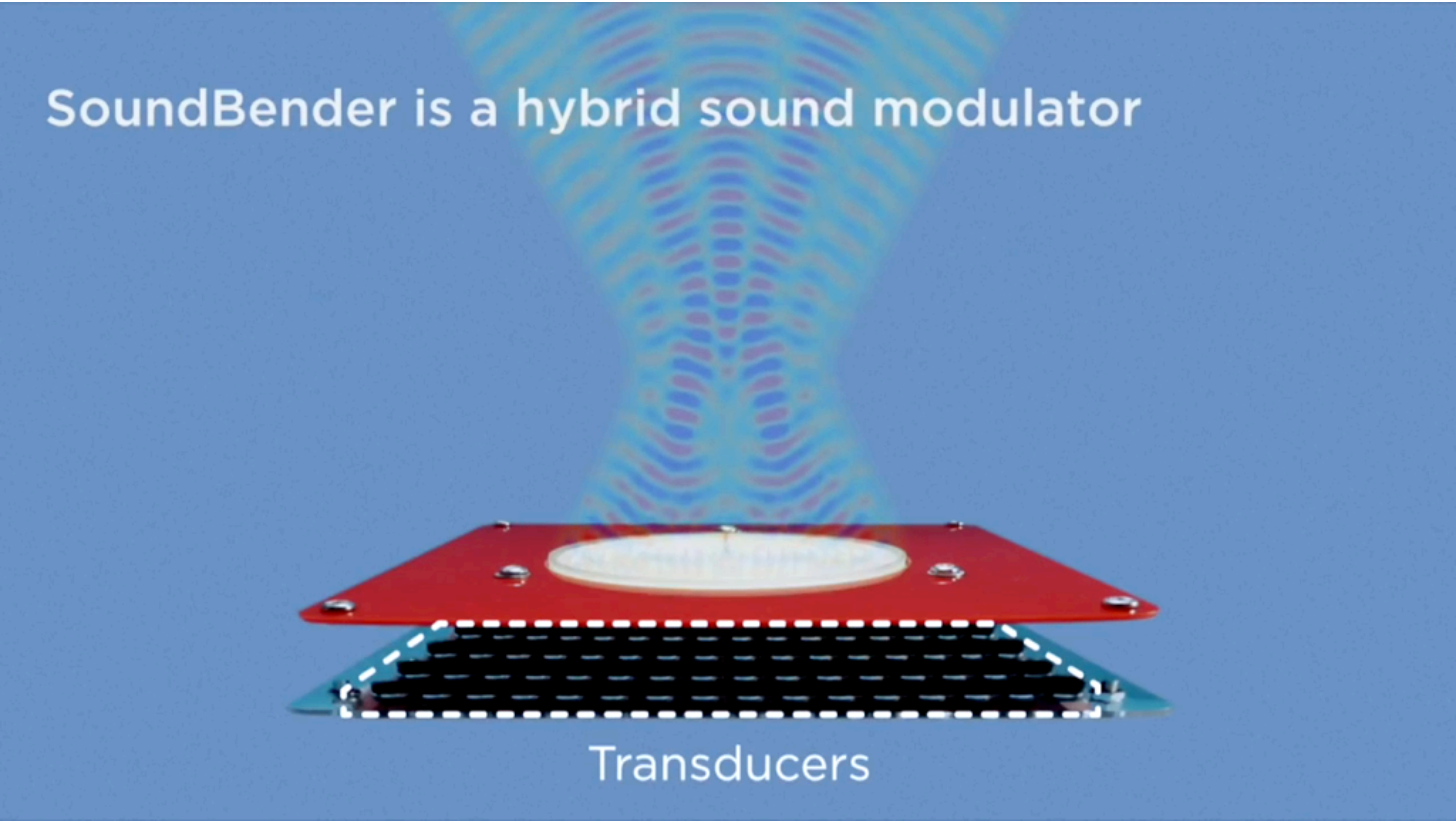
if you want to **add a display surface** on top of the transducer what property does it need to have?





if you want to **add a display surface** on top of the transducer what property does it need to have?

- needs to be **acoustically transparent**
- e.g. perforated sheets, loosely woven fabric

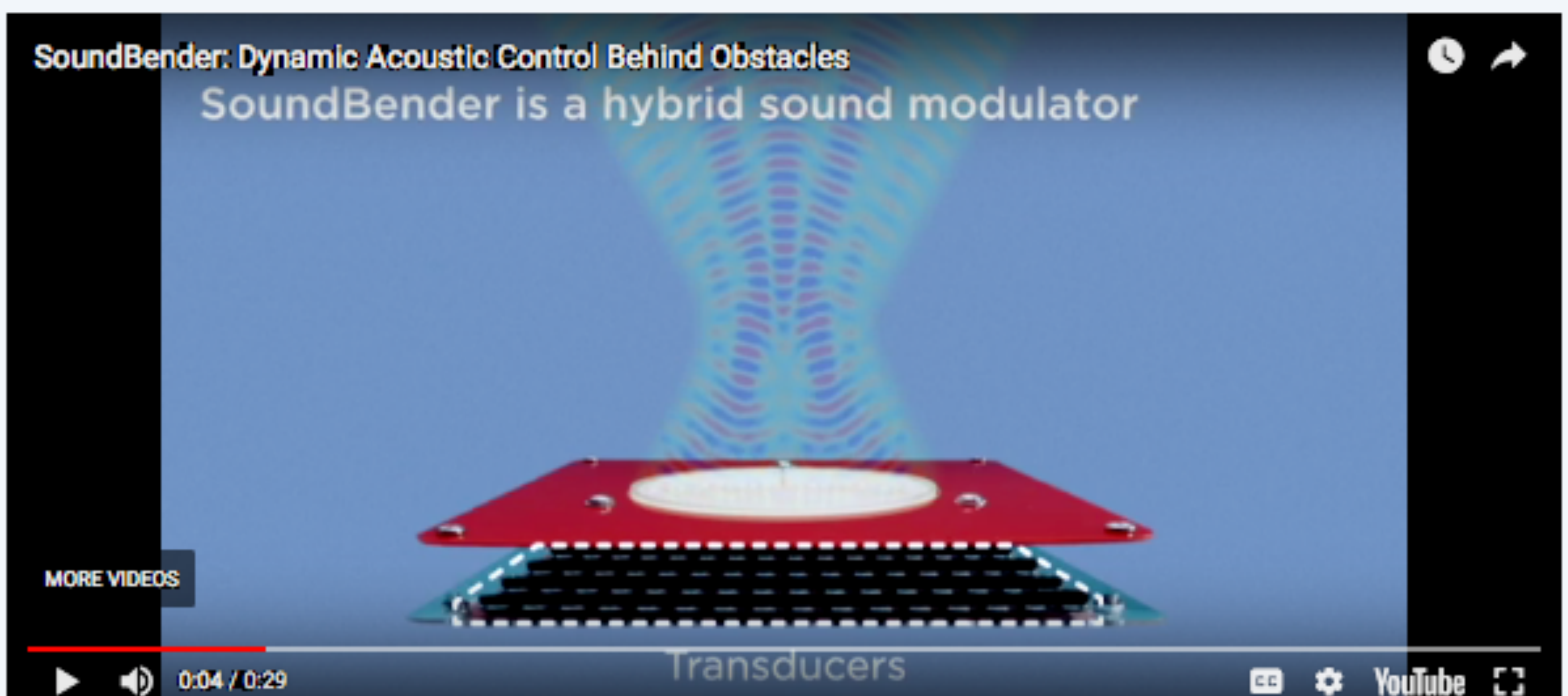


2018 bend sound waves to for haptic feedback above objects

SoundBender: Dynamic Acoustic Control Behind Obstacles [paper]

Mohd Adili Norasikin, University of Sussex
Diego Martinez Plasencia, University of Sussex
Spyros Polychronopoulos, University of Sussex
Gianluca Memoli, University of Sussex
Yutaka Tokuda, University of Sussex
Sriram Subramanian, University of Sussex

Ultrasound manipulation is growing in popularity in the HCI community with applications in haptics, on-body interaction, and levitation-based displays. Most of these applications share two key limitations: a) the complexity of the sound fields that can be produced is limited by the physical size of the transducers, and b) no obstacles can be present between the transducers and the control point. We present SoundBender, a hybrid system that overcomes these limitations by combining the versatility of phased arrays of Transducers (PATs) with the precision of acoustic metamaterials. In this paper, we explain our approach to design and implement such hybrid modulators (i.e. to create complex sound fields) and methods to manipulate the field dynamically (i.e. stretch, steer). We demonstrate our concept using self-bending beams enabling both levitation and tactile feedback around an obstacle and present example applications enabled by SoundBender.



Acoustic manipulation, Metamaterials, Self-bending beams

ultrahaptics

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The Team

At Ultrahaptics we create tactile sensations in mid-air. No controllers or wearables are needed: our patented "virtual touch" technology uses ultrasound to project shapes and textures directly onto the user's hands. Controls can be operated without touching a surface, gestures can be enhanced with tactile feedback, and users can interact in a natural way with virtual objects.

Ultrahaptics was founded in 2013 based on technology developed at the University of Bristol, UK. In 2014 we secured seed funding, in 2015 we raised an A round of funding of £10.1m ($15m) and received a European Commission Grant of €1.49m ($1.8m), and in 2017 we closed a B Round of £18.9m ($23m).

