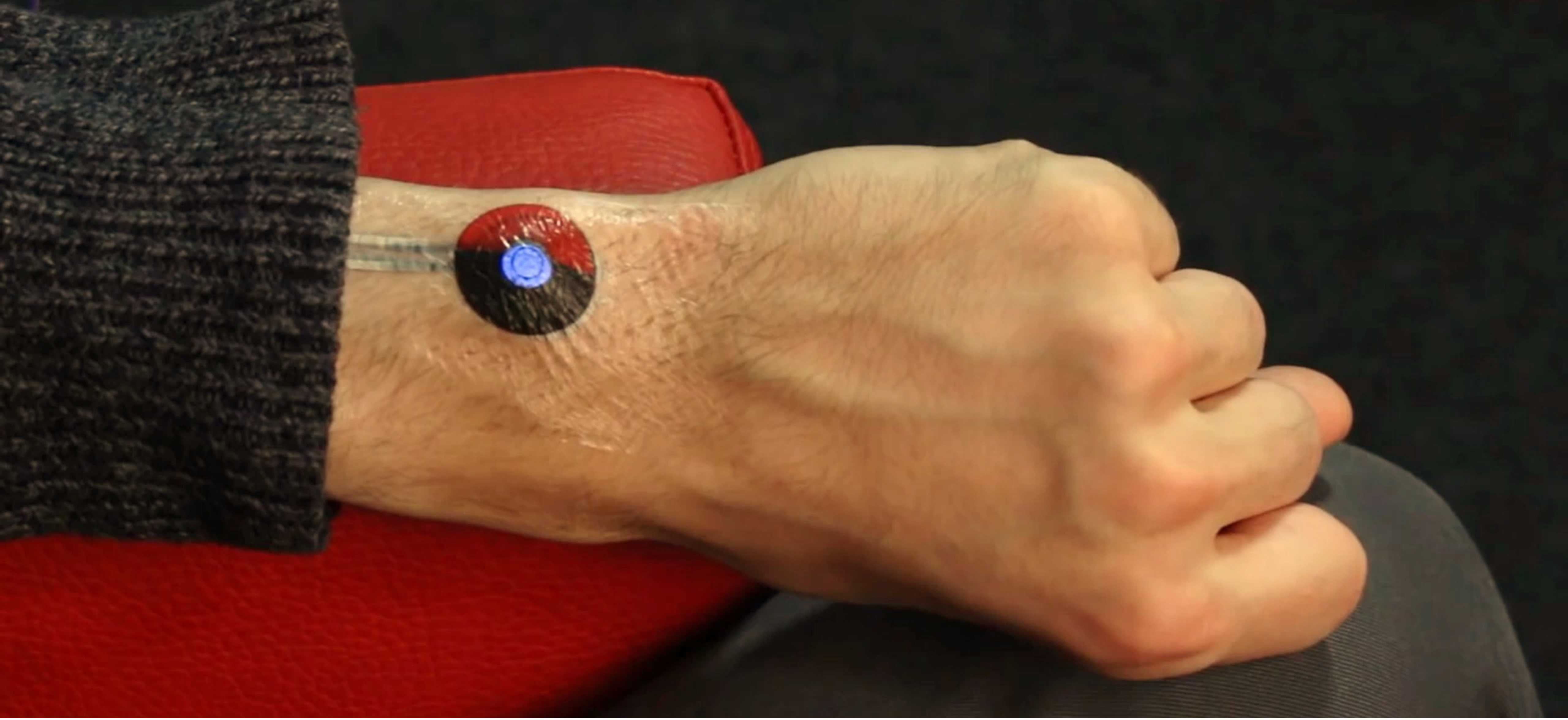


“Ubiquitous” Display

CMSC730 | Huaishu Peng | Spring 2026

ubiquitous computing

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

computing is made to **appear anytime** and **anywhere**

if everything is a computer,
everything will also **sense** user input
and everything will be a **display** for output

Mark Weiser

ubiquitous computing

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”

computing is made to **appear anytime** and **anywhere**

if everything is a computer,
everything will also **sense** user input
and everything will be a **display** for output

Mark Weiser

how can we **prototype** this to

make everything in our surrounding appear to be a display?

projection

as a place holder for freeform screens

Foldable display?

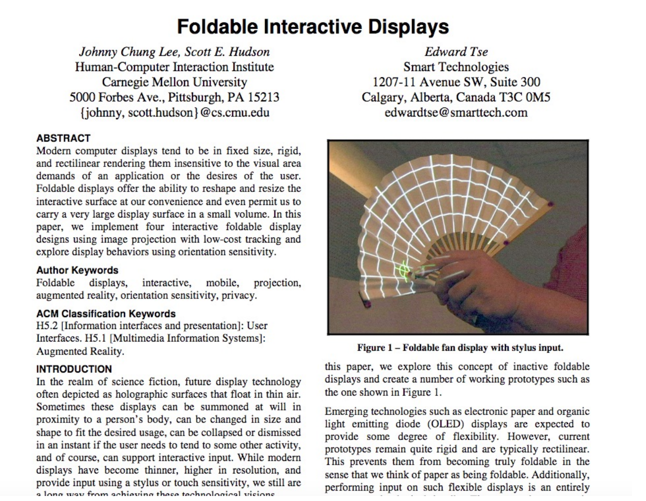
Tracking with infrared (IR) LEDs
Display with a projector

Goal is to simulate the flexible display interaction when technology is not ready yet

Foldable display?

Tracking with infrared (IR) LEDs
Display with a projector

Goal is to simulate the flexible display interaction when technology is not ready yet



Foldable Interactive Displays

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ABSTRACT
Modern computer displays tend to be in fixed size, rigid, and rectilinear rendering them insensitive to the visual area demands of an application or the desires of the user. Foldable displays offer the ability to reshape and resize the interactive surface at our convenience and even permit us to carry a very large display surface in a small volume. In this paper, we implement four interactive foldable display designs using image projection with low-cost tracking and explore display behaviors using orientation sensitivity.

Author Keywords
Foldable displays, interactive, mobile, projection, augmented reality, orientation sensitivity, privacy.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces. H5.1 [Multimedia Information Systems]: Augmented Reality.

INTRODUCTION
In the realm of science fiction, future display technology often depicted as holographic surfaces that float in thin air. Sometimes these displays can be summoned at will in proximity to a person's body, can be changed in size and shape to fit the desired usage, can be collapsed or dismissed in an instant if the user needs to tend to some other activity, and of course, can support interactive input. While modern displays have become thinner, higher in resolution, and provide input using a stylus or touch sensitivity, we still are a long way from achieving these technological visions

Figure 1 – Foldable fan display with stylus input.

this paper, we explore this concept of inactive foldable displays and create a number of working prototypes such as the one shown in Figure 1.

Emerging technologies such as electronic paper and organic light emitting diode (OLED) displays are expected to provide some degree of flexibility. However, current prototypes remain quite rigid and are typically rectilinear. This prevents them from becoming truly foldable in the sense that we think of paper as being foldable. Additionally, performing input on such flexible displays is an entirely

UIST 08
Lee et.al.

Sphere display?

No Master User Position or Orientation

Visible Content Changes with Position and Height

Smooth Transition Between Vertical and Horizontal Surfaces

Borderless, but Finite Display

Sphere: Multi-Touch Interactions on a Spherical Display

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ABSTRACT

Sphere is a multi-user, multi-touch-sensitive spherical display in which an infrared camera used for touch sensing shares the same optical path with the projector used for the display. This novel configuration permits: (1) the enclosure of both the projection and the sensing mechanism in the base of the device, and (2) easy 360-degree access for multiple users, with a high degree of interactivity without shadowing or occlusion. In addition to the hardware and software solution, we present a set of multi-touch interaction techniques and interface concepts that facilitate collaborative interactions around Sphere. We designed four spherical application concepts and report on several important observations of collaborative activity from our initial Sphere installation in three high-traffic locations.

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

General terms: Design, Human Factors

Keywords: Spherical display, multi-touch, surface computing, collaboration, single-display groupware.

INTRODUCTION

Spherical displays offer an unobstructed 360° field of view to all users, enabling them to explore different perspectives of the displayed data by physically moving around the display. Viewers can use the spherical nature of the display, their physical body position and orientation, and additional

In this paper, we present an implementation of a novel, multi-touch-sensitive, spherical display prototype called *Sphere* (Figure 1). We use Sphere to explore the interactive and collaborative possibilities of spherical interfaces through the development of several concept applications. Our work makes the following three contributions:

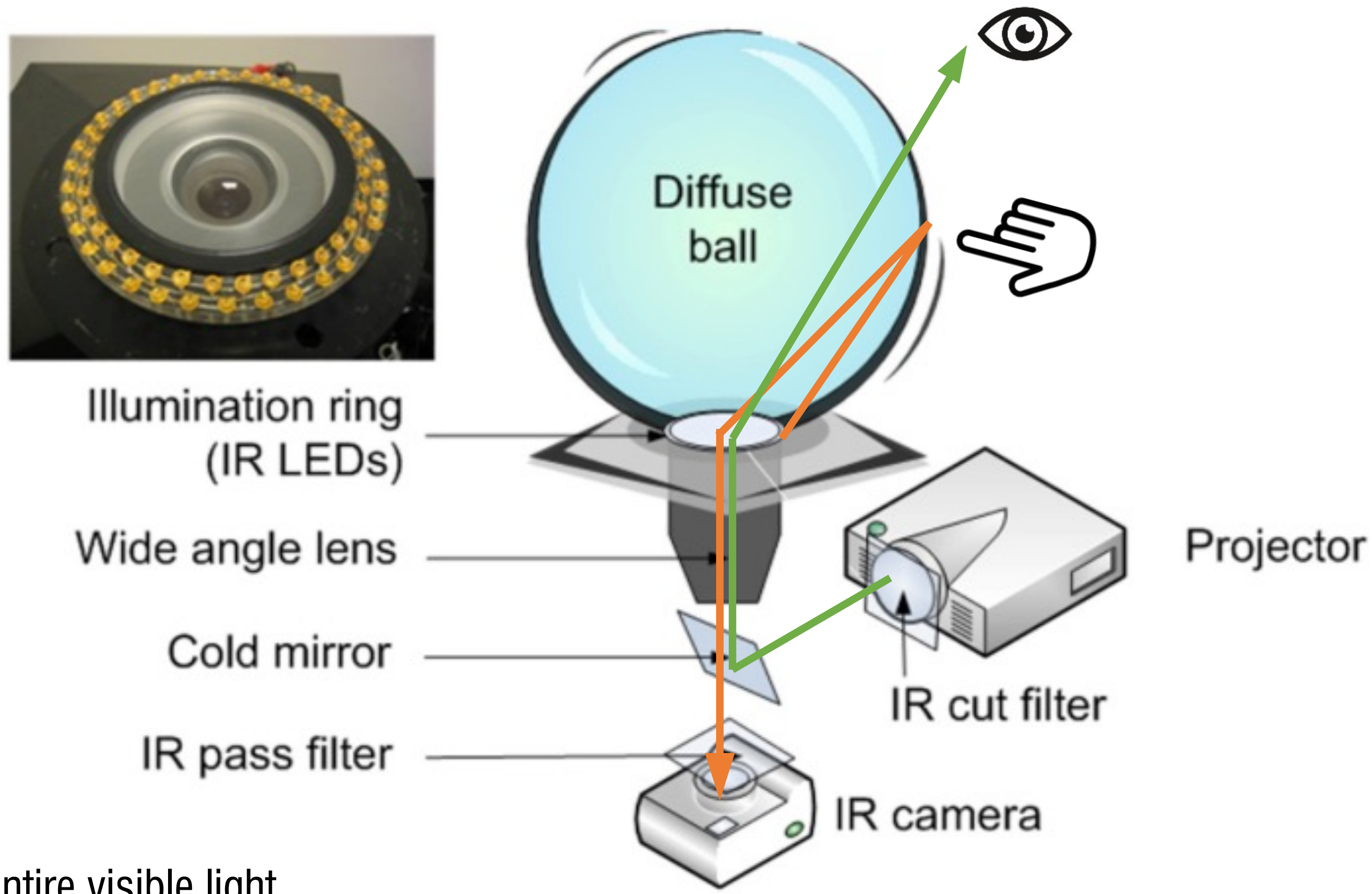
First, we outline and discuss the unique benefits of spherical displays in comparison to flat displays. While the challenges of designing applications and interactions are arguably greater for a spherical than for a flat surface, applications can be designed that exploit the unique characteristics of spherical displays to create interesting user experience.

Second, we describe hardware and software components needed to facilitate multi-touch sensing on a spherical display. Sphere uses a commercially available Magic Planet display [13] as its core, augmented by our custom touch-sensing hardware. We also discuss the projections needed to pre-distort data for display on a spherical surface.

Third, we present a set of direct touch interaction techniques – including dragging, scaling, rotating, and flicking of objects – that permit interaction and collaboration around Sphere. We also contribute gestural interactions and user interface concepts that account for the spherical nature of the interface. While general in nature, these interactions were developed within the context of four simple prototype application concepts that help us explore Sphere's interactive capabilities, including a picture and video browser, an omni-directional data viewer, a paint application, and a

UIST 08
Benko et.al.

how does this work?

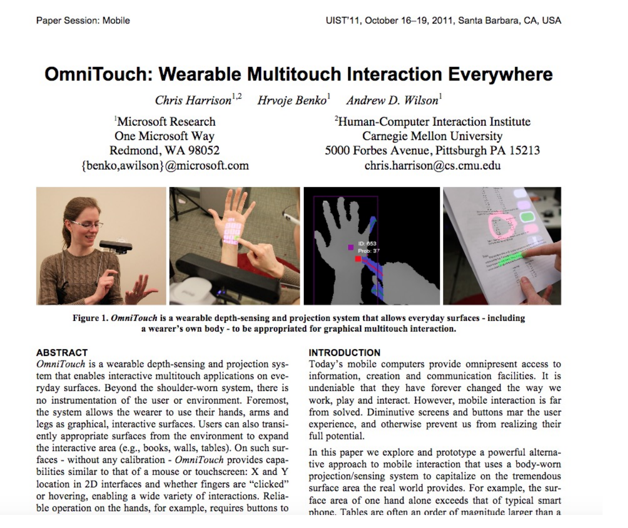


Cold mirror: reflects the entire visible light spectrum while very efficiently transmitting infrared wavelengths

Foldable display

Skin as display?

Skin as display?



Paper Session: Mobile UIST'11, October 16–19, 2011, Santa Barbara, CA, USA

OmniTouch: Wearable Multitouch Interaction Everywhere

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Figure 1. *OmniTouch* is a wearable depth-sensing and projection system that allows everyday surfaces - including a wearer's own body - to be appropriated for graphical multitouch interaction.

ABSTRACT

OmniTouch is a wearable depth-sensing and projection system that enables interactive multitouch applications on everyday surfaces. Beyond the shoulder-worn system, there is no instrumentation of the user or environment. Foremost, the system allows the wearer to use their hands, arms and legs as graphical, interactive surfaces. Users can also transiently appropriate surfaces from the environment to expand the interactive area (e.g., books, walls, tables). On such surfaces - without any calibration - *OmniTouch* provides capabilities similar to that of a mouse or touchscreen: X and Y location in 2D interfaces and whether fingers are "clicked" or hovering, enabling a wide variety of interactions. Reliable operation on the hands, for example, requires buttons to

INTRODUCTION

Today's mobile computers provide omnipresent access to information, creation and communication facilities. It is undeniable that they have forever changed the way we work, play and interact. However, mobile interaction is far from solved. Diminutive screens and buttons mar the user experience, and otherwise prevent us from realizing their full potential.

In this paper we explore and prototype a powerful alternative approach to mobile interaction that uses a body-worn projection/sensing system to capitalize on the tremendous surface area the real world provides. For example, the surface area of one hand alone exceeds that of typical smart phone. Tables are often an order of magnitude larger than a

UIST 11
Harrison et.al.


Kinect + projector

do not limit your imagination
to what is available in terms of technology right now.

we move very quickly (and also learn from the history)…

in HCI we often **prototype interface concepts**
before the hardware / software becomes available…

so **how far** are we with display tech?

let’s look at where we came from…

(1957)
cathode ray tube (CRT)

(1957)
split-flap display

(1961)
flip-disc display

(1968)
light-emitting diode (LED)

(1968)
stroboscopic display

(1969)
braille display / pin screen

(1971)
liquid crystal display

(1974)
electro-luminescent (EL)

(2004)
e-ink

so **how far** are we with display tech?