Ultrahaptics is currently engaged with blue-chip clients from multiple markets including automotive, digital signage and location-based entertainment. We also support the international academic community th[illegible] haptics research and development.

now a company!

ultrahaptics

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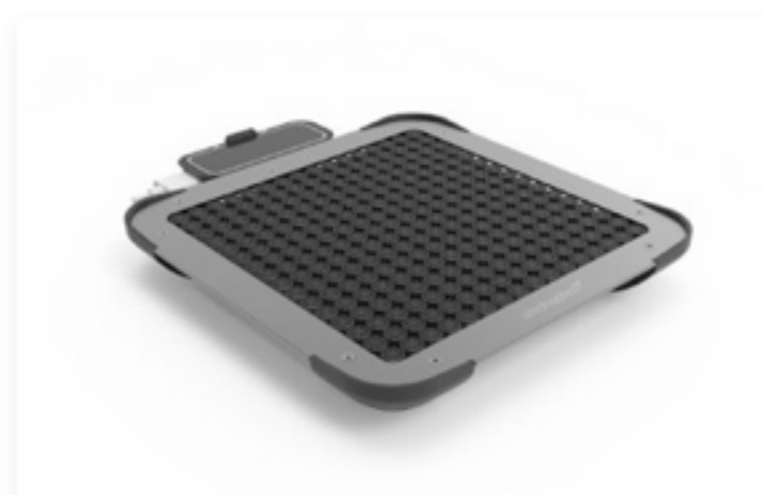
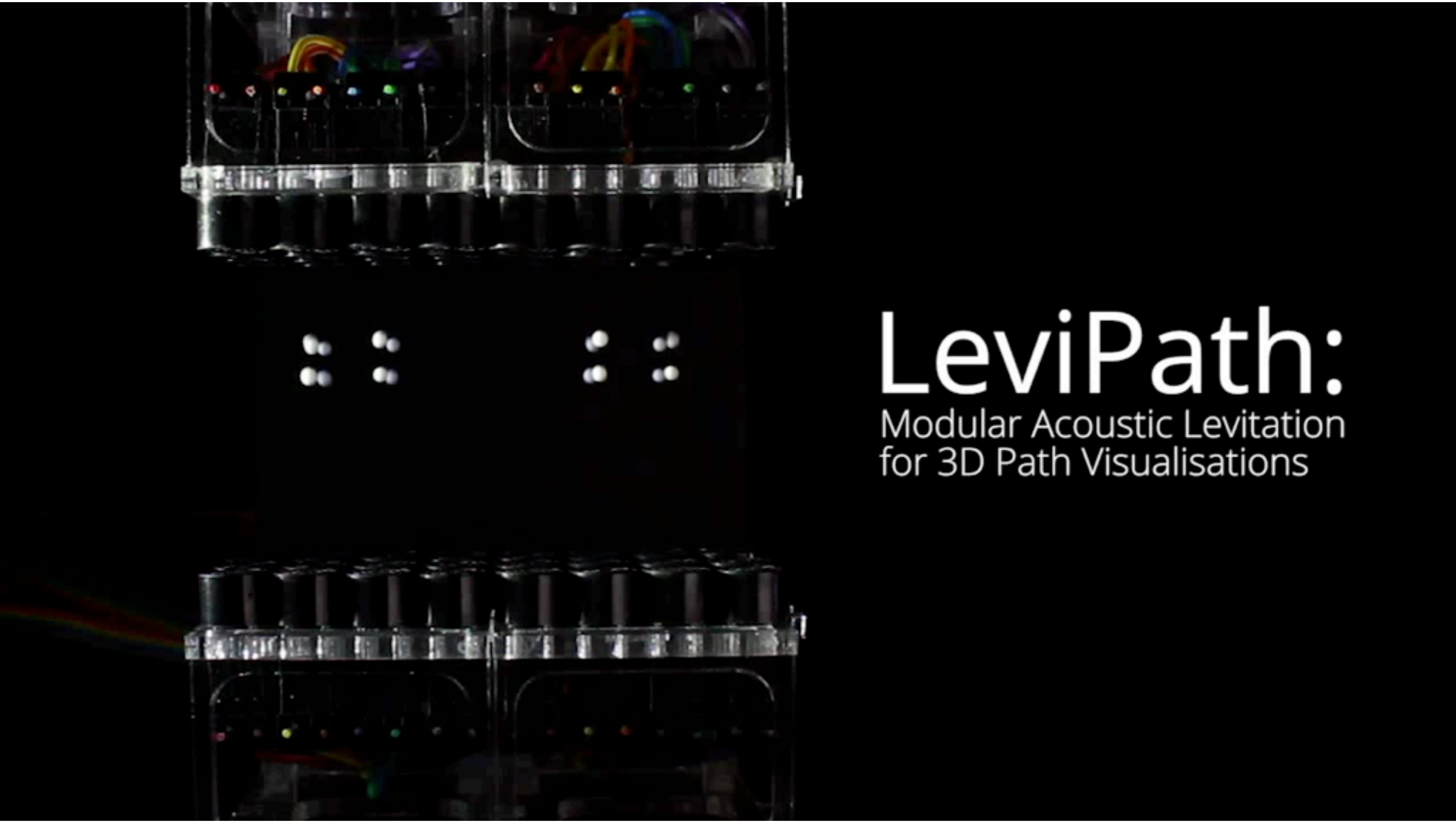


now a company!



2015 LeviPath: acoustic levitation
(not yet for haptics because top & bottom cannot be disturbed)

LeviPath: Modular Acoustic Levitation for 3D Path Visualisations

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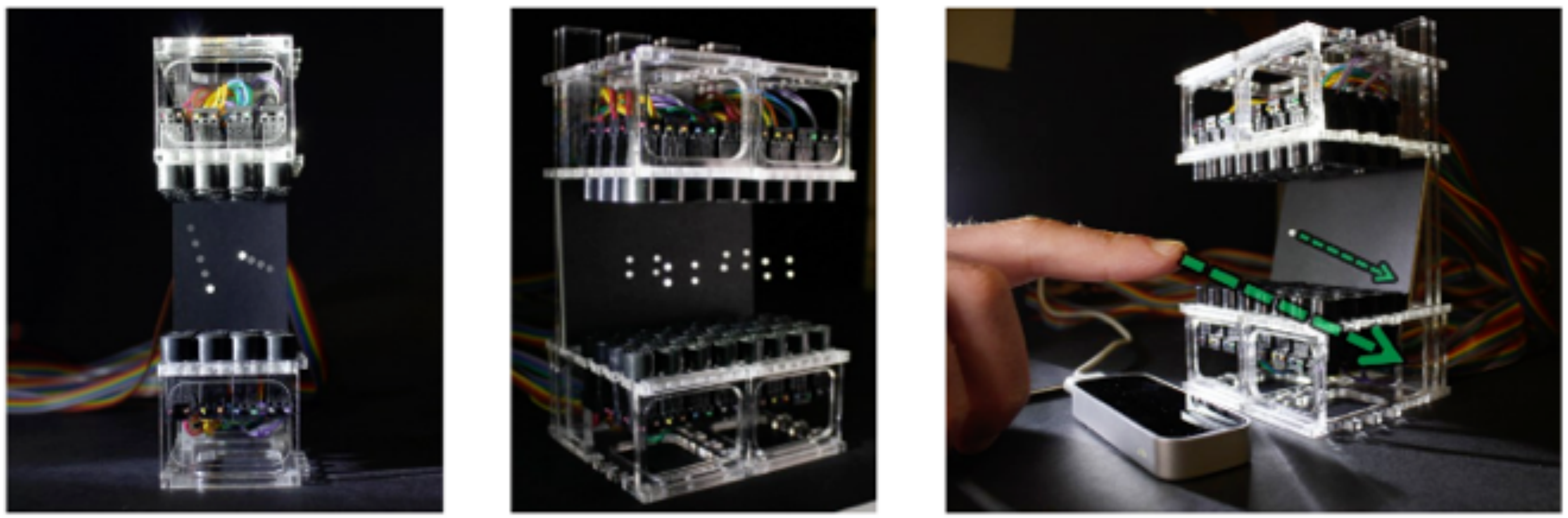

Figure 1: a) LeviPath uses two opposed arrays of transducers to levitate multiple objects across independent 3D paths; b) Interaction space can be increased by joining several LeviPaths together; c) Various devices can be used to interact with it.

ABSTRACT
LeviPath is a modular system to levitate objects across 3D paths. It consists of two opposed arrays of transducers that create a standing wave capable of suspending objects in mid-air. To control the standing wave, the system employs a novel algorithm based on combining basic patterns of movement. Our approach allows the control of multiple beads simultaneously along different 3D paths. Due to the patterns and the use of only two opposed arrays, the system is modular and can scale its interaction space by joining several LeviPaths. In this paper, we describe the hardware architecture, the basic patterns of movement and how to combine them to produce 3D path visualisations.

Author Keywords
Acoustic levitation; modular system; 3D paths; physical visualisations

ACM Classification Keywords

INTRODUCTION
Mathematicians have used physical representations of data since the 16^{th} century. They calculated and assembled wood slices to represent and better understand 3D functions. Physical visualisations promote cognition and support visual thinking allowing humans to use an inherent skill set [8]. In a recent study Jansen et al showed that users preferred physical 3D bar charts as they were able to touch and point important parts of the chart with their fingers as well as rotate them naturally [5].

Even with the use of 3d printers and laser cutters, physical representations lack dynamicity to reflect changes in data. Shape-changing interfaces, such as inFORM [3], aim at solving this issue. inFORM consists of a 30x30 matrix of actuated columns that can individually change in height to create tangible dynamic height-fields. However, having solid columns can occlude some visualisations.

drawbacks:

- hands need to be away 15-20cm (focus distance of transmitter array)
- low resolution, ca. 1cm
- sensation is very subtle

air vertices

(contact-less)

air cannons shoot **air vertices** at the user…

2013 uses a regular speaker to create the pressure

AirWave: Non-Contact Haptic Feedback Using Air Vortex Rings

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ABSTRACT

Input modalities such as speech and gesture allow users to interact with computers without holding or touching a physical device, thus enabling at-a-distance interaction. It remains an open problem, however, to incorporate haptic feedback into such interaction. In this work, we explore the use of air vortex rings for this purpose. Unlike standard jets of air, which are turbulent and dissipate quickly, vortex rings can be focused to travel several meters and impart perceptible feedback. In this paper, we review vortex formation theory and explore specific design parameters that allow us to generate vortices capable of imparting haptic feedback. Applying this theory, we developed a prototype system called AirWave. We show through objective measurements that AirWave can achieve spatial resolution of less than 10 cm at a distance of 2.5 meters. We further demonstrate through a user study that this can be used to direct tactile stimuli to different regions of the human body.

Author Keywords

Non-contact haptic feedback; air vortex rings

ACM Classification Keywords

H.5.m Information interfaces and presentation: Miscellaneous

INTRODUCTION

Haptic feedback – more generally, the sense of touch – is a critical component of our interactions with the physical world. Numerous studies have demonstrated that haptic

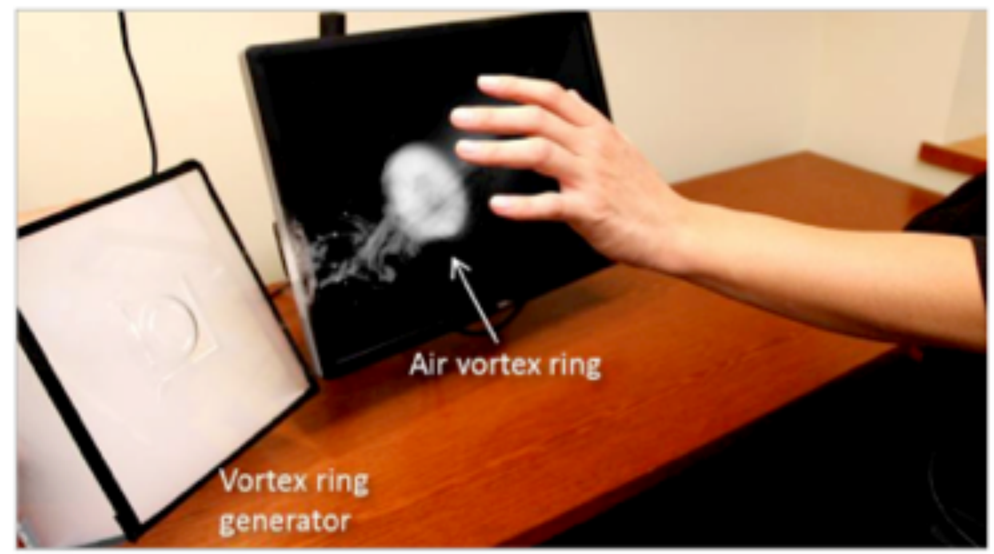
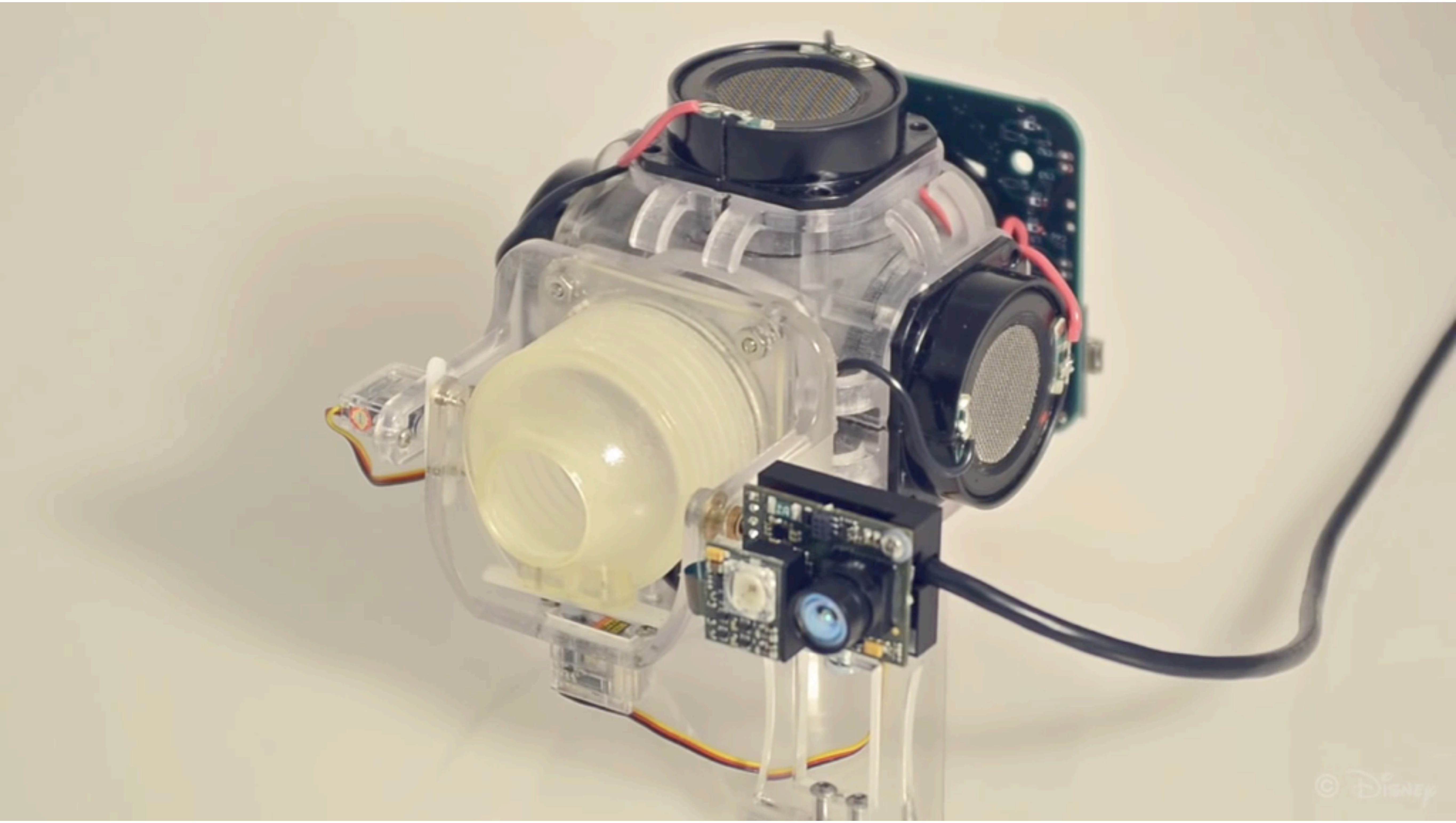


Figure 1: AirWave prototype filled with fog to visualize a vortex ring being used for providing precise non-contact haptic feedback to a user.

vice and provide direct mechanical stimulation. However, this assumption is no longer universal, as non-contact and at-a-distance sensing (e.g., computer vision and speech recognition) is becoming more prevalent in our computing environments. The Microsoft Xbox Kinect, for example, allows immersive gaming and media control through computer vision and speech recognition, which require no physical contact between the user and the computer. This presents a new challenge to haptic feedback systems, and our core research question:

How do we restore haptic realism to virtual environments



2013 adding adjustable direction & orientation

AIREAL: Interactive Tactile Experiences in Free Air

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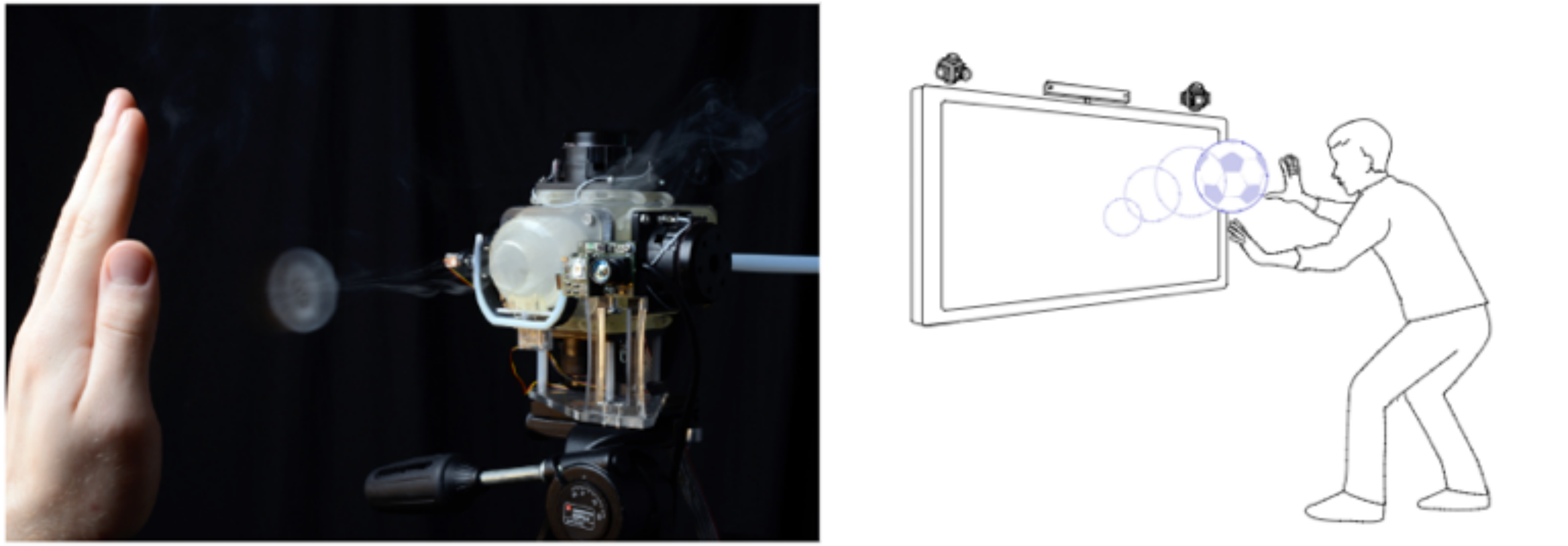