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braille display / pin screen

(1971)
liquid crystal display

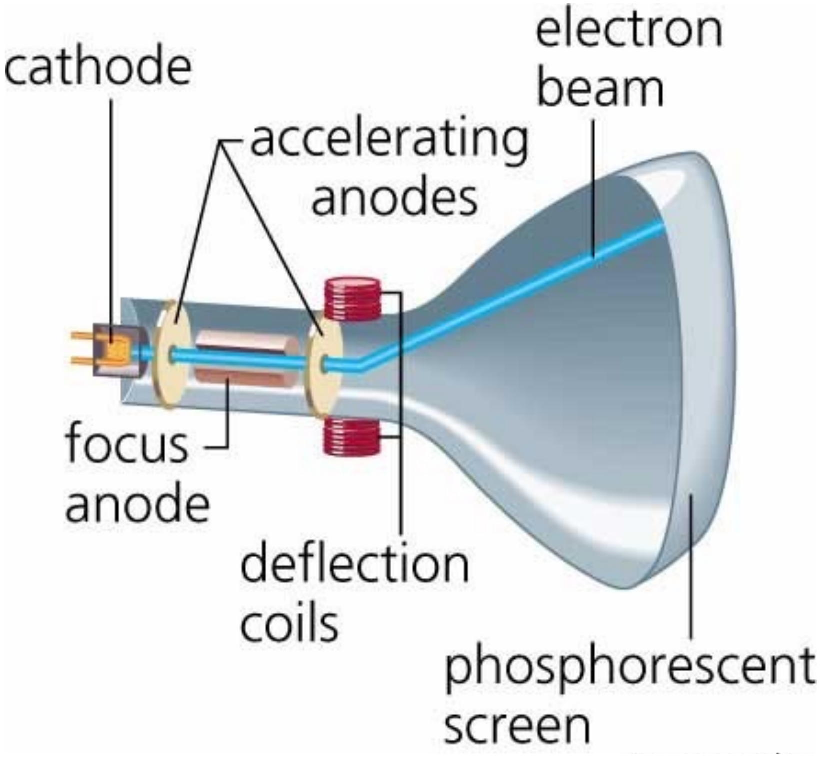
(1974)
electro-luminescent (EL)

(2004)
e-ink

(1957)

cathode ray tube (CRT)

monochrome cathode ray tubes


cathode
accelerating anodes
electron beam
focus anode
deflection coils
phosphorescent screen

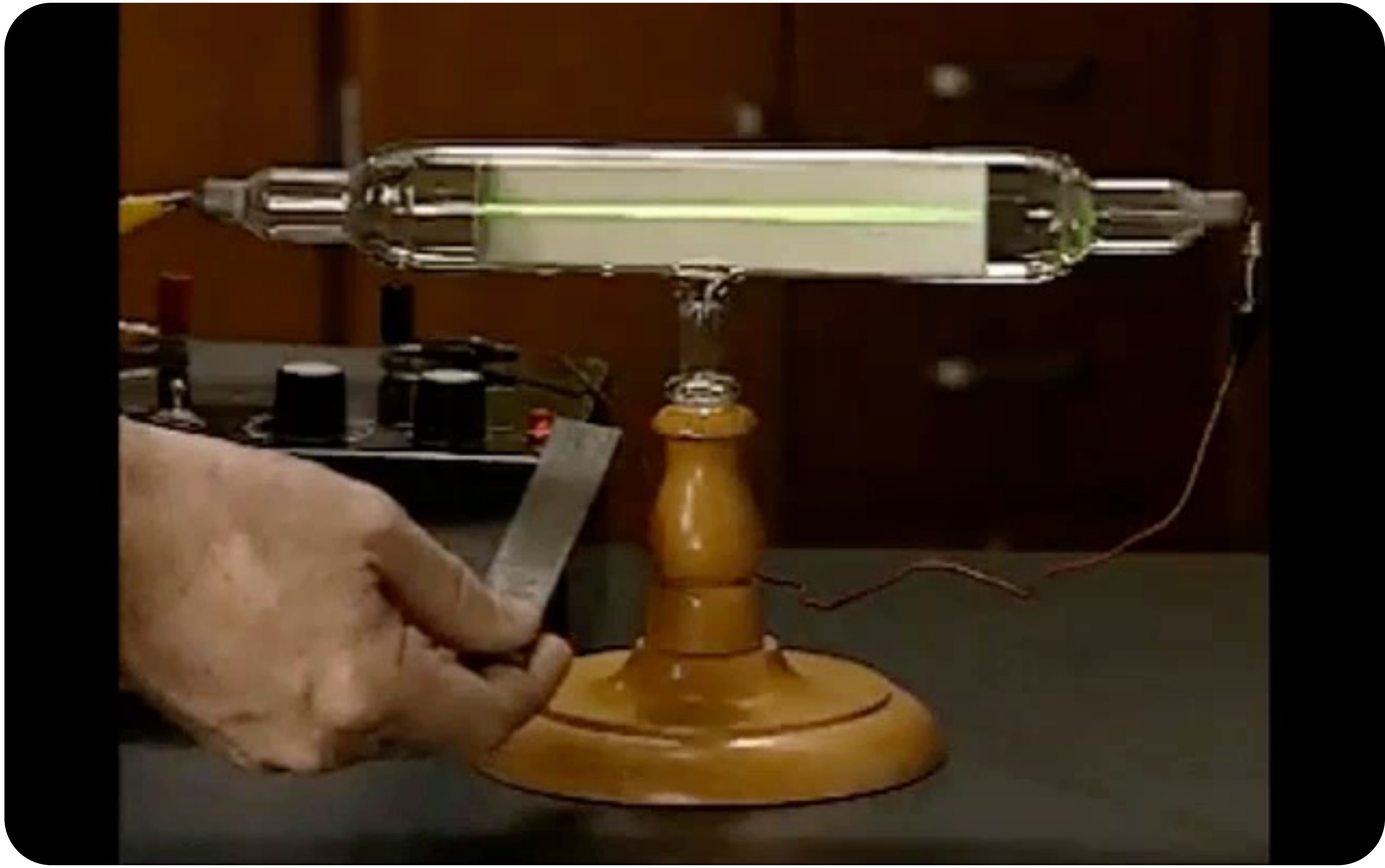
cathode ray tube (CRT):

image is created line by line

beam consists of negatively charged electrons

electromagnets steer the beam to the correct location

screen is coated with **phosphor** that lights up when hit



Light Pen

when CRT beam hits the light pen, the pen senses the light changes and notifies the computer about the exact timing

since CRT scans display line by line, one pixel at a time, the computer can infer the pen's position from the latest timestamp

1963: Ivan Sutherland’s Light Pen on CRT

the light pen does no longer work on today’s screen,
but the **interaction concept** remains.

in HCI we develop **interaction concepts that work across technology**

(1957)

split-flap display

(1961)

flip-disc display

1957 split flap display (electro-mechanical)

Fig.4

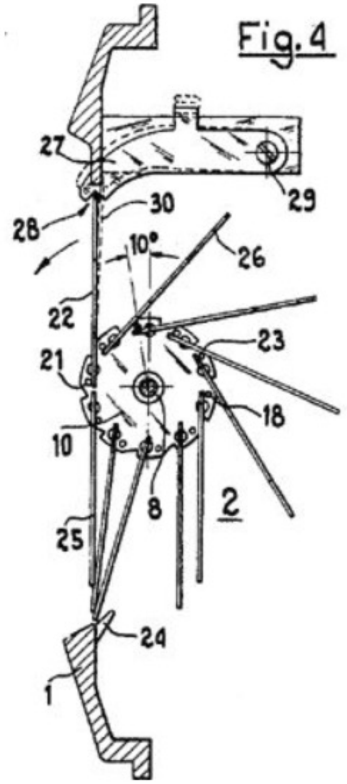
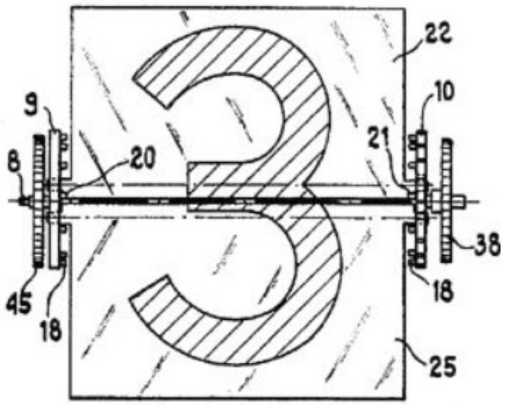
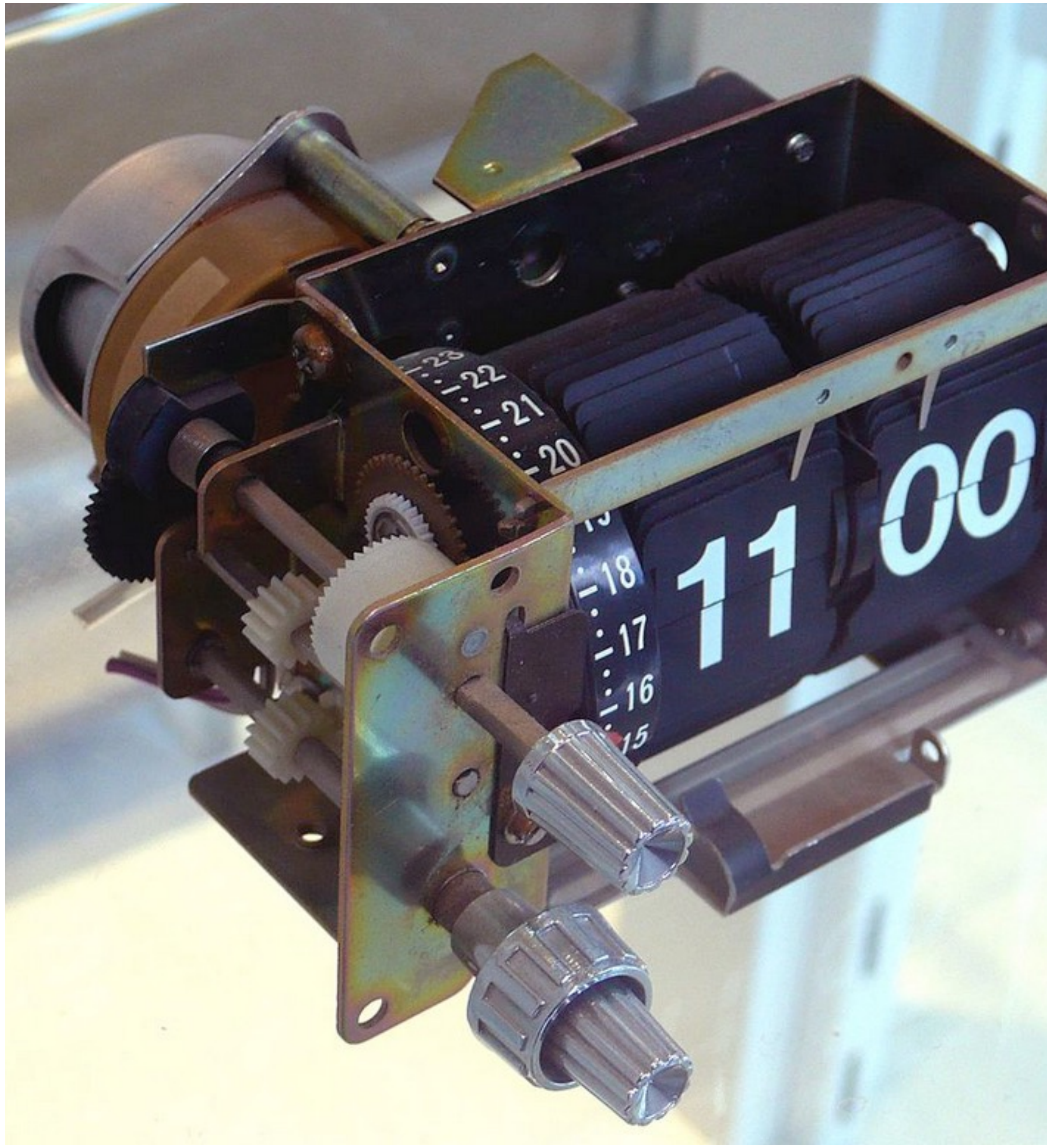


Fig.5

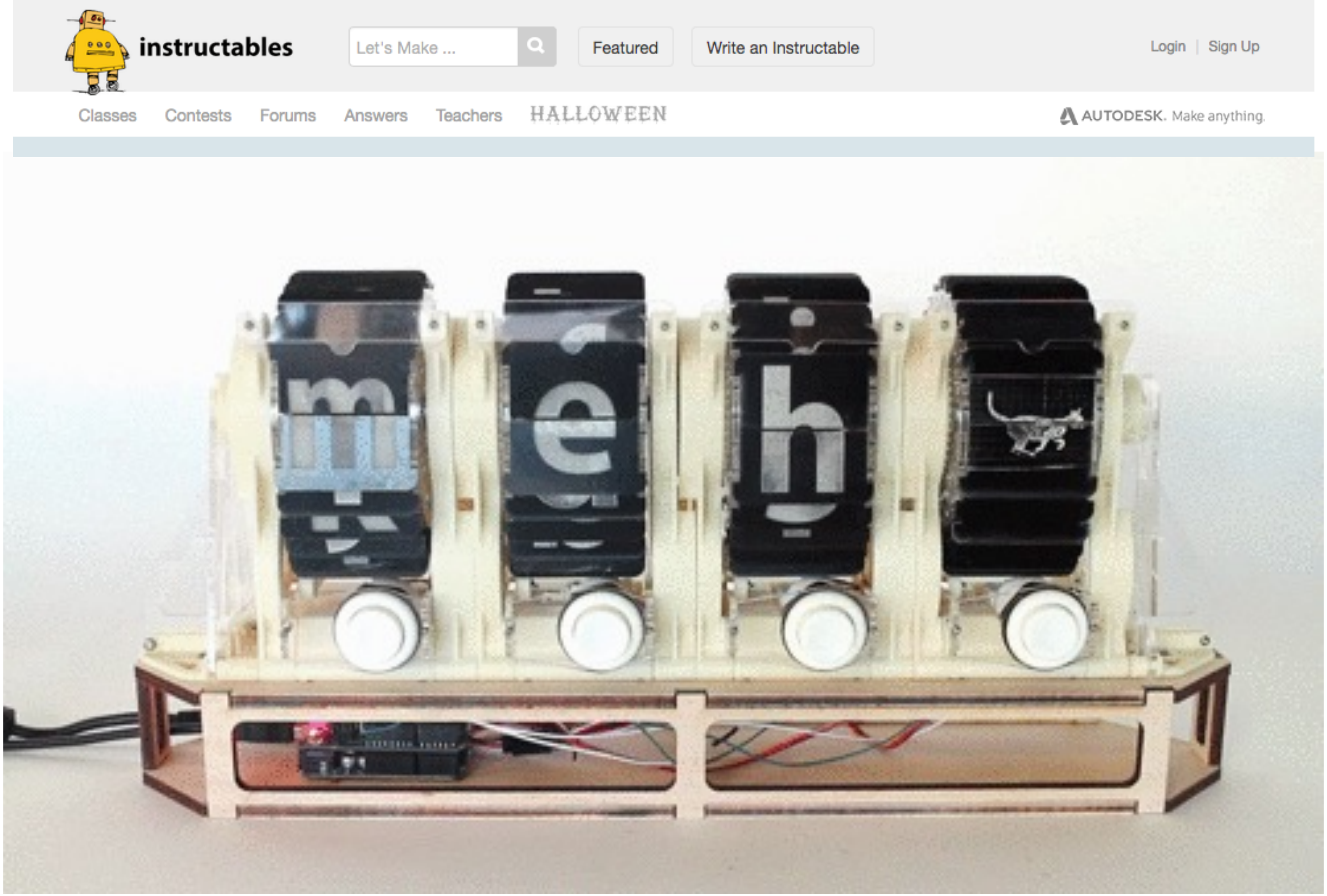




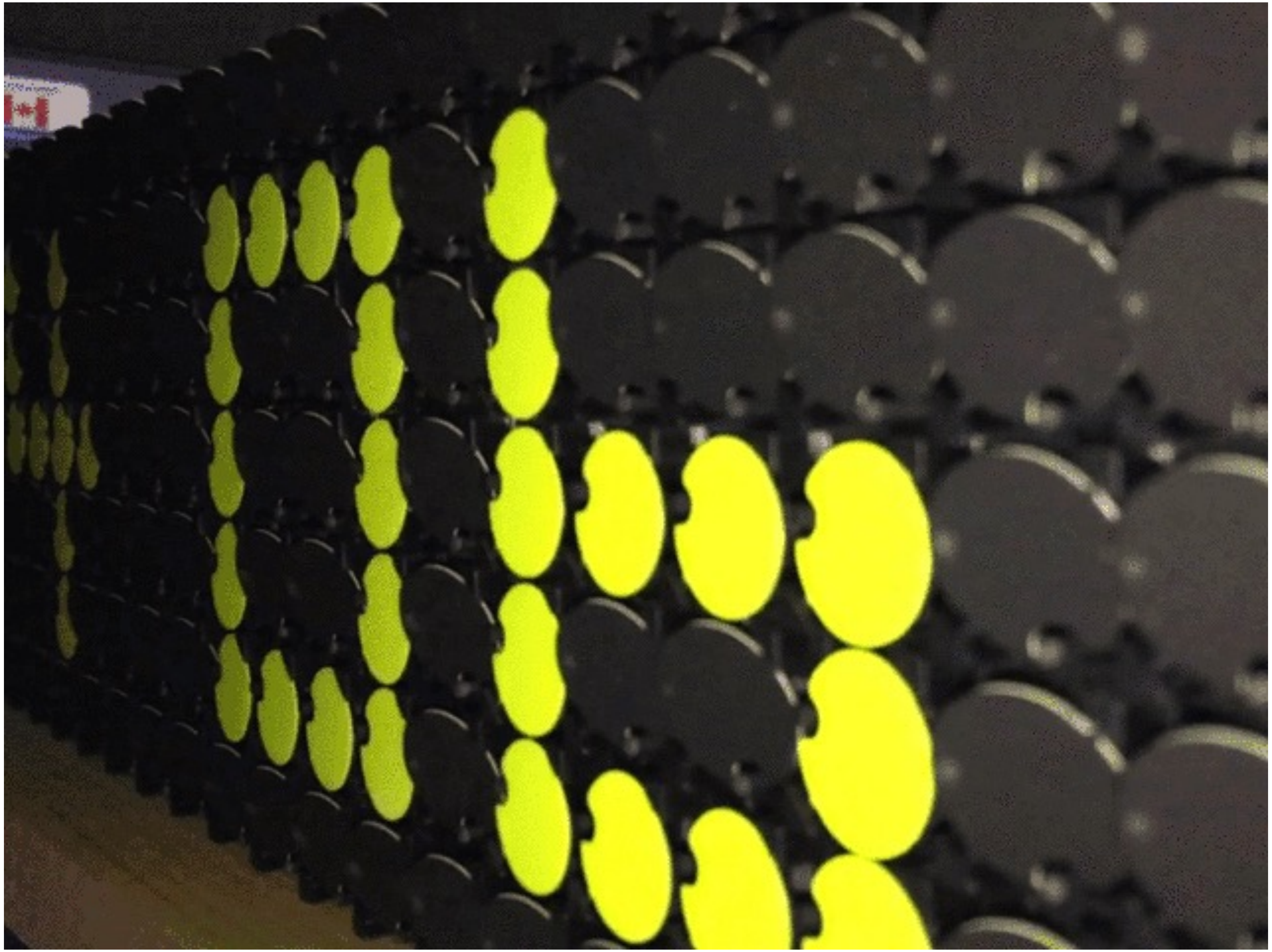
The characters are split between two flaps

the flaps are hinged on a rotating spool

there's a catch at the top to keep the upper flap from falling down

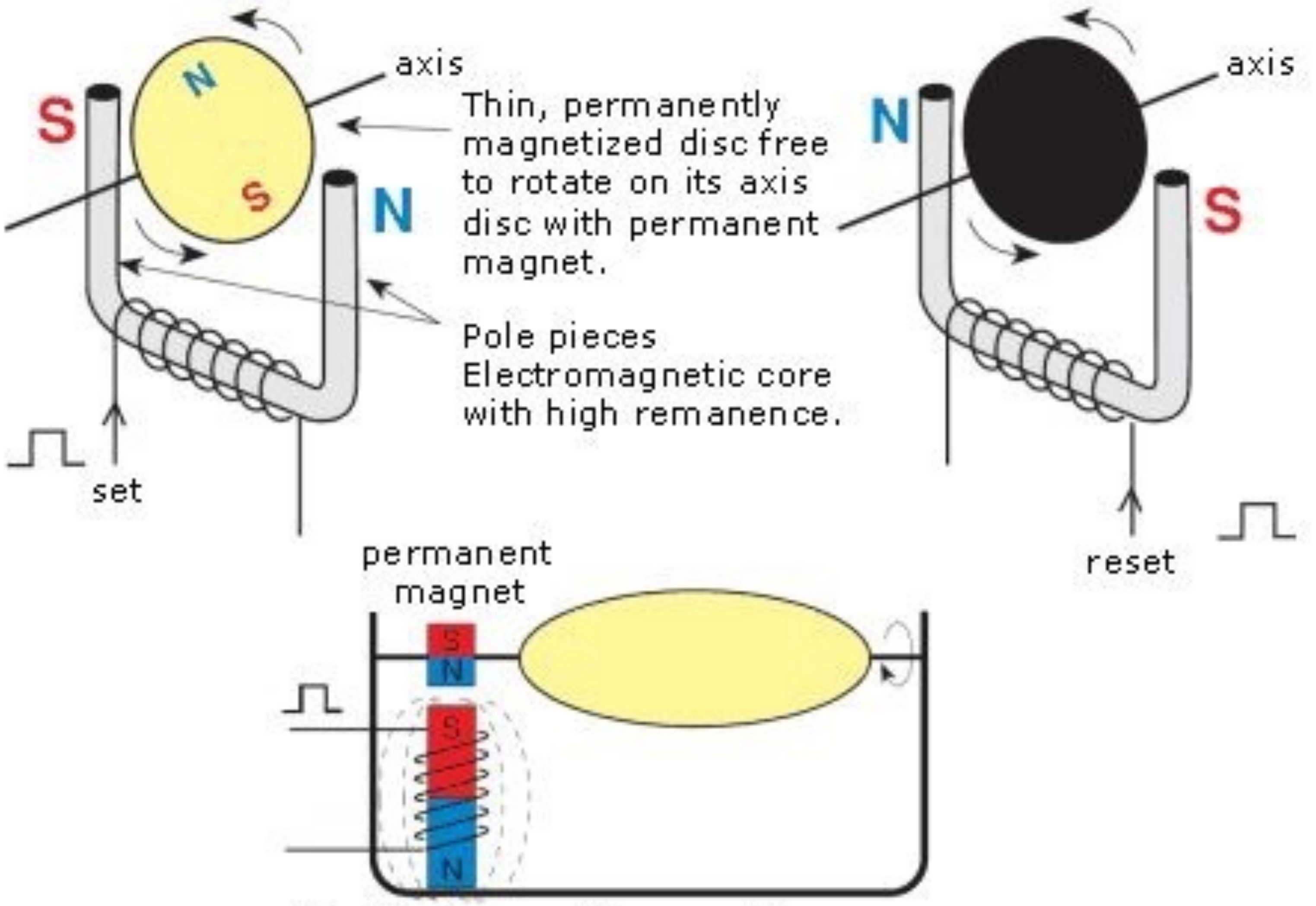


http://www.instructables.com/id/Split-Flap-Display/



1961 flip-disc display (electro-magnetic)

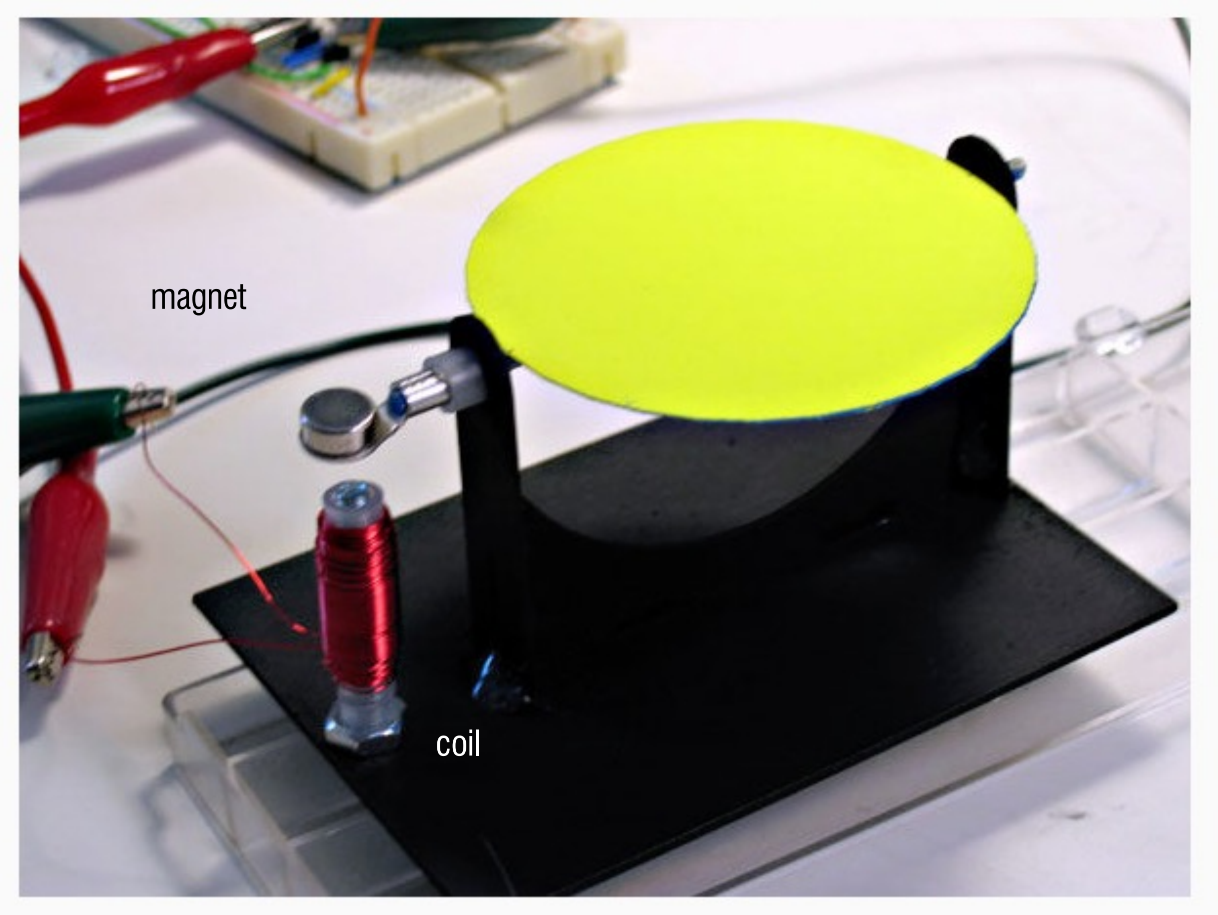
100 µs to 1 ms pulse depending on coil type



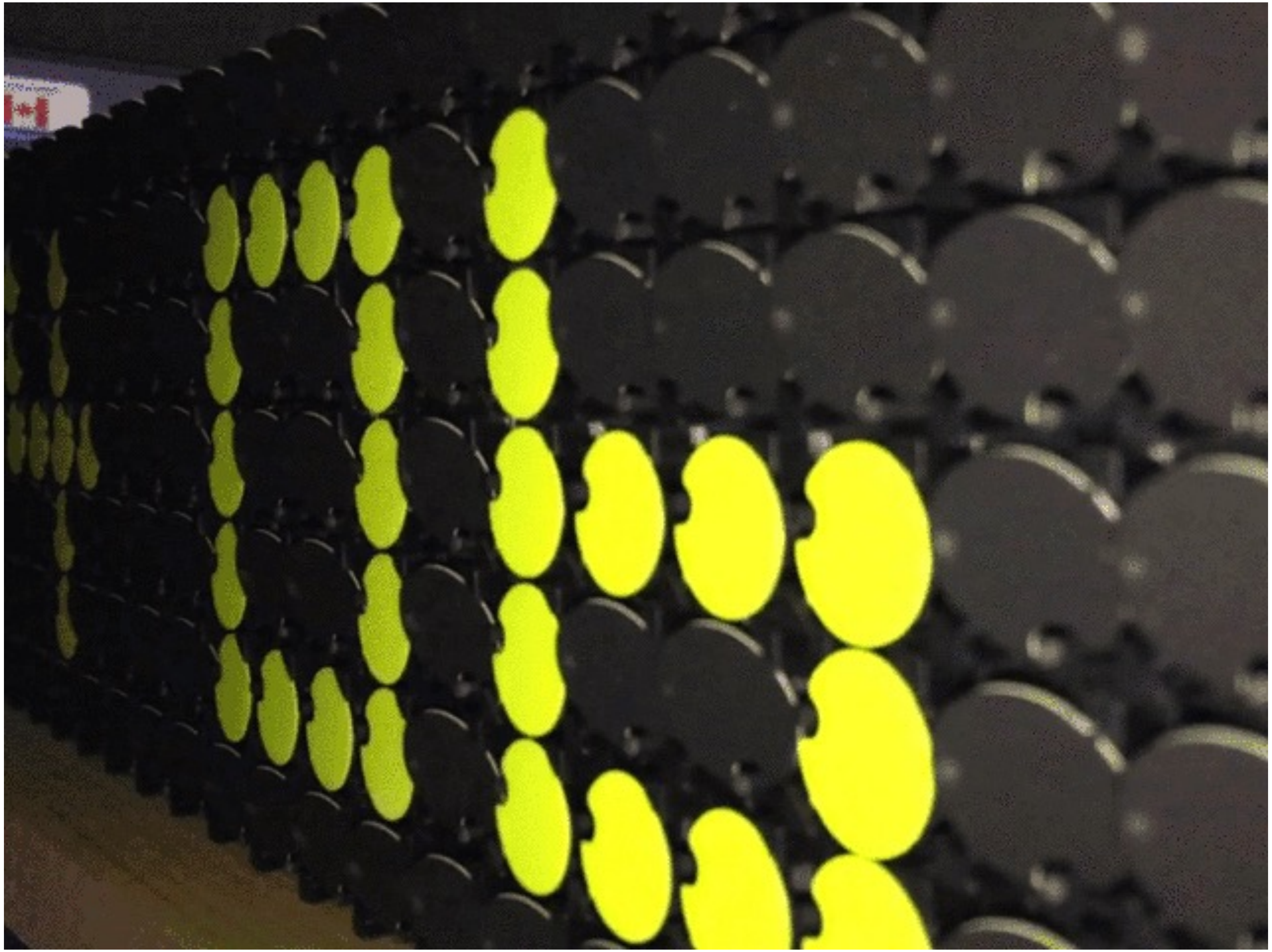
Thin, permanently magnetized disc free to rotate on its axis disc with permanent magnet.

Pole pieces Electromagnetic core with high remanence.

Residual magnetism provides memory.


magnet
coil

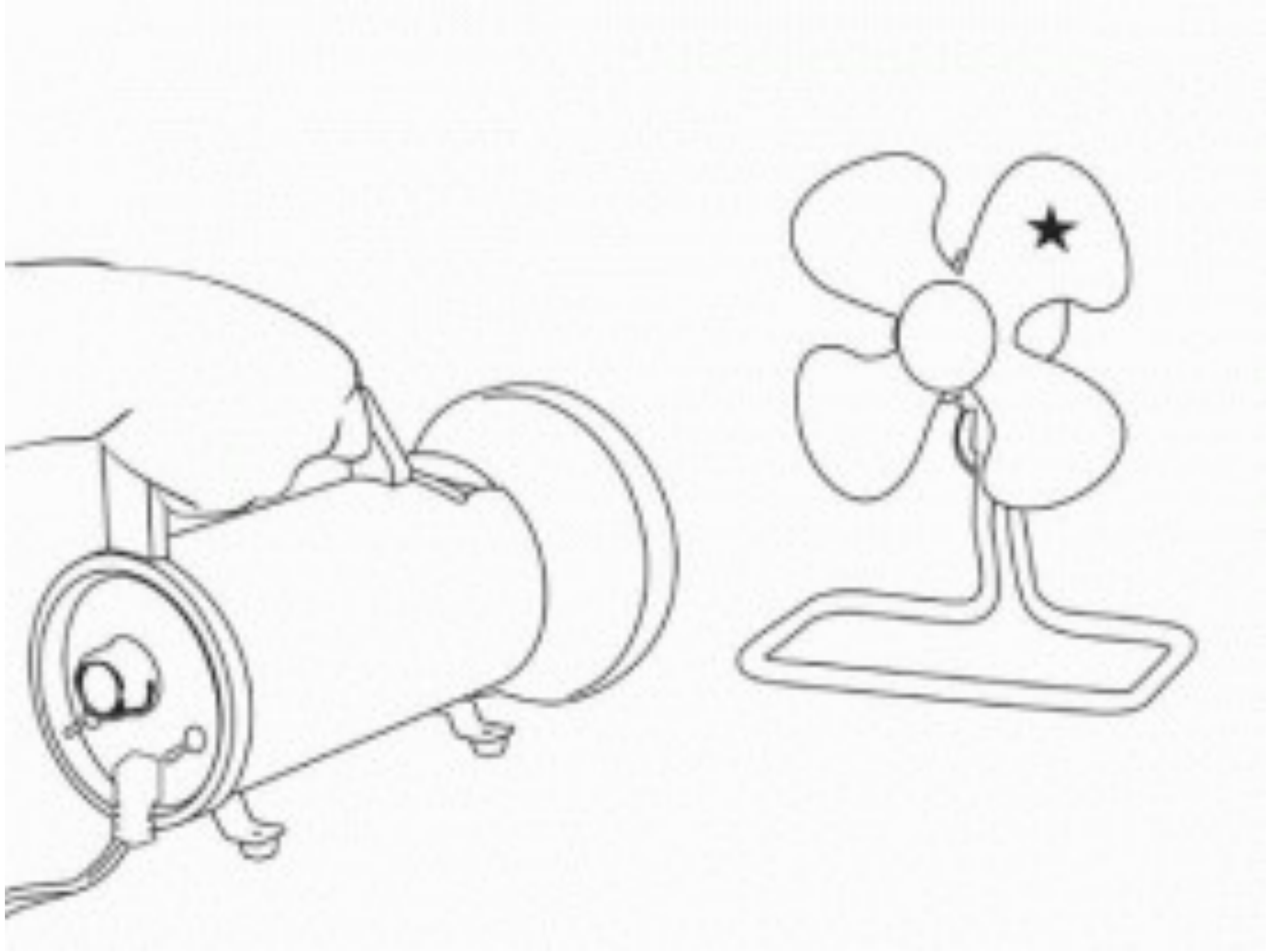
how would you build a equivalent “light pen” input for this?



(1968)

stroboscopic display

1960s stroboscopic displays:
rotating cylinder, but it appears to be standing still

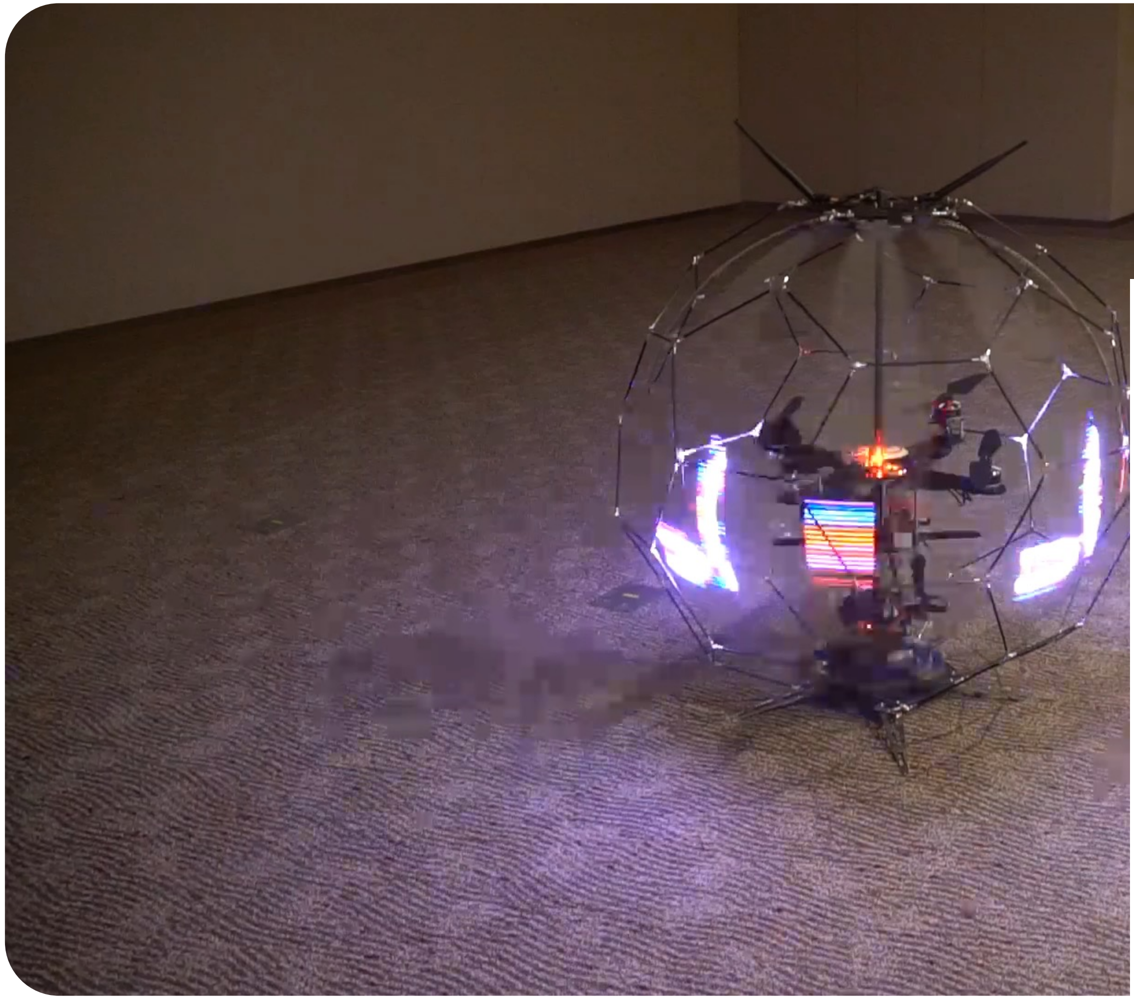


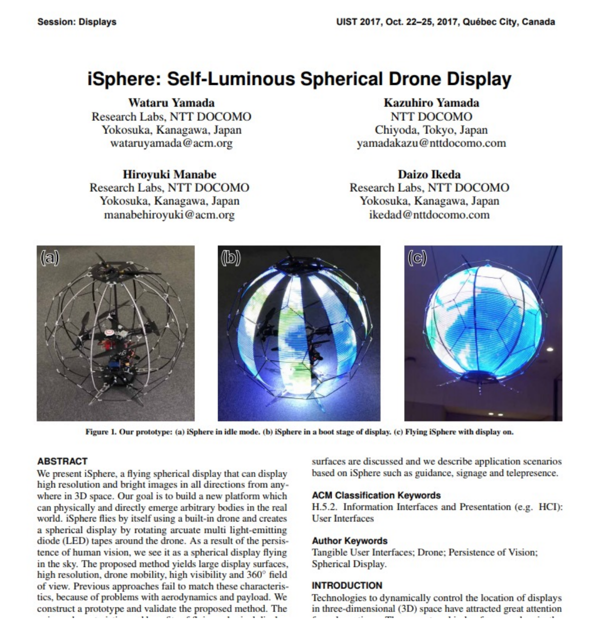
stroboscopic effect

series of intense light flashes at specific intervals
emitted onto an object that rotates at high speed
makes the object appear to stand still
if you have one flash per turn, you see the actual number of fan blades

Art installation

Floating sphere display





Session: Displays UIST 2017, Oct. 22–25, 2017, Québec City, Canada

iSphere: Self-Luminous Spherical Drone Display

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Figure 1. Our prototype: (a) iSphere in idle mode. (b) iSphere in a boot stage of display. (c) Flying iSphere with display on.