Figure 1: *On the left, the AIREAL device emits a ring of air called a vortex, which can impart physical forces a user can feel in free air. On the right, multiple AIREAL devices can be used to provide free air tactile sensations while interacting with virtual objects.*

Abstract

AIREAL is a novel haptic technology that delivers effective and expressive tactile sensations in free air, without requiring the user to wear a physical device. Combined with interactive computers graphics, AIREAL enables users to feel virtual 3D objects, experience free air textures and receive haptic feedback on gestures performed in free space. AIREAL relies on air vortex generation directed by an actuated flexible nozzle to provide effective tactile feedback with a 75 degrees field of view, and within an 8.5cm resolution at 1 meter. AIREAL is a scalable, inexpensive and practical free air haptic technology that can be used in a broad range of applications, including gaming, mobile applications, and gesture interaction among many others. This paper reports the details of the AIREAL design and control, experimental evaluations of the device's performance, as well as an exploration of the application space of free air haptic displays. Although we used vortices, we believe that the results reported are generalizable and will inform the design of haptic displays based on alternative principles of free air tactile actuation.

CR Categories: H5.2 [Information interfaces and presentation]:

1 Introduction

This paper presents AIREAL, a technology that delivers interactive tactile experiences in free air without the need for a user to wear or touch any physical device. We were motivated by the rapid expansion of interactive computer graphics from the desktop and movie screen into the real world. Recent developments of inexpensive gesture tracking and recognition technologies, such as the Microsoft Kinect or Nintendo Wii, have enabled millions of people to play computer games using their bodies (Figure 1). Furthermore, with the rapid improvement of computer vision tracking and registration algorithms, development of novel projection devices enable graphical images to be overlaid on the real environment, enabling entirely new spatial augmented reality (AR) applications [Wilson 2012]. As highly interactive computer graphics continue to evolve on mobile platforms, these natural interfaces will become accessible anywhere and at any time. The line between real and virtual is, indeed, rapidly blurring.

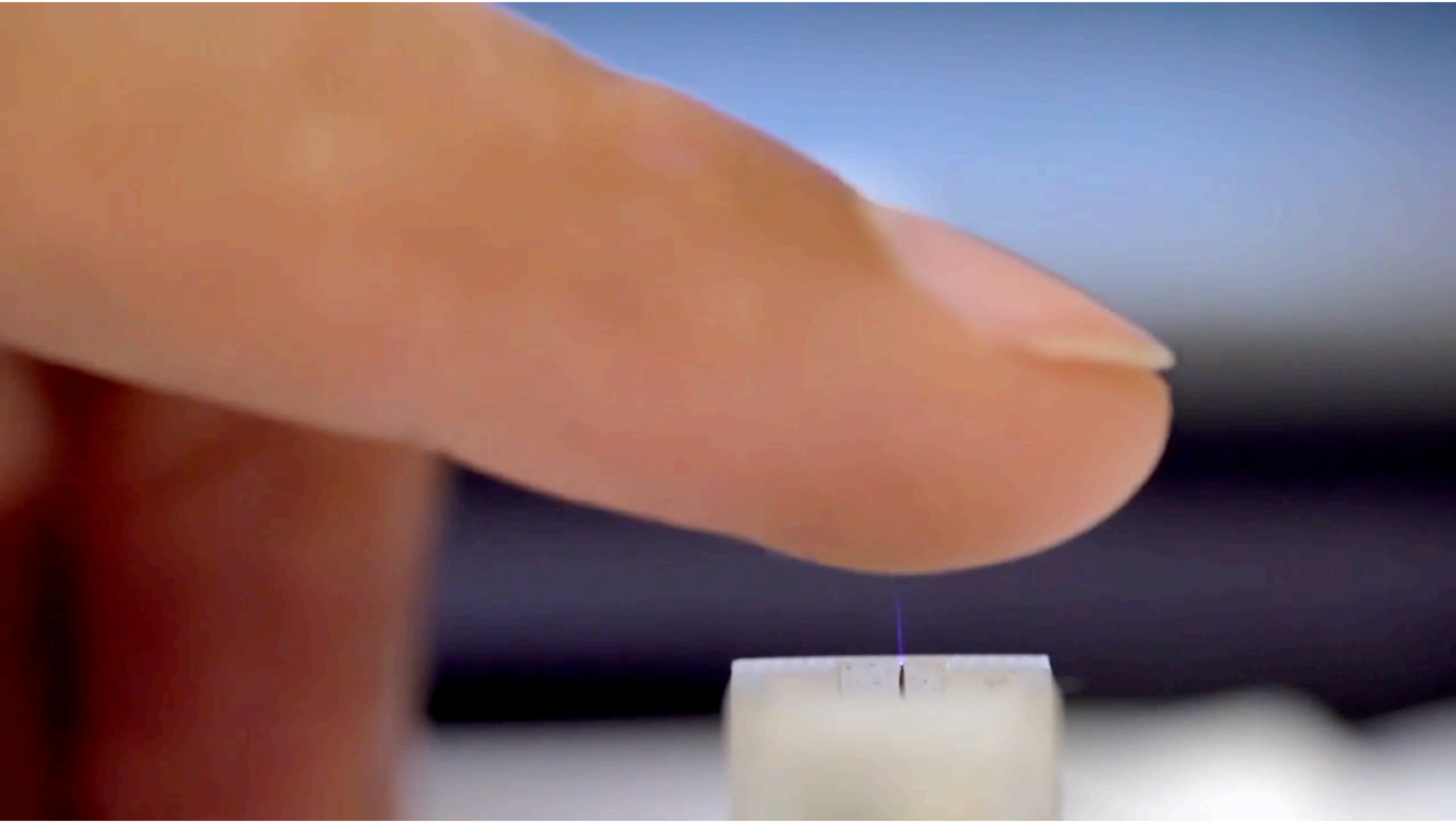
One missing piece in this emerging computer-augmented world is the absence of physical *feeling* of virtual objects. Despite signifi-

drawbacks (similar to ultra-sound):

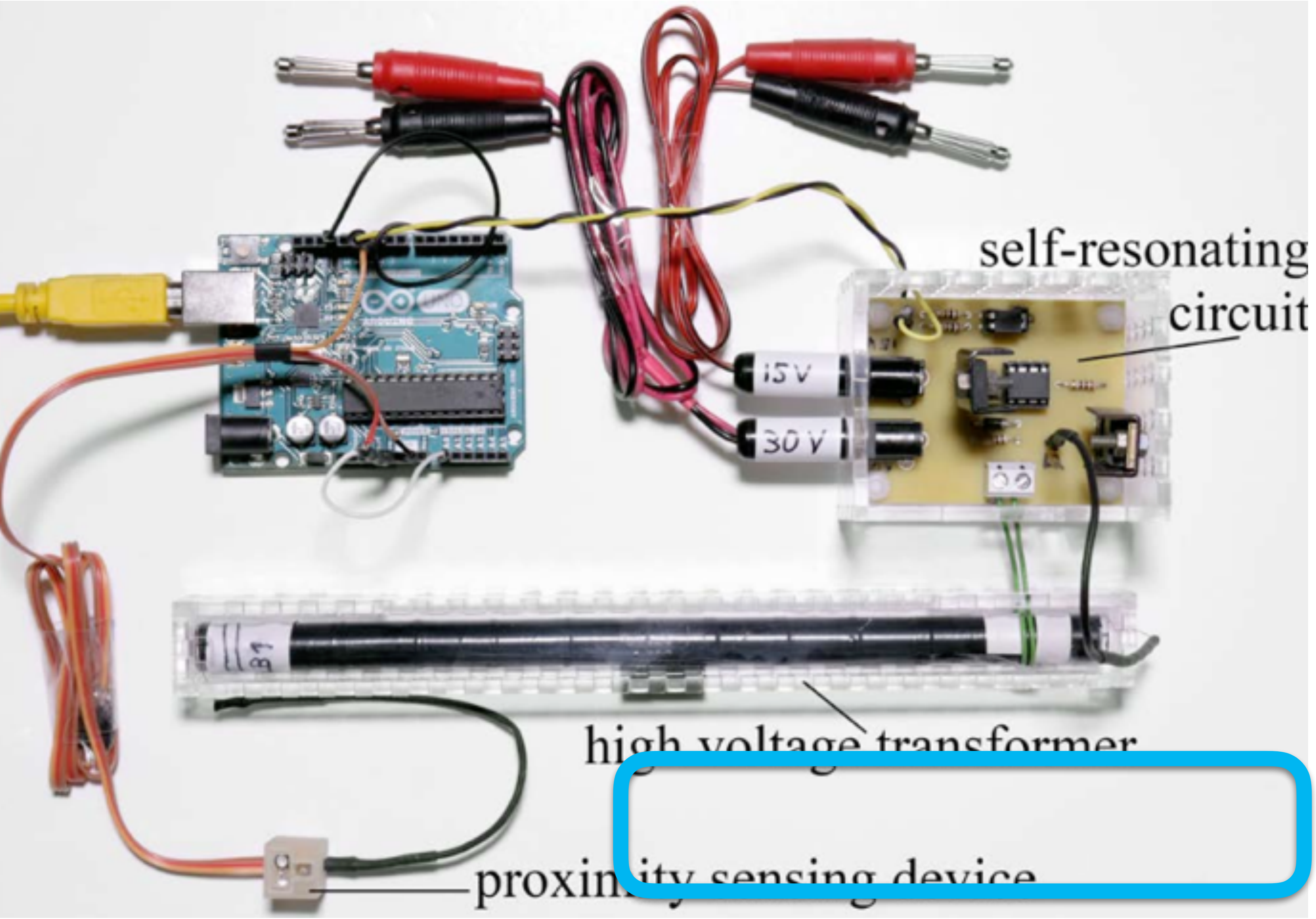
- low targeting resolution
- low resolution of sensations (ca. 5-8cm at 1 m distance)