ABSTRACT

We present iSphere, a flying spherical display that can display high resolution and bright images in all directions from anywhere in 3D space. Our goal is to build a new platform which can physically and directly emerge arbitrary bodies in the real world. iSphere flies by itself using a built-in drone and creates a spherical display by rotating arcuate multi light-emitting diode (LED) tapes around the drone. As a result of the persistence of human vision, we see it as a spherical display flying in the sky. The proposed method yields large display surfaces, high resolution, drone mobility, high visibility and 360° field of view. Previous approaches fail to match these characteristics, because of problems with aerodynamics and payload. We construct a prototype and validate the proposed method. The

surfaces are discussed and we describe application scenarios based on iSphere such as guidance, signage and telepresence.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

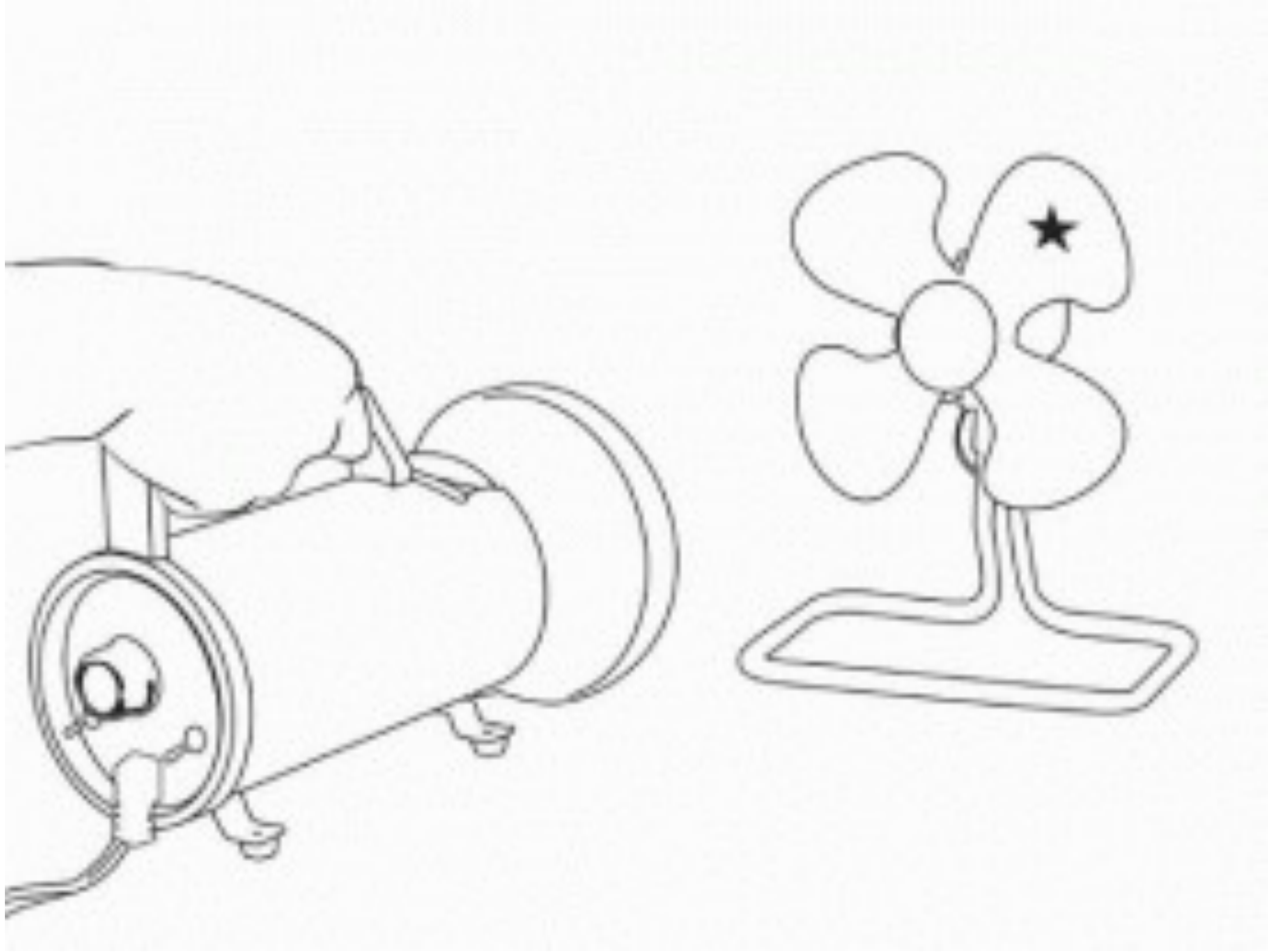
Author Keywords
Tangible User Interfaces; Drone; Persistence of Vision; Spherical Display.

INTRODUCTION

Technologies to dynamically control the location of displays in three-dimensional (3D) space have attracted great attention

UIST 17
Yamada et.al.

Limitation?



BloomBeacon: Blooming Physical Touch Display Surfaces via Persistence-of-Vision Motion

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Figure 1: (a) BloomBeacon is a mobile, expansive touch display based on Persistence-of-Vision motion that 'blooms' from soft, line-like blades. When inactive, it is relatively compact, allowing it to be (b) easily placed in the environment. (c) When blooming, a touch surface emerges from the line. (d-e) A series of studies was conducted to investigate the key factors that affect touch-sensing performance and user experience.

Abstract

We explore how a display surface can physically emerge on demand to support both mid-air visualization and direct touch interaction. We introduce blooming, a concept that repurposes Persistence-of-Vision (POV) motion to deploy a large, touchable surface from a compact, relocatable device. Using a soft, rotating line with arch-shaped electrodes, our system renders dynamic mid-air visuals while enabling direct touch input on the manifested surface. Realizing this concept requires addressing the unique challenges of touching spinning elements, including ensuring safety, minimizing disturbances to rotation caused by touch, and detecting brief unstable touches during spinning. We present a safety-oriented device design, special blades effective in minimizing finger disturbance, and optimization techniques tailored to transient, noisy touches. We also reveal how rotation speed and electrode height significantly affect sensing accuracy and user experience. Finally, we demonstrate applications that show how blooming touch displays can flexibly augment everyday objects and environments.

CCS Concepts

• **Human-centered computing → Touch screens**.

Keywords

Mid-Air Display, Direct Touch, Persistence-of-Vision Display, Environmental Augmentation

ACM Reference Format:
Willa Yunqi Yang, Justice T Andersen, David Dajun Yuan, and Ken Nakagaki. 2026. BloomBeacon: Blooming Physical Touch Display Surfaces via Persistence-of-Vision Motion. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems (CHI '26), April 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 19 pages. https://doi.org/10.1145/3772318.3790357

1 Introduction

How can we make display surfaces *physically emerge* on demand—not only to display information but also to support *direct touch* interaction? Science fiction movies have long envisioned such scenarios. For example, as illustrated in *Iron Man*'s workshop[1] or Black Panther's wrist UI[2], mid-air display surfaces appear from a single point to dynamically display information while providing touch interaction, and collapse when not in use.

Mid-air display technologies (e.g., employing fog/mist [5, 21, 30, 34], water droplets [10], and styrofoam particles [46]) have

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*Contributed equally to this work.

[1] Iron Man 2

[2] Black Panther: Wakanda Forever

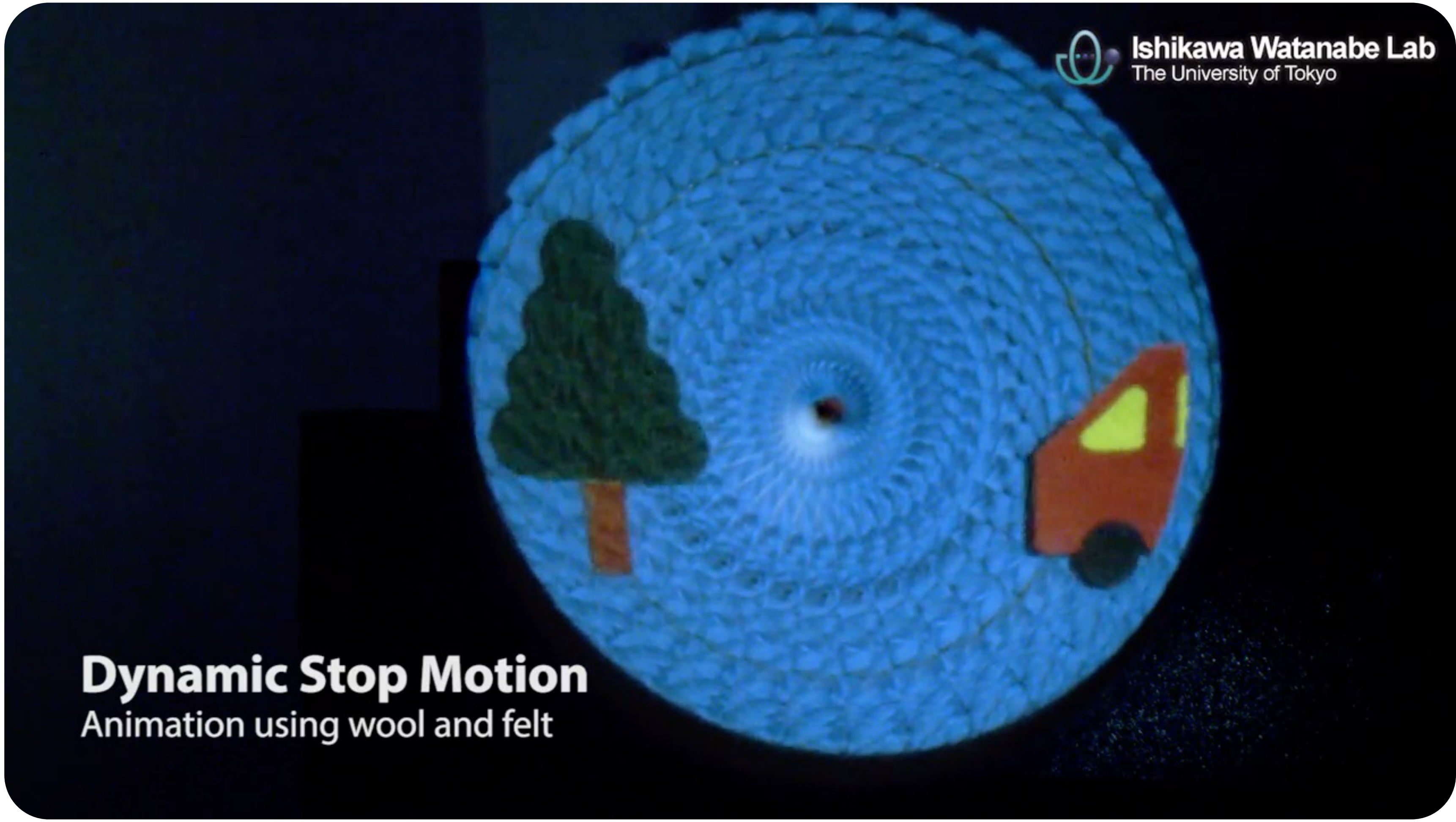
CHI '26, Barcelona, Spain

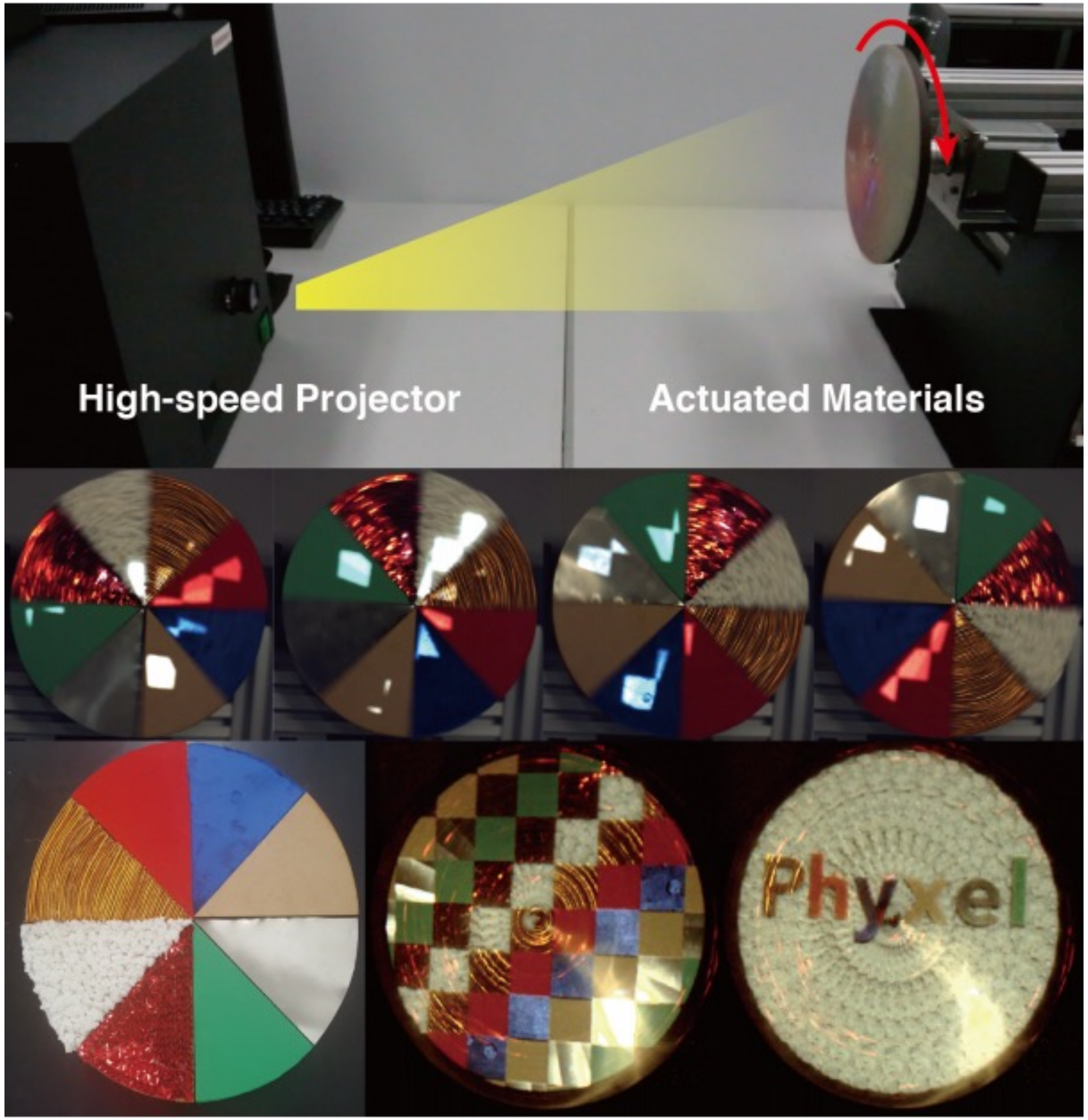
ACM ISBN 979-8-4007-2278-3/26/04
https://doi.org/10.1145/3772318.3790357

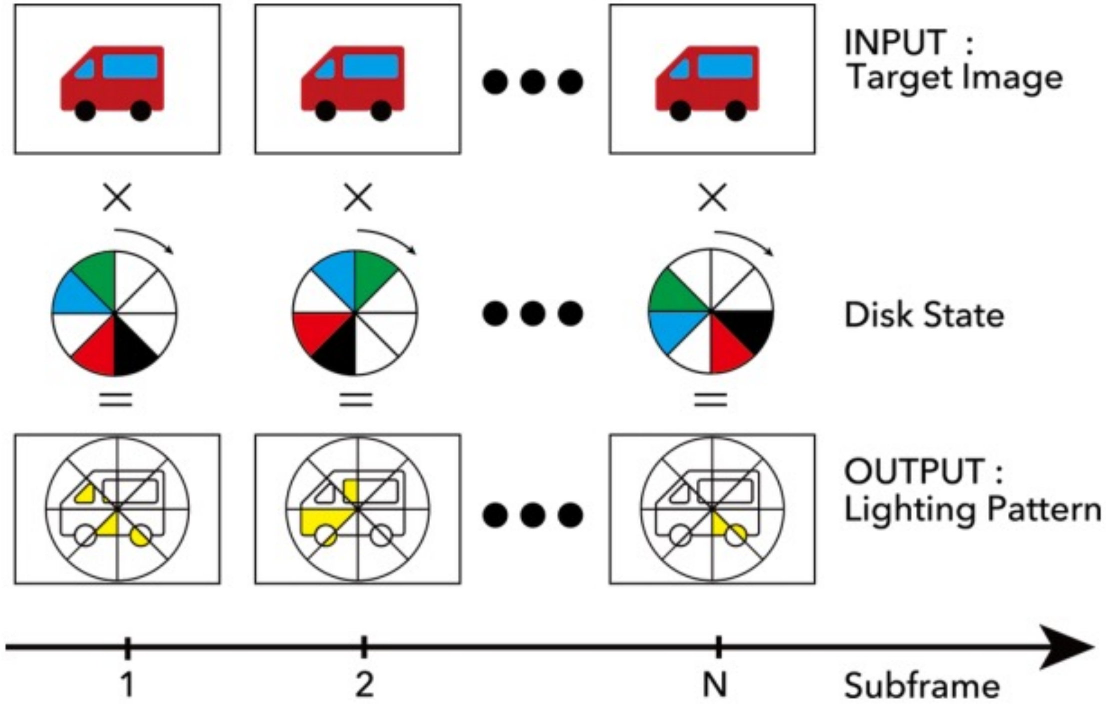
CHI 26
Yang et.al.

What if we apply to objects with different textures?

yes this is real wool and real felt.
any idea how this works?






INPUT :
Target Image

×

Disk State

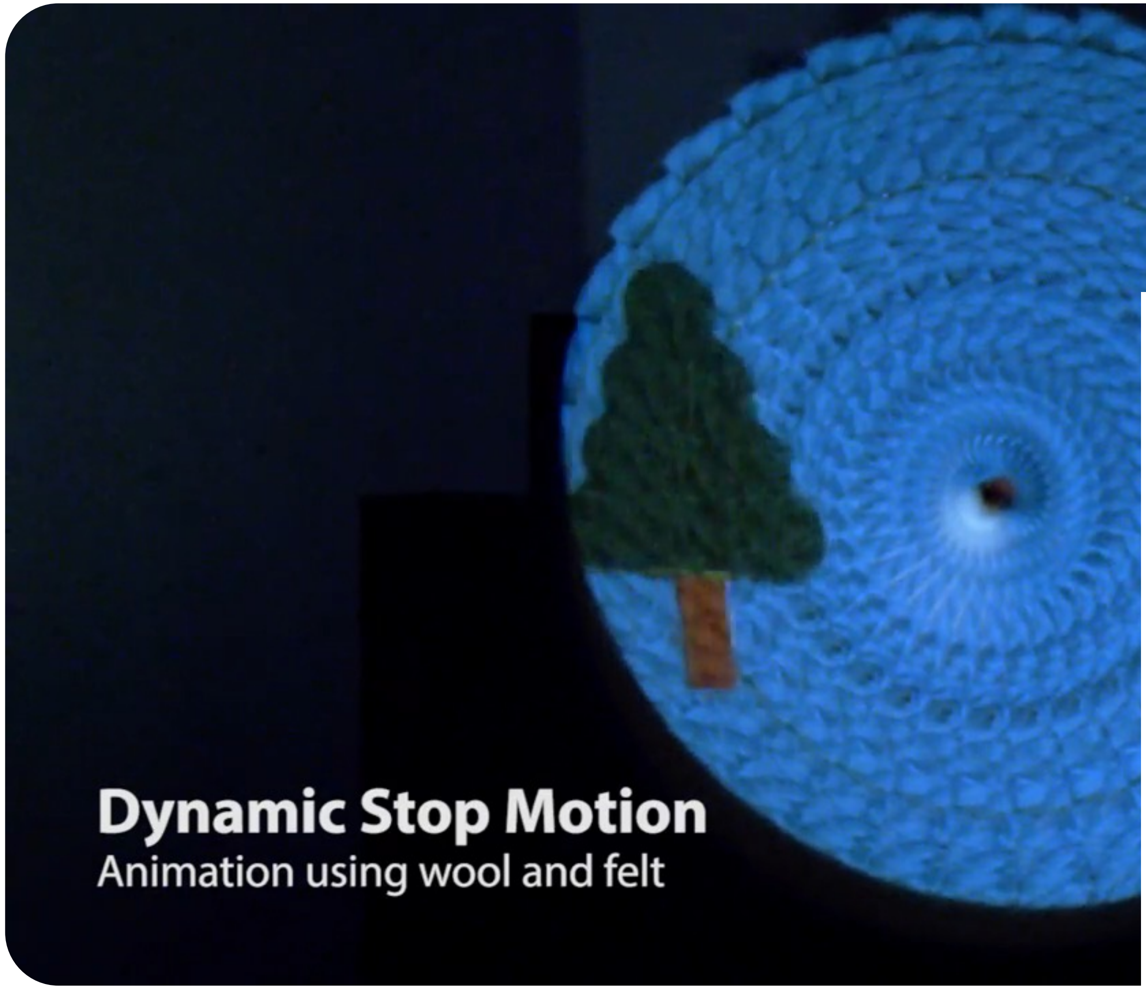
=

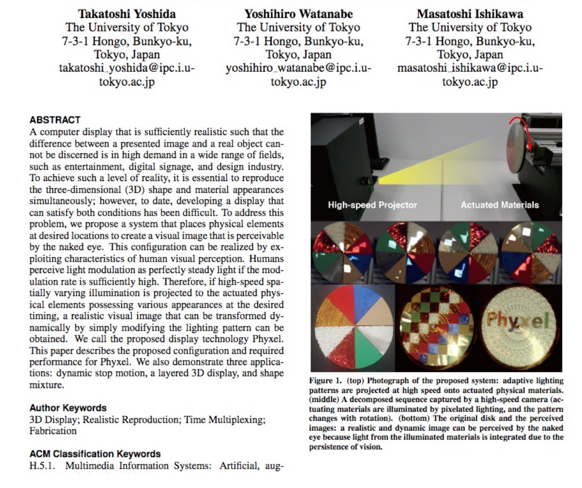
OUTPUT :
Lighting Pattern

1
2
N
Subframe

Rendering shape with **real** material

Remix **real** physical objects





Phyxel: Realistic Display of Shape and Appearance using Physical Objects with High-speed Pixelated Lighting

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ABSTRACT

A computer display that is sufficiently realistic such that the difference between a presented image and a real object cannot be discerned is in high demand in a wide range of fields, such as entertainment, digital signage, and design industry. To achieve such a level of reality, it is essential to reproduce the three-dimensional (3D) shape and material appearances simultaneously; however, to date, developing a display that can satisfy both conditions has been difficult. To address this problem, we propose a system that places physical elements at desired locations to create a visual image that is perceivable by the naked eye. This configuration can be realized by exploiting characteristics of human visual perception. Humans perceive light modulation as perfectly steady light if the modulation rate is sufficiently high. Therefore, if high-speed spatially varying illumination is projected to the actuated physical elements possessing various appearances at the desired timing, a realistic visual image that can be transformed dynamically by simply modifying the lighting pattern can be obtained. We call the proposed display technology Phyxel. This paper describes the proposed configuration and required performance for Phyxel. We also demonstrate three applications: dynamic stop motion, a layered 3D display, and shape mixture.

Author Keywords
3D Display; Realistic Reproduction; Time Multiplexing; Fabrication

ACM Classification Keywords
H.5.1. Multimedia Information Systems: Artificial, aug-

Figure 1. (top) Photograph of the proposed system: adaptive lighting patterns are projected at high speed onto actuated physical materials. (middle) A decomposed sequence captured by a high-speed camera (actuating materials are illuminated by pixelated lighting, and the pattern changes with rotation). (bottom) The original disk and the perceived images: a realistic and dynamic image can be perceived by the naked eye because light from the illuminated materials is integrated due to the persistence of vision.

UIST 16
Yoshida et.al.

(1971)

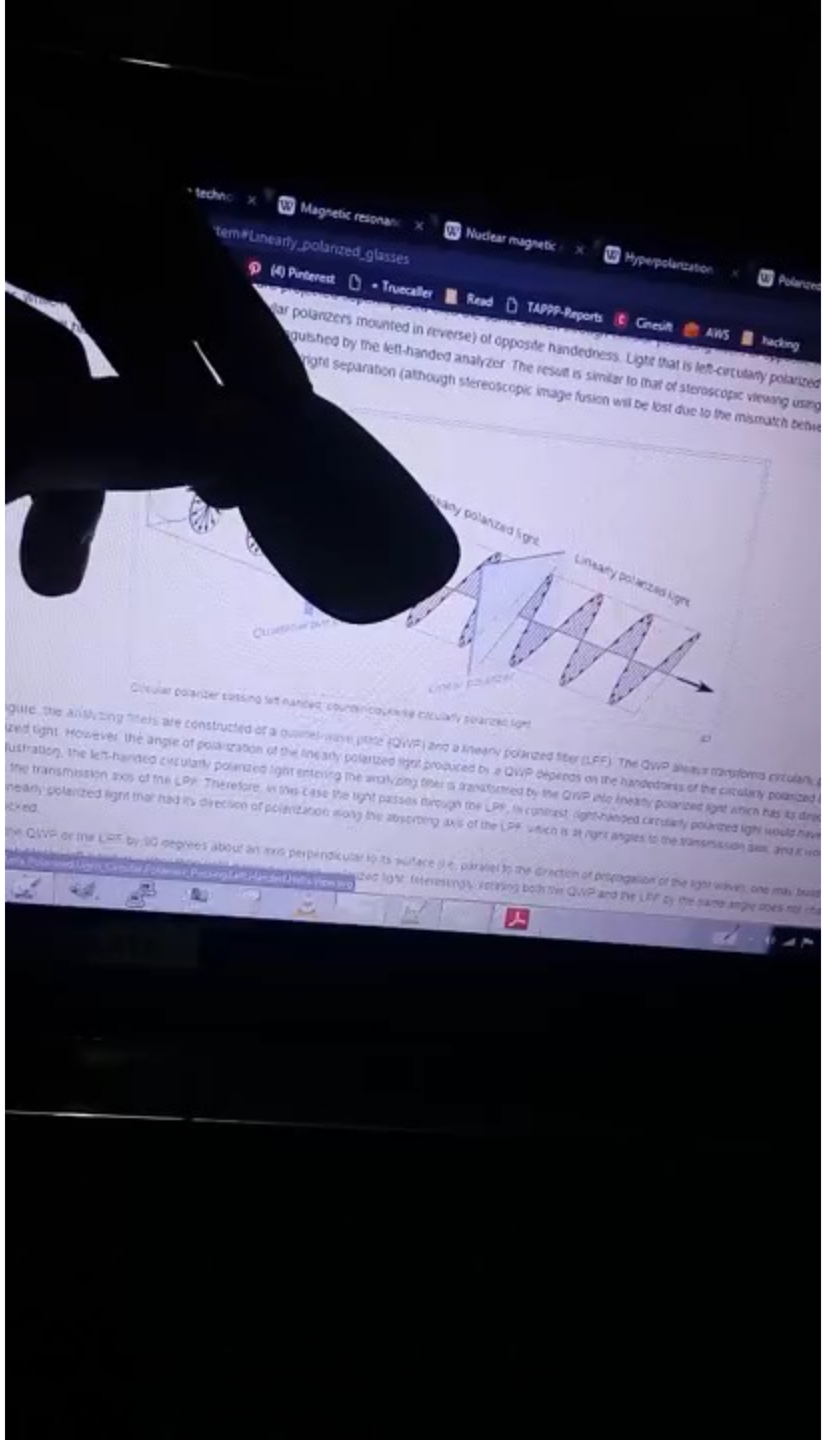
liquid crystal display

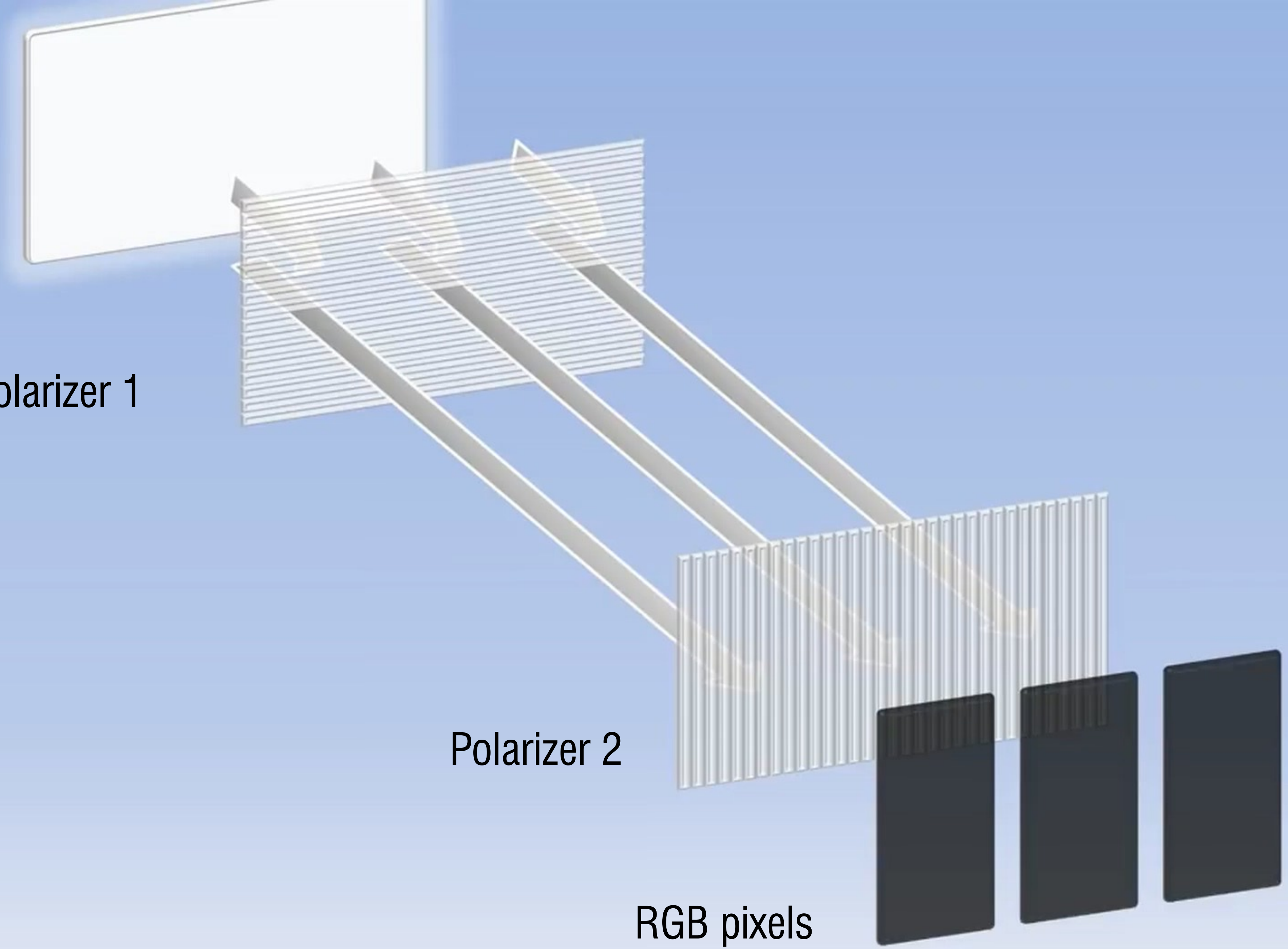
liquid crystal display

polarizer

optical filter
lets light waves of a specific polarization pass
blocks light waves of other polarizations

liquid crystals acts as a polarizer switch!