electric arcs

(contact-less)



2017 Sparkle: electric arcs as haptic feedback



- when the electric field is strong enough, the **molecules in the air get ionized** and create a conductive region
- when an external **conductive object (e.g. finger)** comes close, the ions move towards the finger due to the electric field and create the arc

Sparkle: Hover Feedback with Touchable Electric Arcs

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ABSTRACT

Many finger sensing input devices now support proximity input, enabling users to perform in-air gestures. While near-surface interactions increase the input vocabulary, they lack tactile feedback, making it hard for users to perform gestures or to know when the interaction takes place. Sparkle stimulates the fingertip with touchable electric arcs above a hover sensing device to give users in-air tactile or thermal feedback, sharper and more feelable than acoustic mid-air haptic devices. We present the design of a high voltage resonant transformer with a low-loss soft ferrite core and self-tuning driver circuit, with which we create electric arcs 6 mm in length, and combine this technology with infrared proximity sensing in two proof-of-concept devices with form factor and functionality similar to a button and a touchpad. We provide design guidelines for Sparkle devices and examples of stimuli in application scenarios, and report the results of a user study on the perceived sensations. Sparkle is the first step towards providing a new type of hover feedback, and it does not require users to wear tactile stimulators.

Author Keywords

In-air feedback; Electric discharge; High voltage resonant transformer; Hover input; Infrared proximity sensor.

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation (e.g. HCI)]:

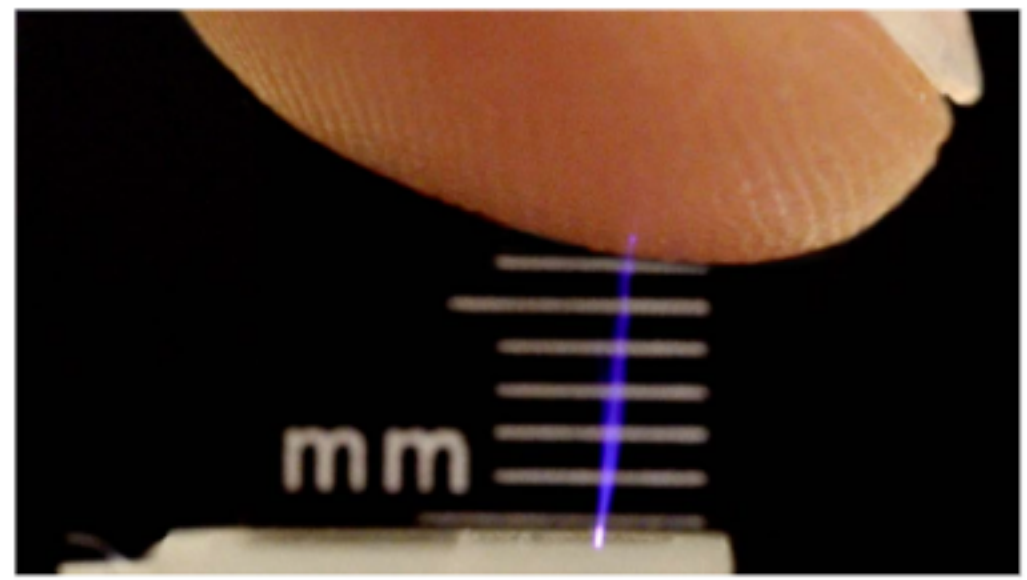


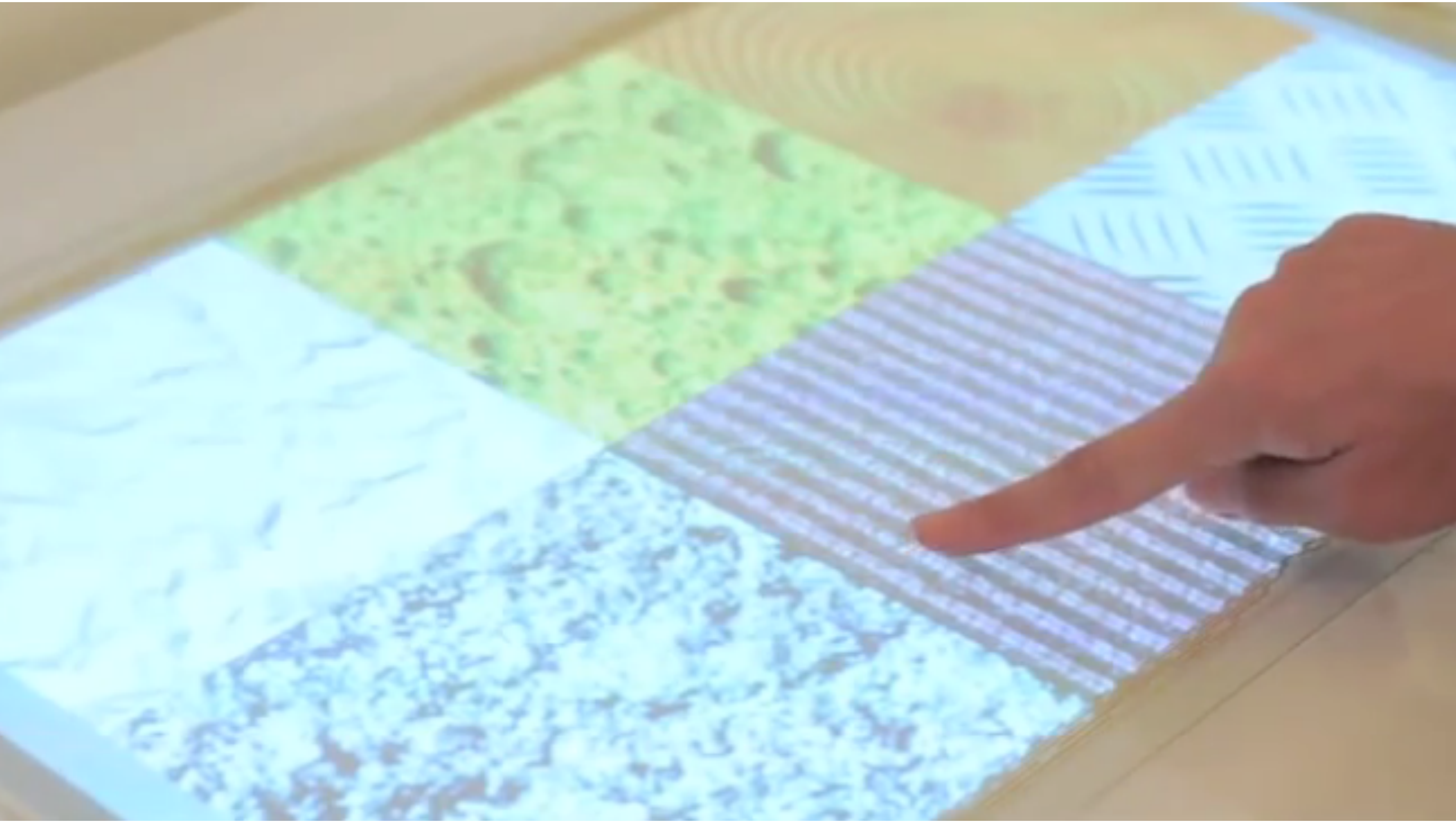
Figure 1. Touchable electric arcs spark tactile and thermal sensations.

most apparent for hover gestures when users have to position and maintain the height of their finger without performing a touch or leaving the hover range.