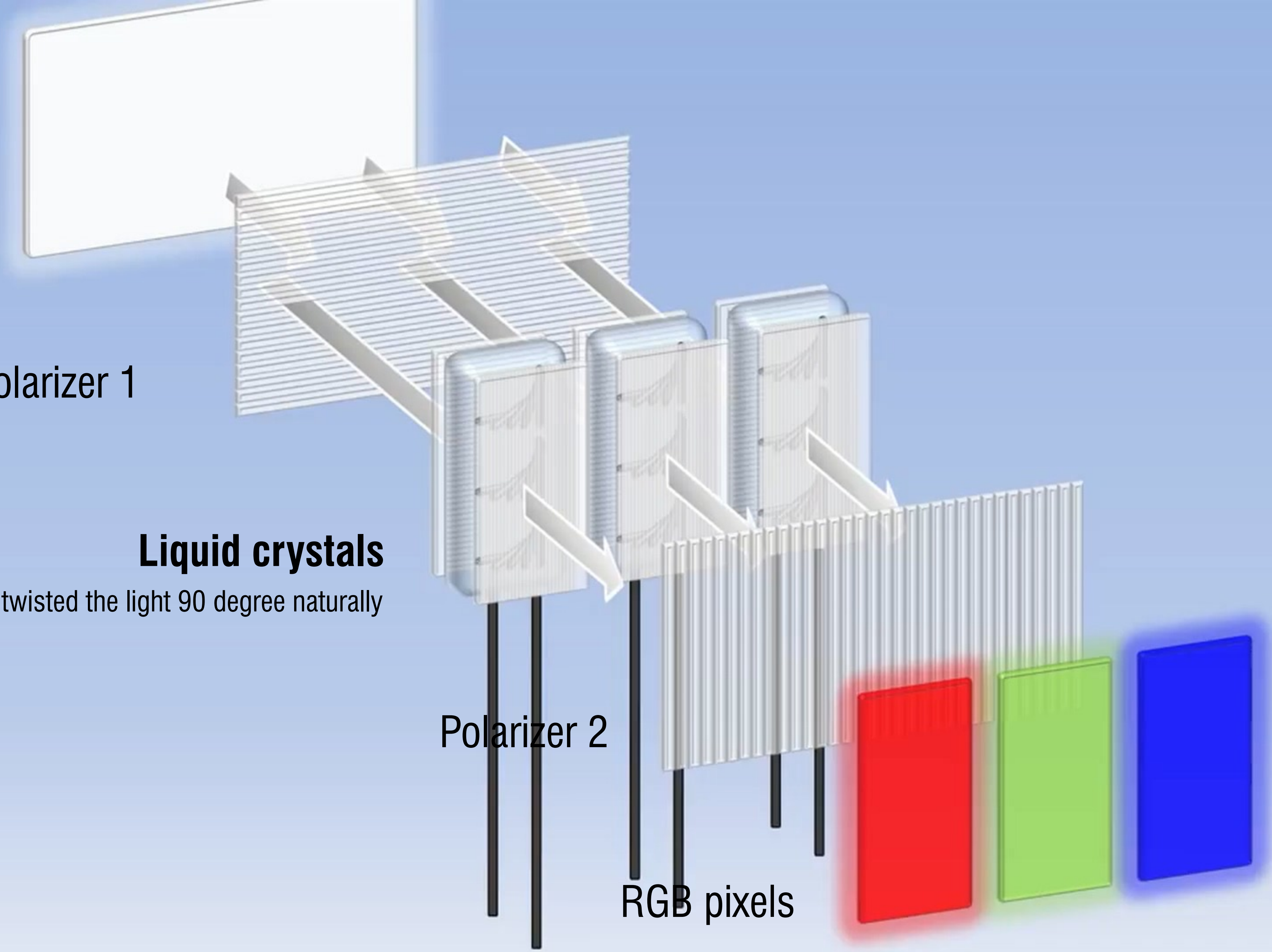


Light panel

Polarizer 1

Polarizer 2

RGB pixels



Light panel

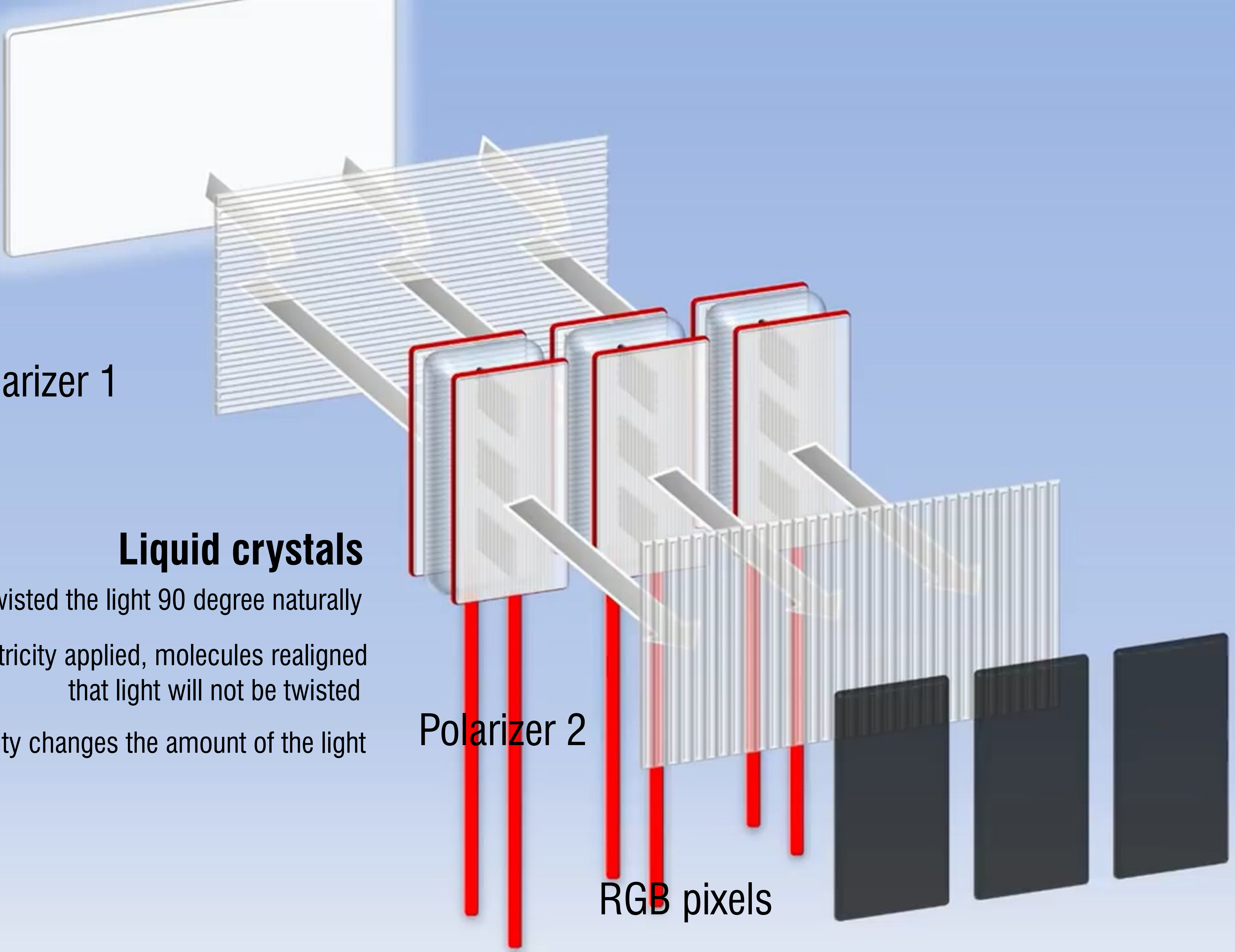
Polarizer 1

Liquid crystals

twisted the light 90 degree naturally

Polarizer 2

RGB pixels



Liquid crystals

twisted the light 90 degree naturally

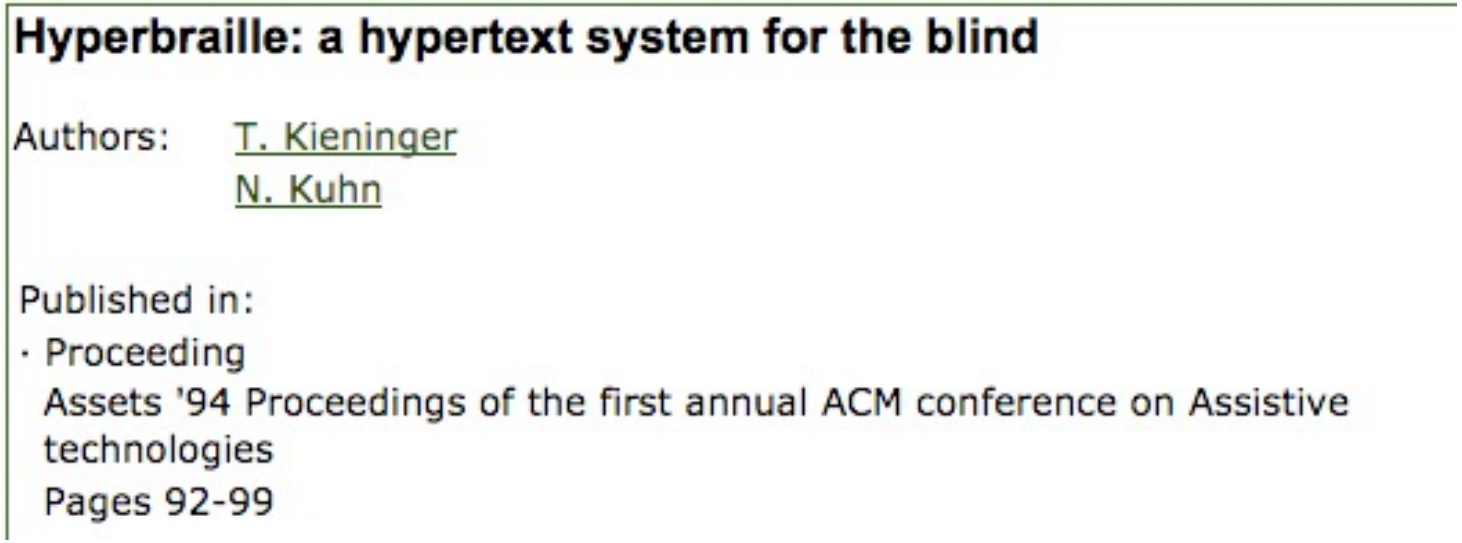
when electricity applied, molecules realigned
that light will not be twisted

control the electricity changes the amount of the light

(1969)

braille display / pin screen

1969 braille display for the blind and visually impaired

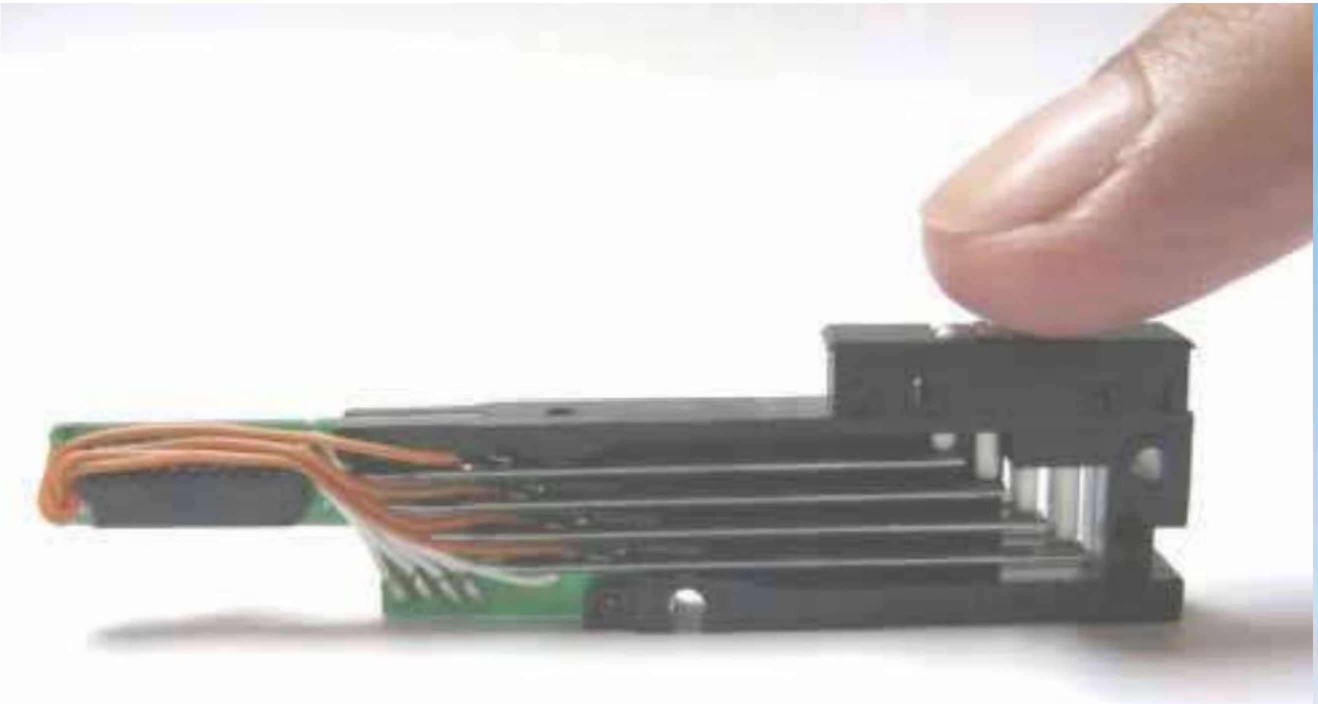


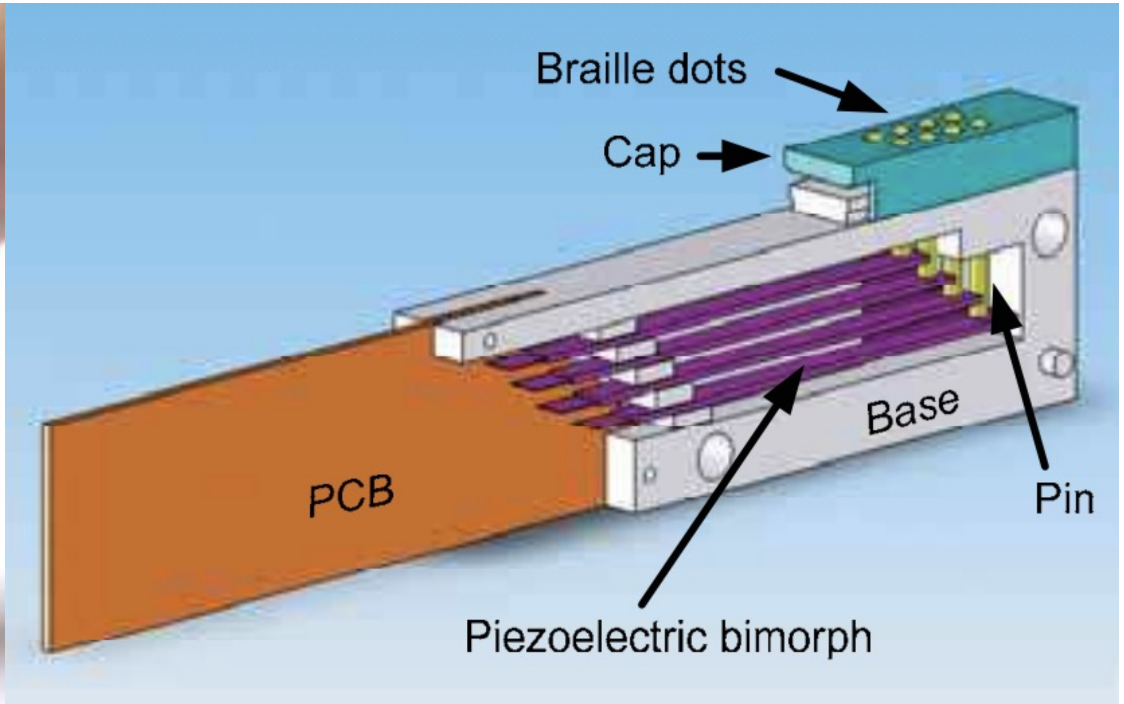
Hyperbraille: a hypertext system for the blind

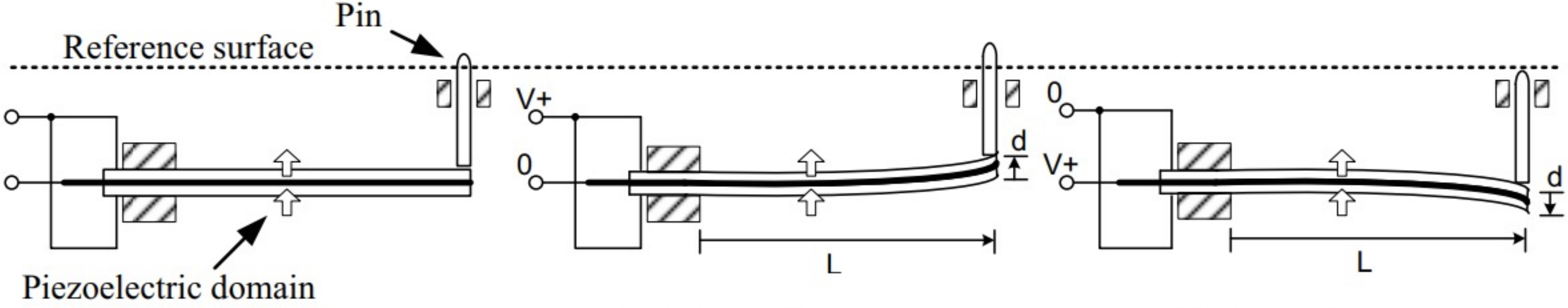
Authors: T. Kieninger
N. Kuhn

Published in:
- Proceeding
  Assets '94 Proceedings of the first annual ACM conference on Assistive technologies
  Pages 92-99

much later 1994: HyperBraille
(allows blind users to browse the internet)

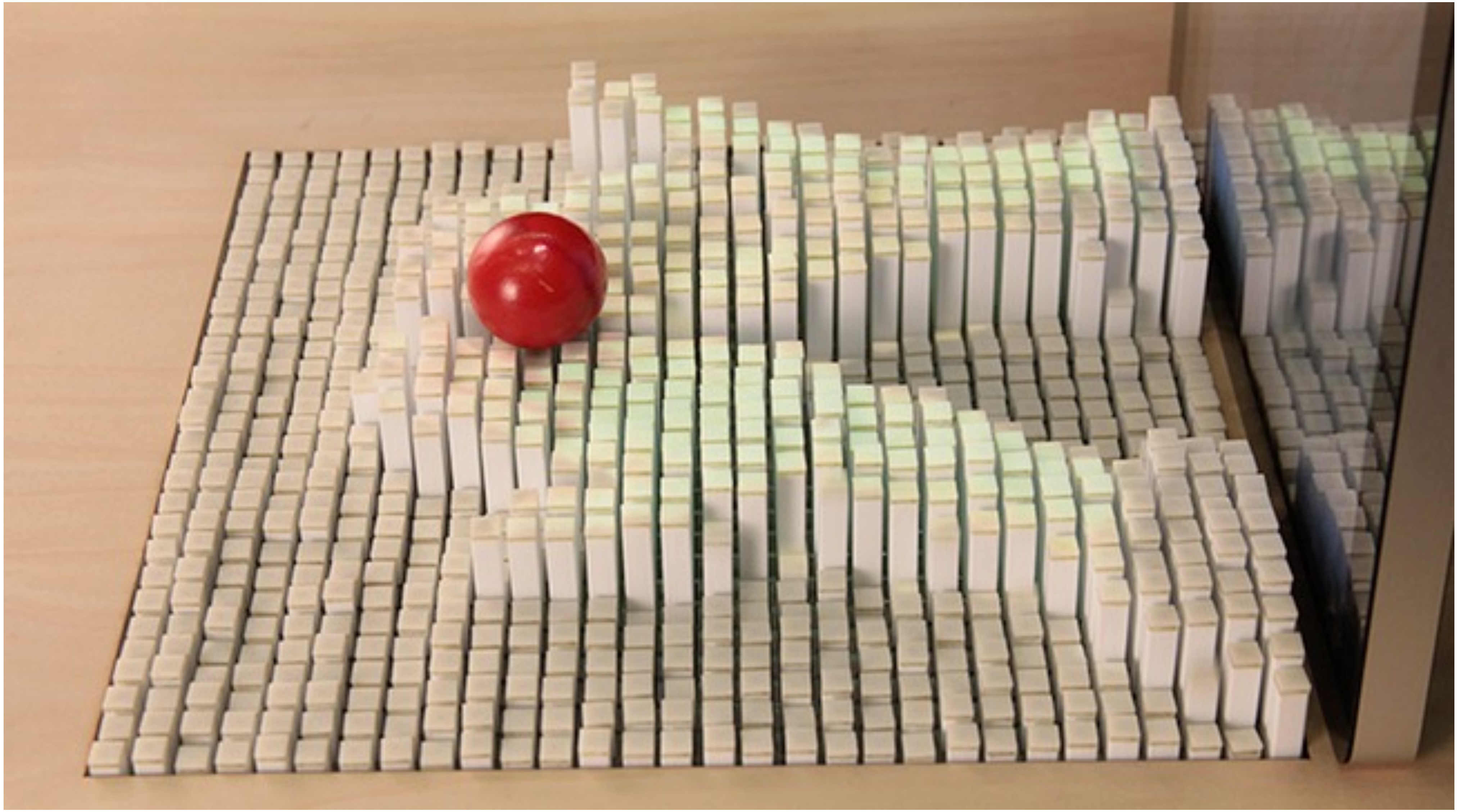






a) Normal position b) Rise position c) Fall position

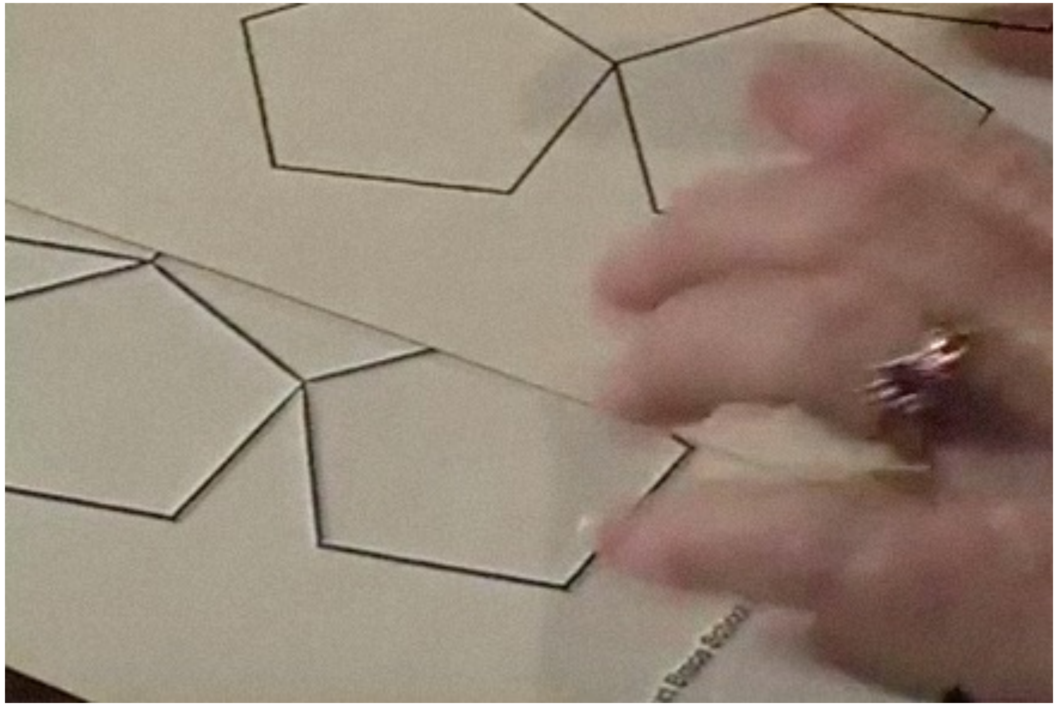
What if we scale it up?



was the inspiration for some newer tech…

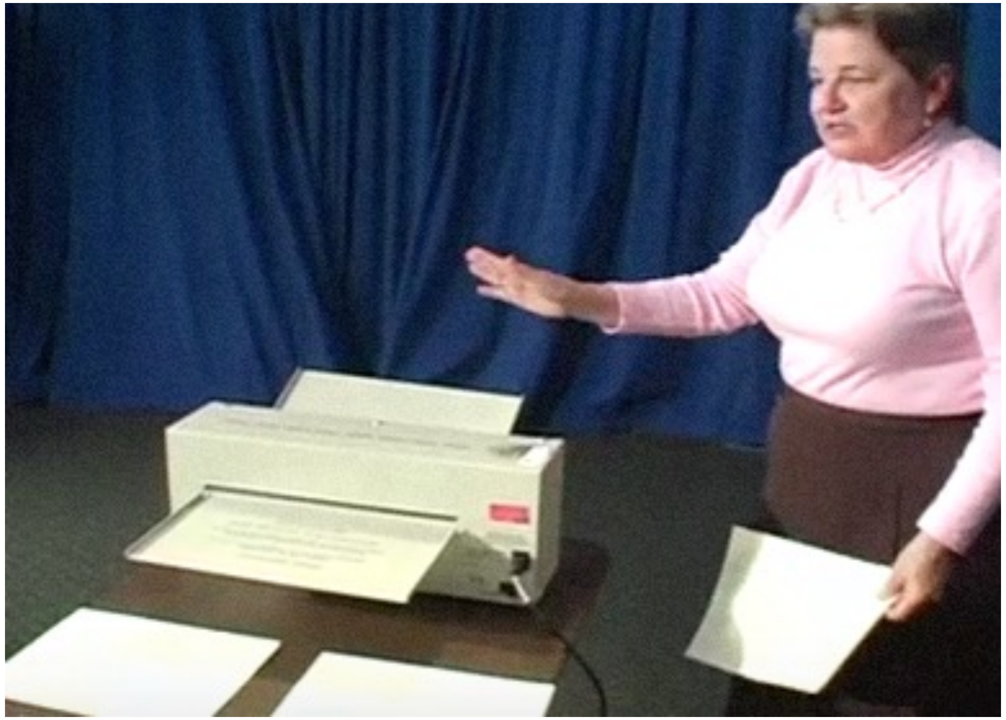
this is very expensive… $10,000+
how would you build a **cheaper** tactile interactive display?

swell paper

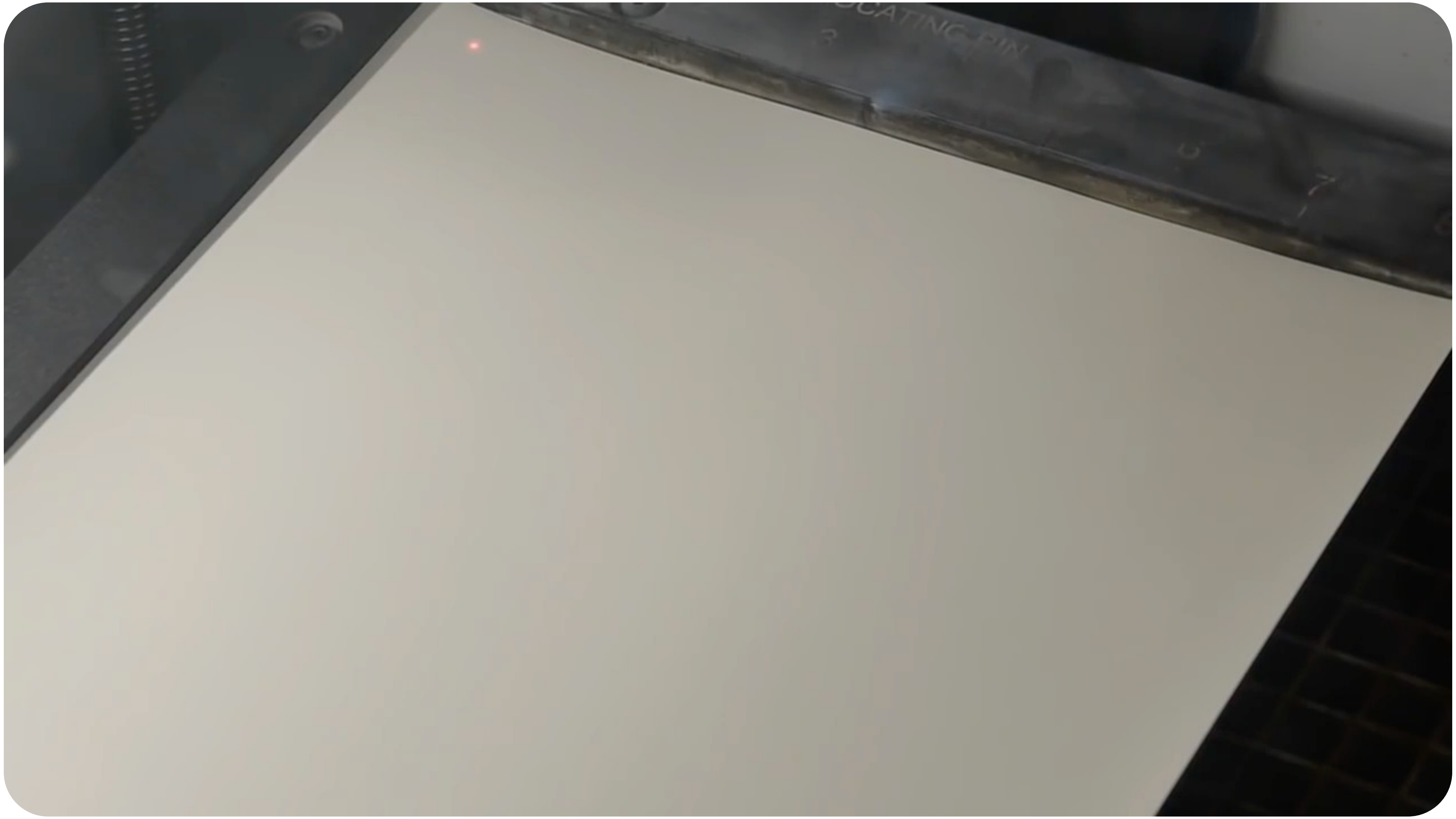


create black line drawing

->



put in heater
only black lines
attract heat & swell



swell paper + laser cutter (almost 0% power + defocus)

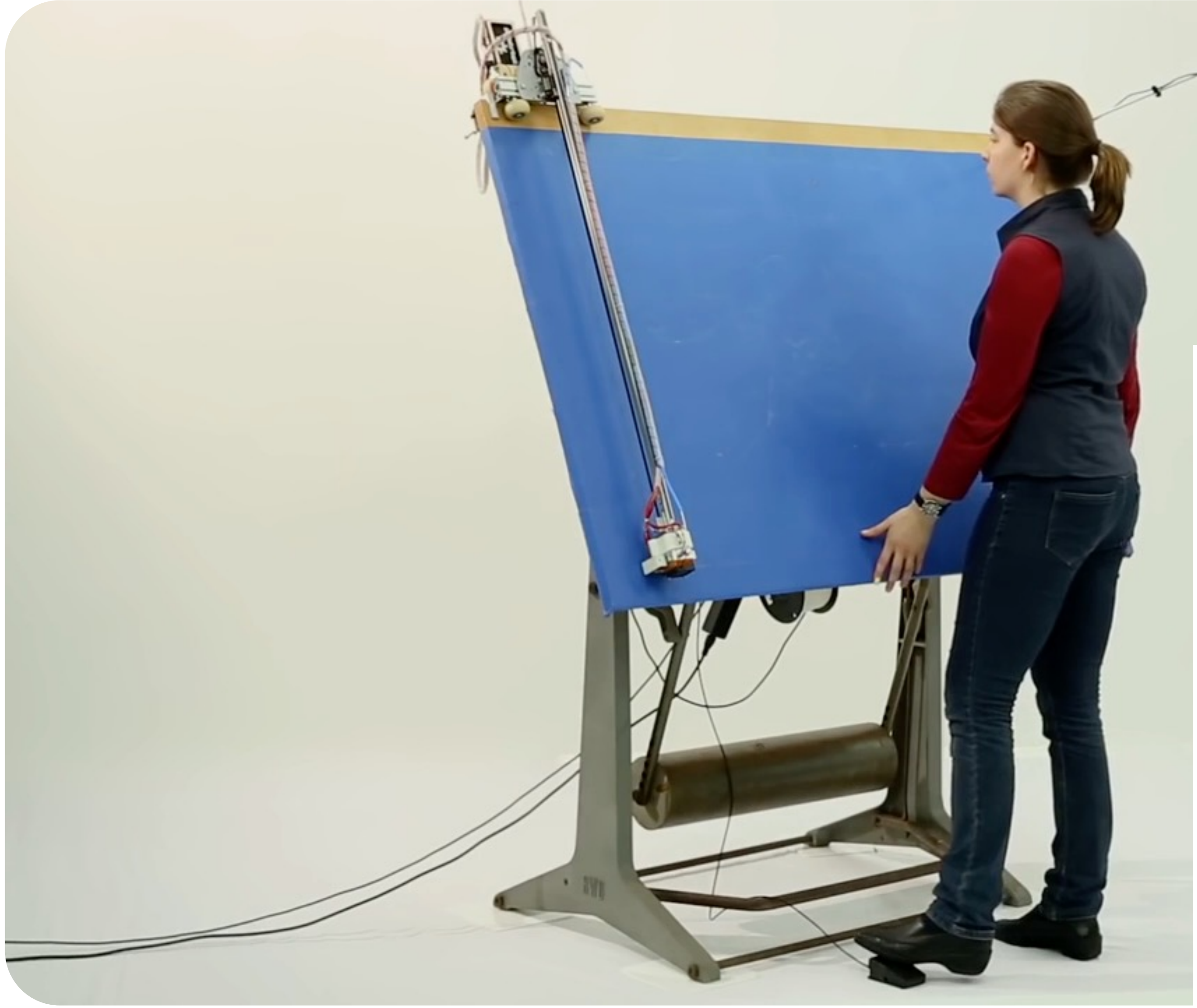
Can we make the “display” **refreshable**?

use a 3D printer!

Printed lines offer haptic feedback

Large space so no need for fast refresh rate

Printed line can be removed off



Visual Impairment and Technology #chi4good, CHI 2016, San Jose, CA, USA

Linespace: A Sensemaking Platform for the Blind

Saiganesh Swaminathan, Thijs Roumen, Robert Kovacs,
David Stangl, Stefanie Mueller, and Patrick Baudisch
Hasso Plattner Institute, Potsdam, Germany
{firstname.lastname}@hpi.de

ABSTRACT

For visually impaired users, making sense of spatial information is difficult as they have to scan and memorize content before being able to analyze it. Even worse, any update to the displayed content invalidates their spatial memory, which can force them to manually rescan the entire display. Making display contents persist, we argue, is thus the highest priority in designing a sensemaking system for the visually impaired. We present a tactile display system designed with this goal in mind. The foundation of our system is a large tactile display (140x100cm, 23x larger than *Hyperbraille*), which we achieve by using a 3D printer to print raised lines of filament. The system's software then uses the large space to minimize screen updates. Instead of panning and zooming, for example, our system creates additional views, leaving display contents intact and thus preserving user's spatial memory. We illustrate our system and its design principles at the example of four spatial applications. We evaluated our system with six blind users. Participants responded favorably to the system and expressed, for example, that having multiple views at the same time was helpful. They also judged the increased expressiveness of lines over the more traditional dots as useful for encoding information.

Author Keywords: 3D printing; accessibility.

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

INTRODUCTION

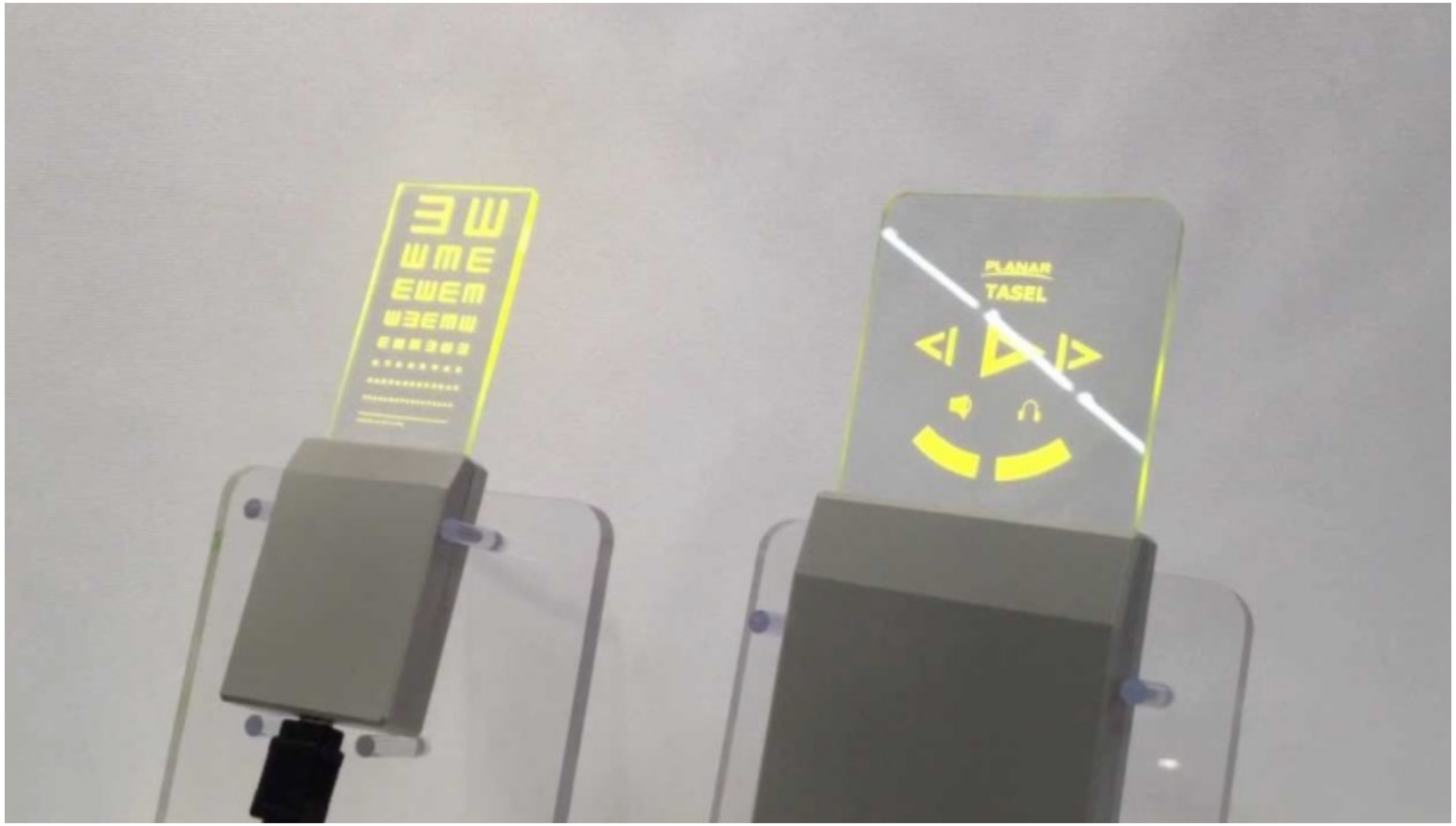
For visually impaired users, making sense of spatial infor-