Here we present SPARKLE, a technology that enables tactile and thermal feedback for hover input with controlled electric arcs that are safe to touch (see Figure 1). To stimulate the fingertip we augment a finger sensing input device with a high voltage resonant transformer and trigger mild electric discharges when the finger is near the surface. We control the moment when the discharge occurs and the duration of the discharge, and we modulate the discharge from resonant

electro-static

2010: TeslaTouch electrostatic friction



feel different textures

TeslaTouch: Electrovibration for Touch Surfaces

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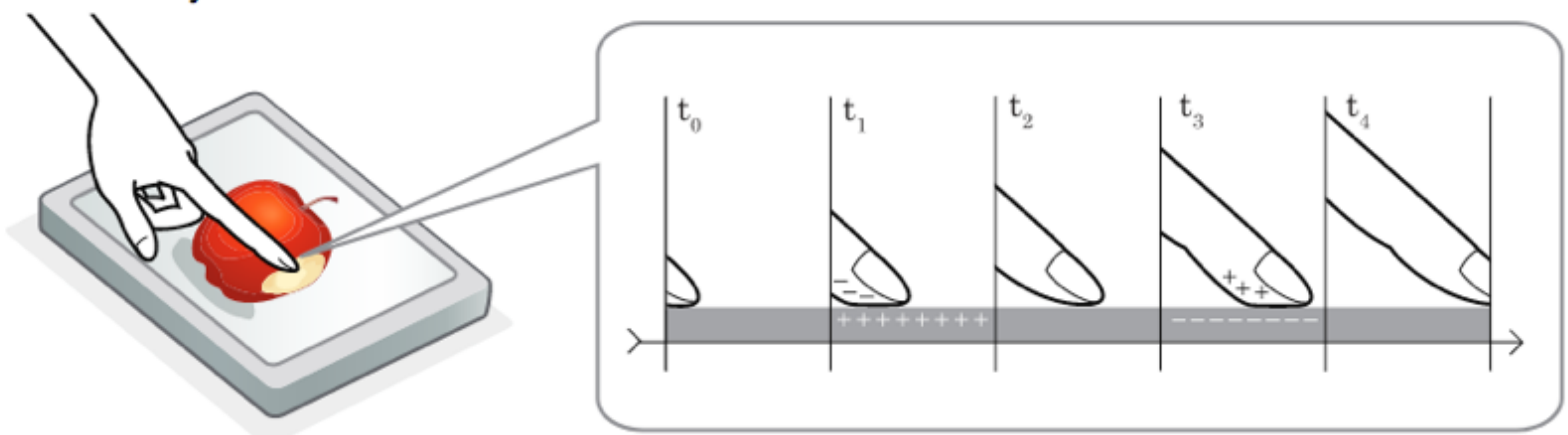


Figure 1: TeslaTouch uses electrovibration to control electrostatic friction between a touch surface and the user's finger.

ABSTRACT

We present a new technology for enhancing touch interfaces with tactile feedback. The proposed technology is based on the electrovibration principle, does not use any moving parts and provides a wide range of tactile feedback sensations to fingers moving across a touch surface. When combined with an interactive display and touch input, it enables the design of a wide variety of interfaces that allow the user to feel virtual elements through touch. We present the principles of operation and an implementation of the technology. We also report the results of three controlled psychophysical experiments and a subjective user evaluation that describe and characterize users' perception of this technology. We conclude with an exploration of the design space of tactile touch screens using two comparable setups,

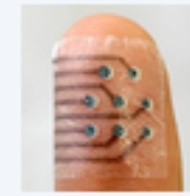
INTRODUCTION

Interest in designing and investigating haptic interfaces for touch-based interactive systems has been rapidly growing. This interest is partially fueled by the popularity of touch-based interfaces, both in research and end-user communities. Despite their popularity, a major problem with touch interfaces is the lack of dynamic tactile feedback. Indeed, as observed by Buxton as early as 1985 [6], a lack of haptic feedback 1) decreases the realism of visual environments, 2) breaks the metaphor of direct interaction, and 3) reduces interface efficiency, because the user can not rely on familiar haptic cues for accomplishing even the most basic interaction tasks.

Most previous work on designing tactile interfaces for interactive touch surfaces falls into two categories. First, the

2018 tacttoo - tattoo size haptic feedback

Tacttoo: A Thin and Feel-Through Tattoo for On-Skin Tactile Output [paper]



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This paper introduces Tacttoo, a feel-through interface for electro-tactile output on the user's skin. Integrated in a temporary tattoo with a thin and conformal form factor, it can be applied on complex body geometries, including the fingertip, and is scalable to various body locations. At less than 35μm in thickness, it is the thinnest tactile interface for wearable computing to date. Our results show that Tacttoo retains the natural tactile acuity similar to bare skin while delivering high-density tactile output. We present the fabrication of customized Tacttoo tattoos using DIY tools and contribute a mechanism for consistent electro-tactile operation on the skin. Moreover, we explore new interactive scenarios that are enabled by Tacttoo. Applications in tactile augmented reality and on-skin interaction benefit from a seamless augmentation of real-world tactile cues with computer-generated stimuli. Applications in virtual reality and private notifications benefit from high-density output in an ergonomic form factor. Results from two psychophysical studies and a technical evaluation demonstrate Tacttoo's functionality, feel-through properties and durability.

☆

On-Body Interaction, Skin, Tactile Display, Electro-Tactile, Tattoo, Fabrication, Printed Electronics, Wearable Computing

many open challenges…

how to make force feedback **mobile…**

2013: finger is moved by device

Gesture Output: Eyes-Free Output Using a Force Feedback Touch Surface

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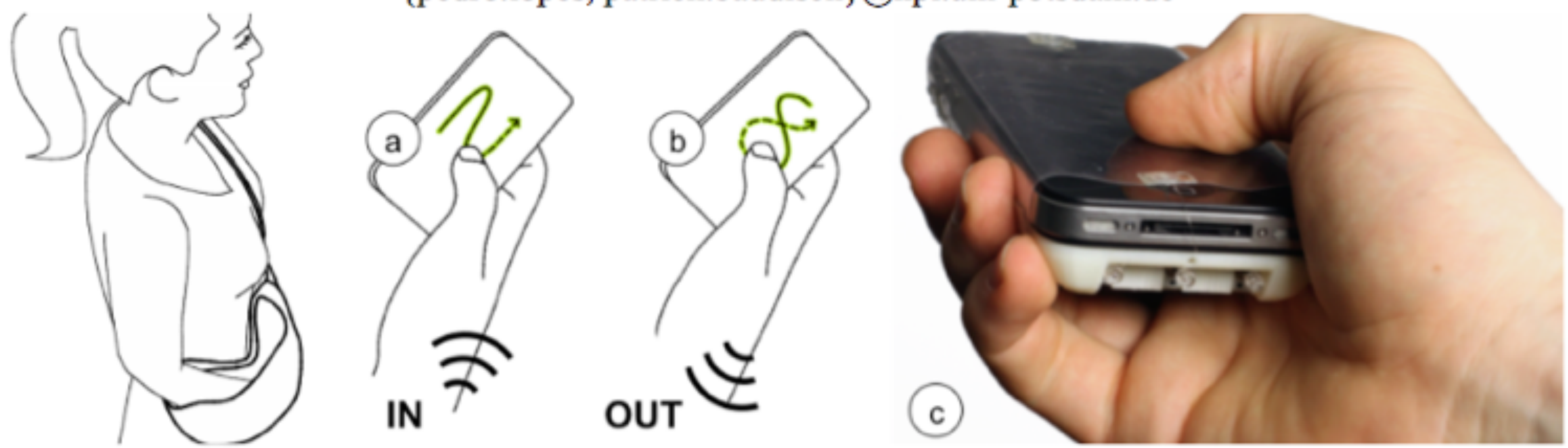

Figure 1: With our proposed gesture output, the device outputs messages to users using the same gesture language used for input. (a) Here, the user draws an N to check the house number of the upcoming meeting. (b) The device replies by translating the user's finger along the path of an 8. (c) The pocketOuija is one of the two force feedback touchscreen devices we built that support gesture output. It translates the user's finger by means of a transparent plastic foil overlaid onto the screen actuated using motors located on the back of the device.

ABSTRACT
We propose using spatial gestures not only for input but also for output. Analogous to gesture input, the proposed *gesture output* moves the user's finger in a gesture, which the *user* then recognizes. We use our concept in a mobile scenario where a motion path forming a "5" informs users about new emails, or a heart-shaped path serves as a message from a friend. We built two prototypes: (1) The *longRangeOuija* is a stationary prototype that offers a motion range of up to 4cm; (2) The *pocketOuija* is self-contained mobile device based on an iPhone with up to 1cm motion

Keywords: Gestures; Eyes Free; Force feedback; Touch.

INTRODUCTION
Gesture input allows users to interact eyes-free (non-visual, non-auditory) with their mobile touch devices, using an expressive and mnemonic set of commands [1]. Saponas et al. found that this is even possible while walking, based on users' sense of touch alone [22].

In order to have a dialog with the device, users need not only eyes-free input, but also *output*. Unfortunately, auditory output is not always possible, and vibrotactile output [3], which is the predominant eyes-free non-auditory type and **miniaturization** in general….

how to make this **scale?**


Level-Ups: Motorized Stilts that
Simulate Stair Steps in Virtual Reality
HPI
Hasso
Plattner
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Level-Ups: Motorized Stilts that Simulate Stair Steps in Virtual Reality

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ABSTRACT
We present "Level-Ups", computer-controlled stilts that allow virtual reality users to experience walking up and down steps. Each Level-Up unit is a self-contained device worn like a boot. Its main functional element is a vertical actuation mechanism mounted to the bottom of the boot that extends vertically. Unlike traditional solutions that are integrated with locomotion devices, Level-Ups allow users to walk around freely ("real-walking"). We present Level-Ups in a demo environment based on a head-mounted display, optical motion capture, and integrated with two different game engines. In a user study, participants rated the realism of stepping onto objects 6.0 out of 7.0 when wearing Level-Ups compared to 3.5 without.

Author Keywords: Virtual Reality; Real-Walking; Head-Mounted Display.

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

INTRODUCTION
Ever since its conception in the 1960's, head-mounted virtual reality systems have been primarily concerned with the user's visual senses [10] and optionally spatial audio [1]. As the next step towards realism and immersion, however, many researchers argue that such systems should also pro-

locomotion devices are space efficient, some researchers argue that allowing users to walk around freely ("real-walking") covers more of the user's senses [12].

In this paper, we present a device that allows users to experience elevation in real-walking environments.

THE LEVEL-UP MOTORIZED STILTS
Level-Ups are computer-controlled stilts that allow users to physically experience elevation.

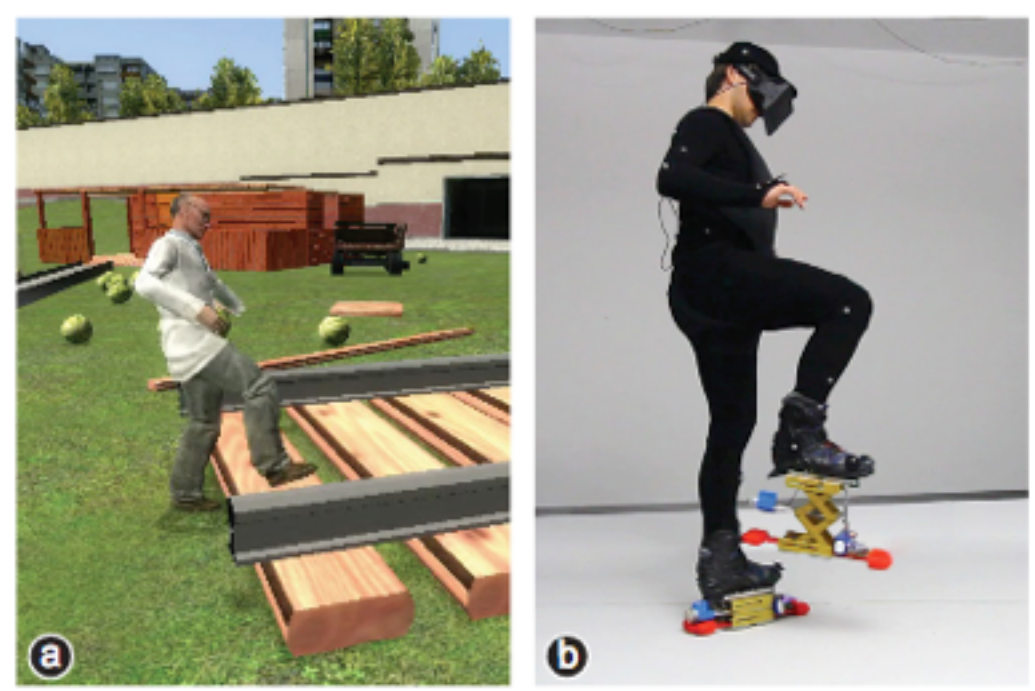
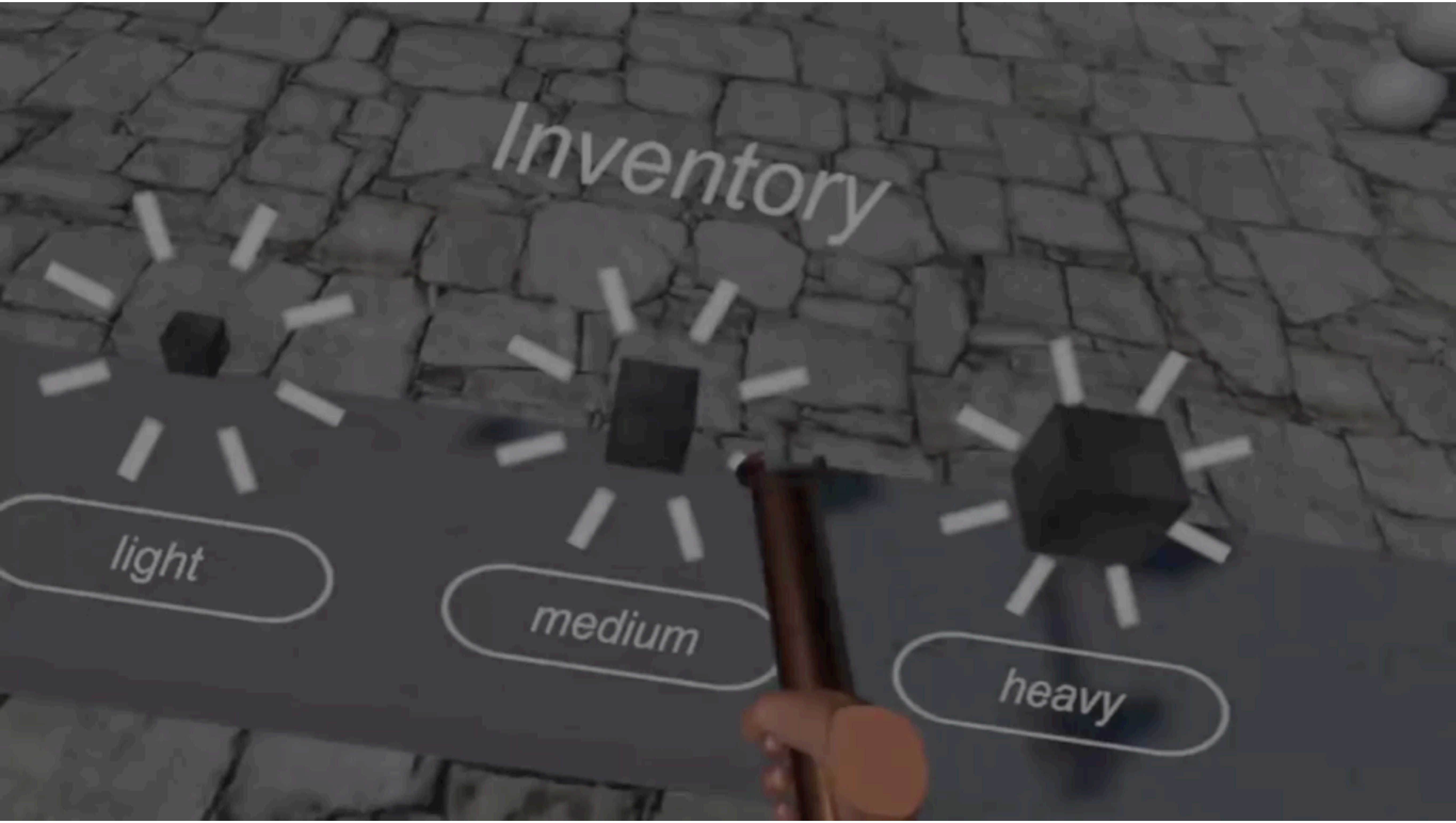
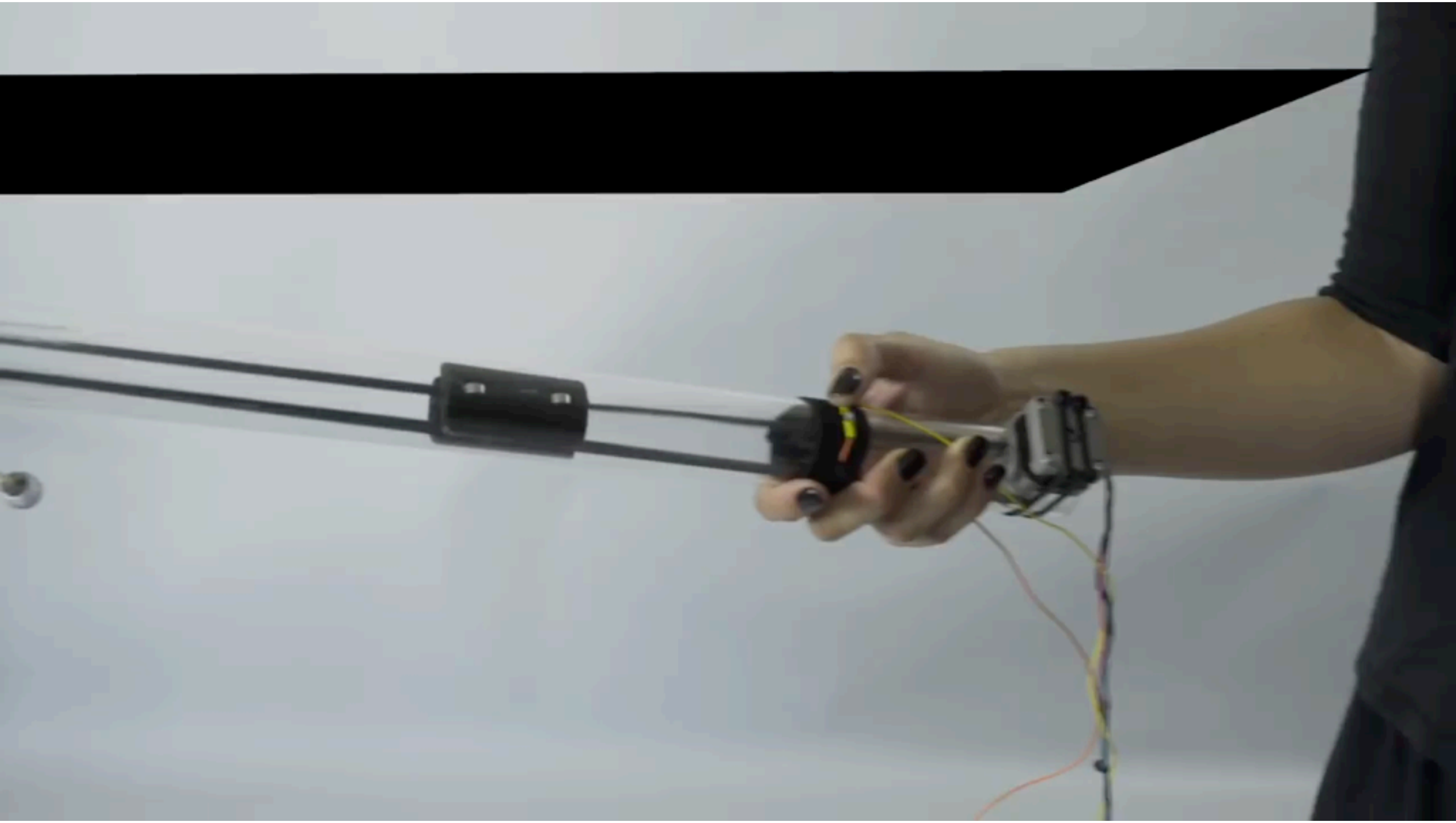


Figure 1: The Level-Up motorized stilts allow users walking in a spatial VR environment to experience physical elevation.

weight?



2017: handheld base + shifting the weight



2017: shifting the weight

Shifty: A Weight-Shifting Dynamic Passive Haptic Proxy to Enhance Object Perception in Virtual Reality

André Zenner and Antonio Krüger

Fig. 1. A user interacting with *Shifty* in our experimental setup. *Shifty* is a rod-shaped dynamic passive haptic proxy that can change its internal weight distribution to automatically adapt its passive haptic feedback. *Shifty* can be used to enhance the perception of virtual objects and provides a compelling and dynamic passive haptic feedback.

Abstract—We define the concept of *Dynamic Passive Haptic Feedback* (DPHF) for virtual reality by introducing the weight-shifting physical DPHF proxy object *Shifty*. This concept combines actuators known from active haptics and physical proxies known from passive haptics to construct proxies that automatically adapt their passive haptic feedback. We describe the concept behind our ungrounded weight-shifting DPHF proxy *Shifty* and the implementation of our prototype. We then investigate how *Shifty* can, by automatically changing its internal weight distribution, enhance the user's perception of virtual objects interacted with in two experiments. In a first experiment, we show that *Shifty* can enhance the perception of virtual objects changing in shape, especially in length and thickness. Here, *Shifty* was shown to increase the user's fun and perceived realism significantly, compared to an equivalent passive haptic proxy. In a second experiment, *Shifty* is used to pick up virtual objects of different virtual weights. The results show that *Shifty* enhances the perception of weight and thus the perceived realism by adapting its kinesthetic feedback to the picked-up virtual object. In the same experiment, we additionally show that specific combinations of haptic, visual and auditory feedback during the pick-up interaction help to compensate for visual-haptic mismatch perceived during the shifting process.

Index Terms—Dynamic passive haptic feedback, input devices, virtual reality, haptics, perception

1 Introduction

Haptic feedback is known to be one of the next big challenges for immersive virtual reality (VR). This paper introduces a new class of haptic feedback that mixes aspects of *Active Haptic Feedback* and *Passive Haptic Feedback* called *Dynamic Passive Haptic Feedback* (DPHF). With DPHF we combine the strengths of passive haptic proxy objects and active haptic systems. As an example we introduce the novel rod-shaped DPHF proxy *Shifty*. It is an ungrounded generic physical proxy that uses actuators to slowly shift an internal weight, changing its passive haptic properties in order to enhance the perception of objects during VR interaction.

When interacting in our daily life, we constantly perceive haptic cues that help us understand an object's physical properties such as its shape, weight, weight distribution, temperature and texture. This is essential for a safe, precise and effective interaction with an object. While sophisticated haptic feedback systems were developed in the past, the systems that come with major VR consumer devices, primarily targeting gaming and education, still use relatively simple controller devices, especially in terms of the kinesthetic feedback provided. Prominent examples are the controllers of the *HTC Vive* [1] or the *Oculus Rift* [2]. These controllers are passive haptic proxy objects that physically represent virtual objects. The realism of their feedback, however, is limited. Equipped with small vibration motors, a set of feedback effects varying in vibration strength and frequency can be achieved. While this can produce very compelling effects for some interactions in the virtual environment (VE), such as tensing a bowstring or pulling a lever, a major drawback is the fact that the kinesthetic properties always remain unchanged. For most interactions like picking up a virtual object with the controller, or holding an object that changes its form or material, users expect different haptic sensations before and after the event. A common problem related to this is the balloon-like feeling of virtual objects: as each picked-up object feels the same with respect to its inertia, picking up larger objects becomes unrealistic as they feel much too lightweight.

With *Shifty* we introduce a novel physical proxy to solve these issues by enhancing the perception of virtual objects users interact with. *Shifty* can, without exerting noticeable active forces, slowly change its kinesthetic feedback automatically during runtime by shifting a weight along its main axis to change its rotational inertia. The user then gets

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support for **visual impaired users?**

2018 DualPanto: haptic device for blind users

DualPanto: A Haptic Device that Enables Blind Users to Continuously Interact with Virtual Worlds [paper]

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Robert Kovacs, Hasso Plattner Institute
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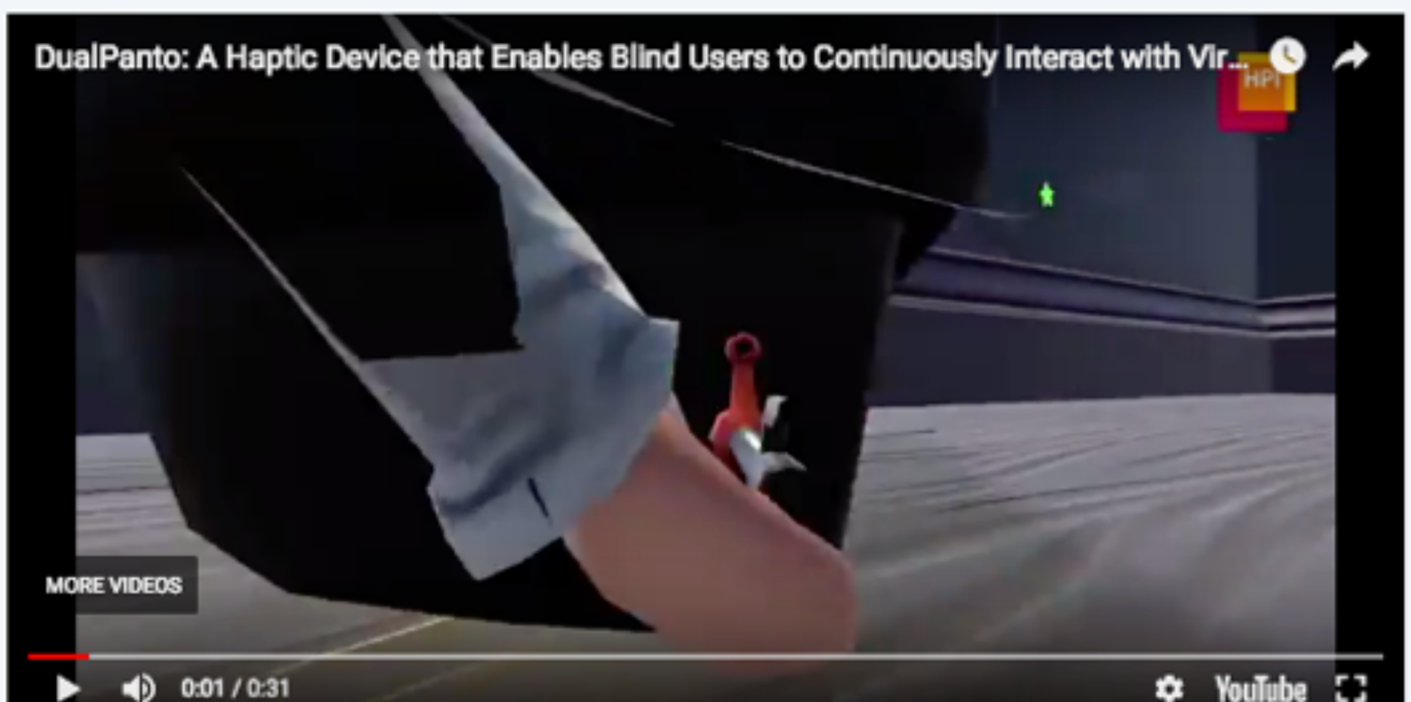
We present a new haptic device that enables blind users to continuously interact with spatial virtual environments that contain moving objects, as is the case in sports or shooter games. Users interact with DualPanto by operating the me handle with one hand and by holding on to the it handle with the other hand. Each handle is connected to a pantograph haptic input/output device. The key feature is that the two handles are spatially registered with respect to each other. When guiding their avatar through a virtual world using the me handle, spatial registration enables users to track moving objects by having the device guide the output hand. This allows blind players of a 1-on-1 soccer game to race for the ball or evade an opponent; it allows blind players of a shooter game to aim at an opponent and dodge shots. In our user study, blind participants reported very high enjoyment when using the device to play (6.5/7).



haptics, force-feedback, accessibility, blind, visually impaired, gaming

lots of interesting research going on in this space…

many open research challenges!

end.