CHI 16

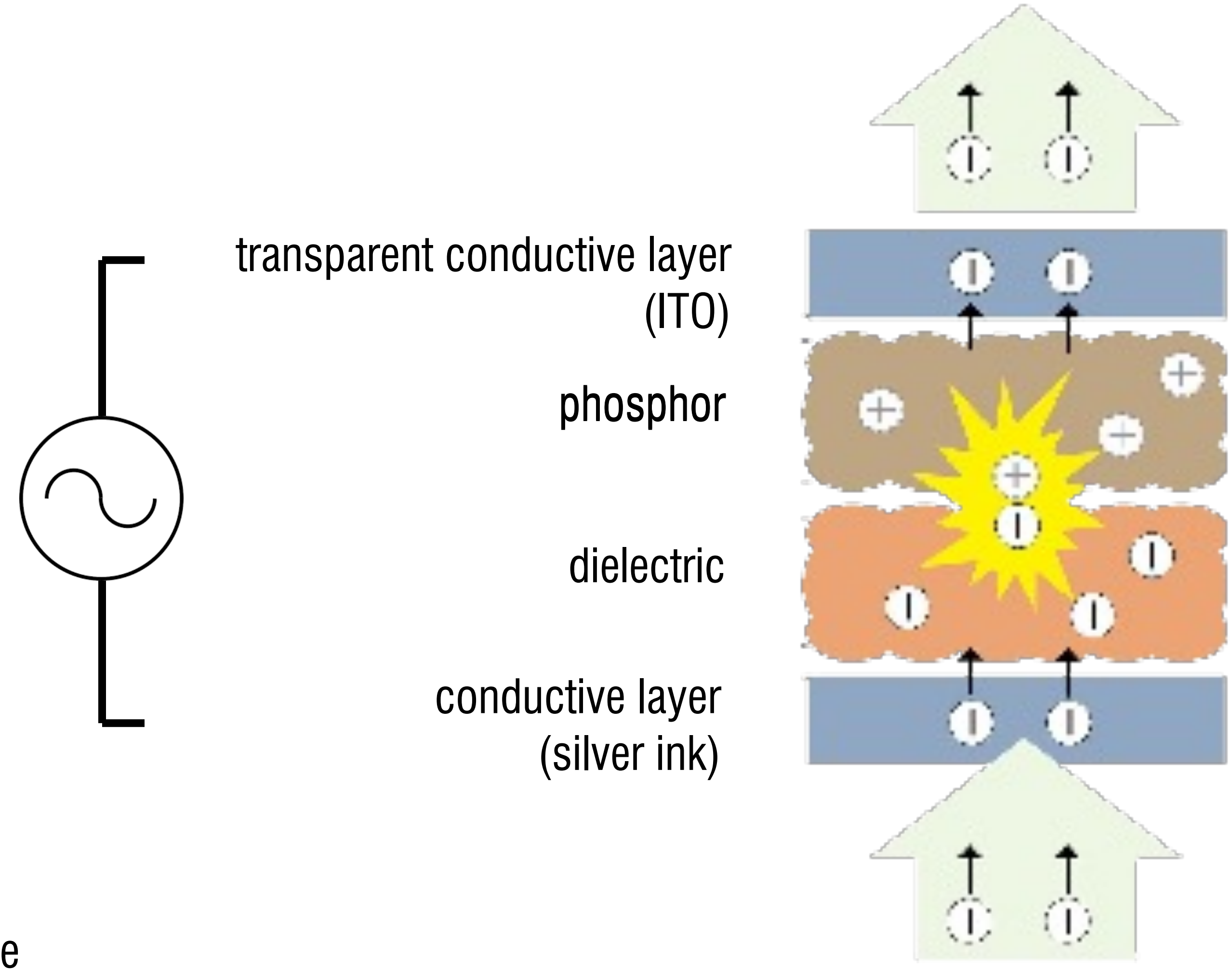
Swaminathan et.al.

(1974)

electro-luminescent (EL)



electroluminescent display: also uses **phosphor!**
—> no more electron beam, instead apply electricity directly



transparent conductive layer
(ITO)

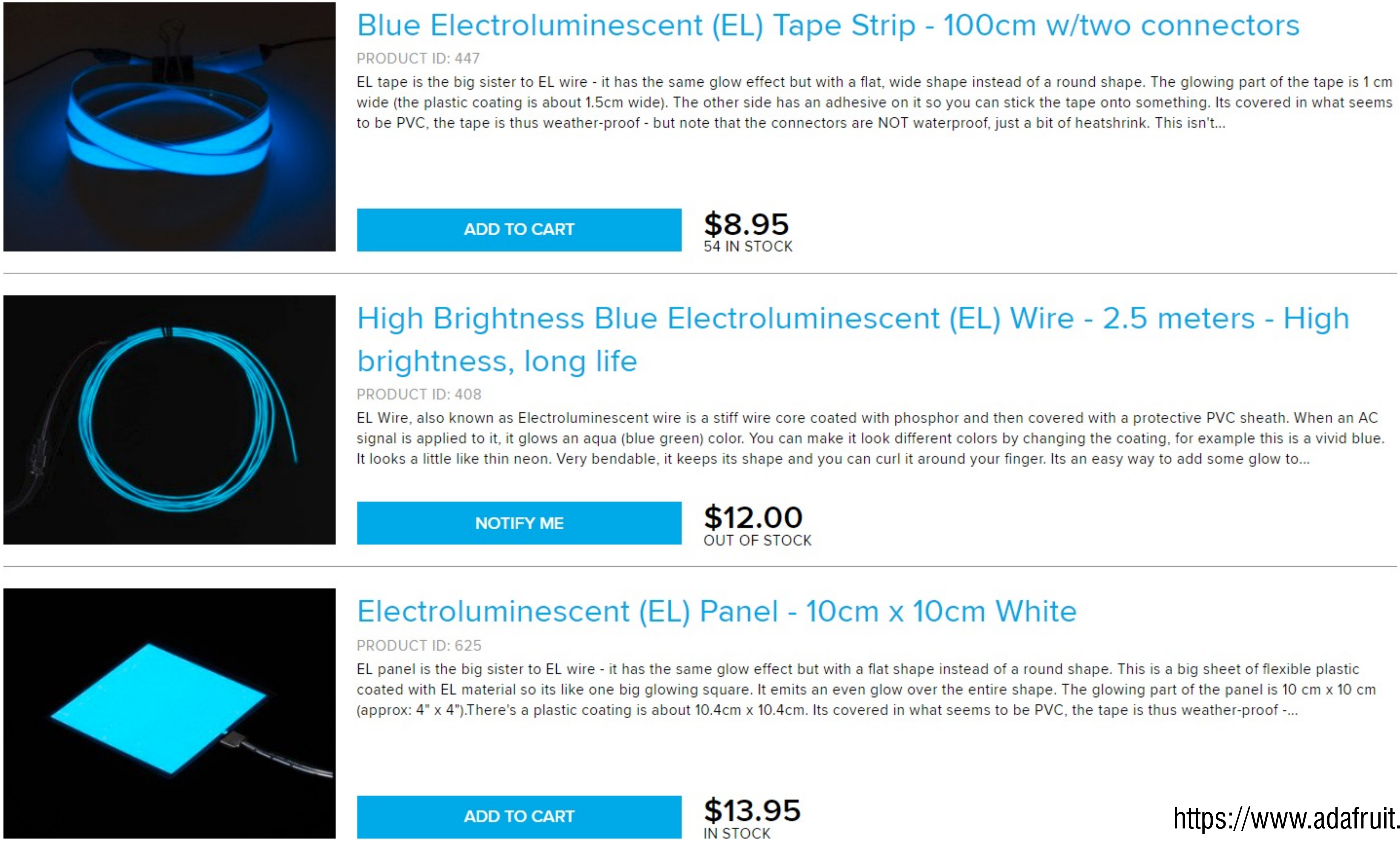
phosphor

dielectric

conductive layer
(silver ink)

4-layer sandwich structure
Top and bottom electrodes act as a capacitor
Apply high voltage and low current AC, **phosphor** emits photons

Why EL display?



Blue Electroluminescent (EL) Tape Strip - 100cm w/two connectors

PRODUCT ID: 447

EL tape is the big sister to EL wire - it has the same glow effect but with a flat, wide shape instead of a round shape. The glowing part of the tape is 1 cm wide (the plastic coating is about 1.5cm wide). The other side has an adhesive on it so you can stick the tape onto something. Its covered in what seems to be PVC, the tape is thus weather-proof - but note that the connectors are NOT waterproof, just a bit of heatshrink. This isn't...

$8.95
54 IN STOCK

High Brightness Blue Electroluminescent (EL) Wire - 2.5 meters - High brightness, long life

PRODUCT ID: 408

EL Wire, also known as Electroluminescent wire is a stiff wire core coated with phosphor and then covered with a protective PVC sheath. When an AC signal is applied to it, it glows an aqua (blue green) color. You can make it look different colors by changing the coating, for example this is a vivid blue. It looks a little like thin neon. Very bendable, it keeps its shape and you can curl it around your finger. Its an easy way to add some glow to...

$12.00
OUT OF STOCK

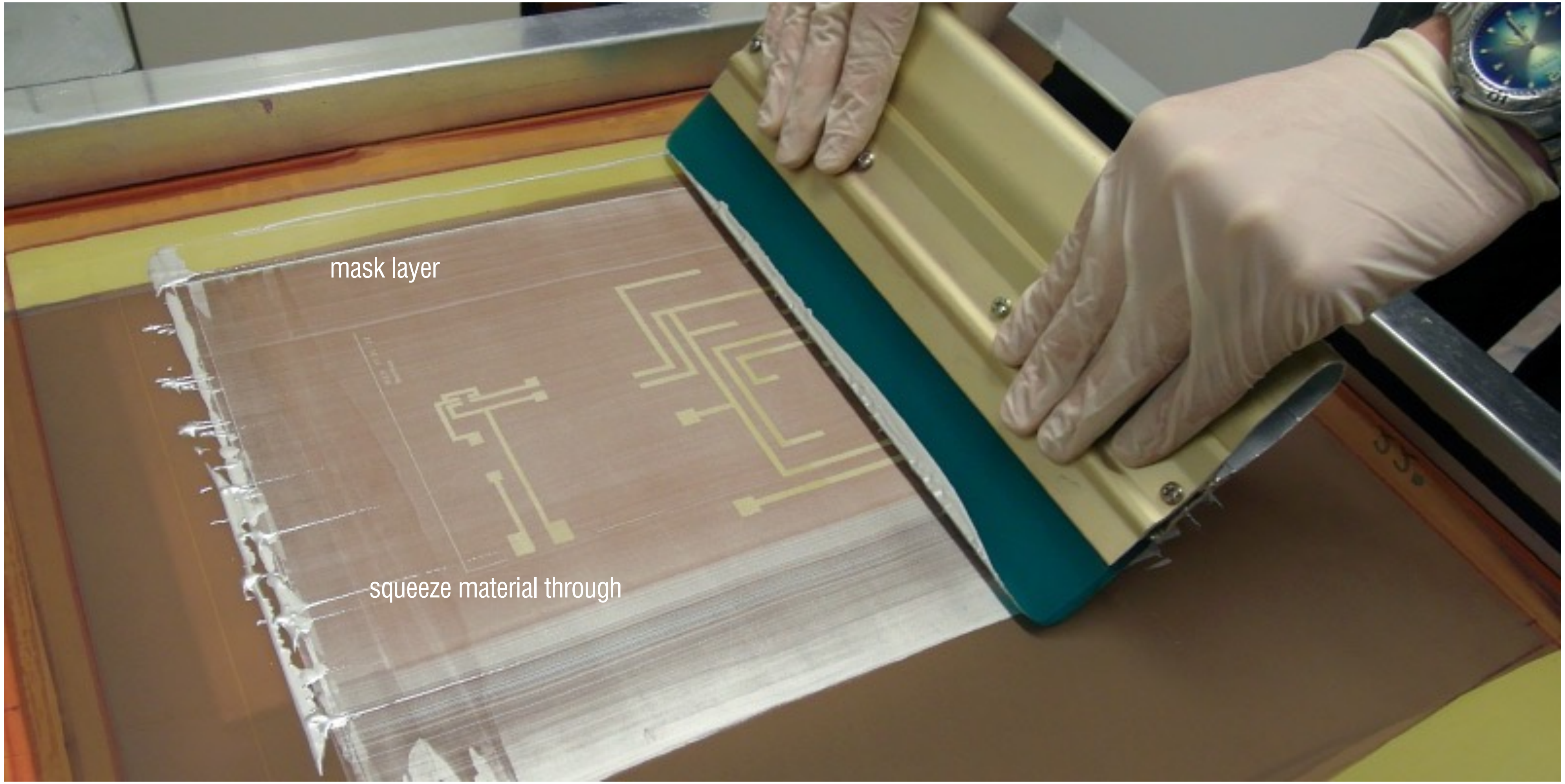
Electroluminescent (EL) Panel - 10cm x 10cm White

PRODUCT ID: 625

EL panel is the big sister to EL wire - it has the same glow effect but with a flat shape instead of a round shape. This is a big sheet of flexible plastic coated with EL material so its like one big glowing square. It emits an even glow over the entire shape. The glowing part of the panel is 10 cm x 10 cm (approx: 4" x 4").There's a plastic coating is about 10.4cm x 10.4cm. Its covered in what seems to be PVC, the tape is thus weather-proof -...

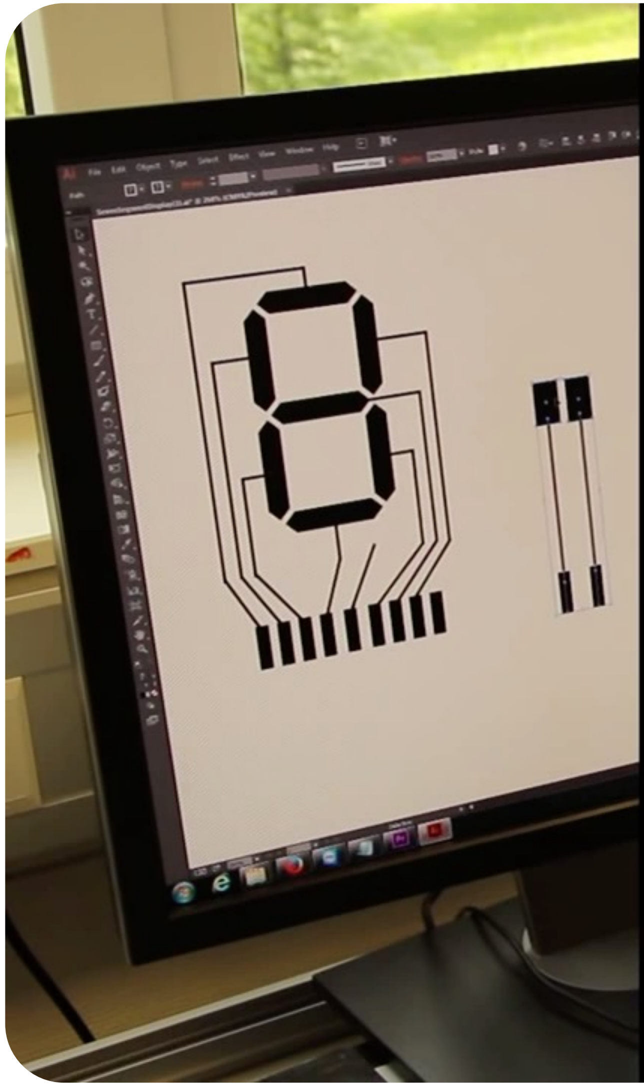
$13.95
IN STOCK

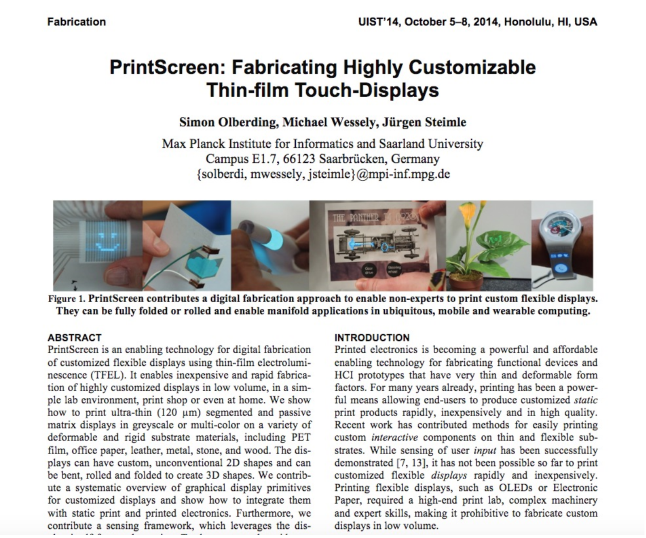
https://www.adafruit.com



use **screen printing** to make them
(2D inkjet printing and 3D printing them is still hard)

Prototyping **ubiquitous display**





Fabrication UIST'14, October 5–8, 2014, Honolulu, HI, USA

PrintScreen: Fabricating Highly Customizable Thin-film Touch-Displays

Simon Olberding, Michael Wessely, Jürgen Steimle
Max Planck Institute for Informatics and Saarland University
Campus E1.7, 66123 Saarbrücken, Germany
{solberdi, mwessely, jsteimle}@mpi-inf.mpg.de

Figure 1. PrintScreen contributes a digital fabrication approach to enable non-experts to print custom flexible displays. They can be fully folded or rolled and enable manifold applications in ubiquitous, mobile and wearable computing.

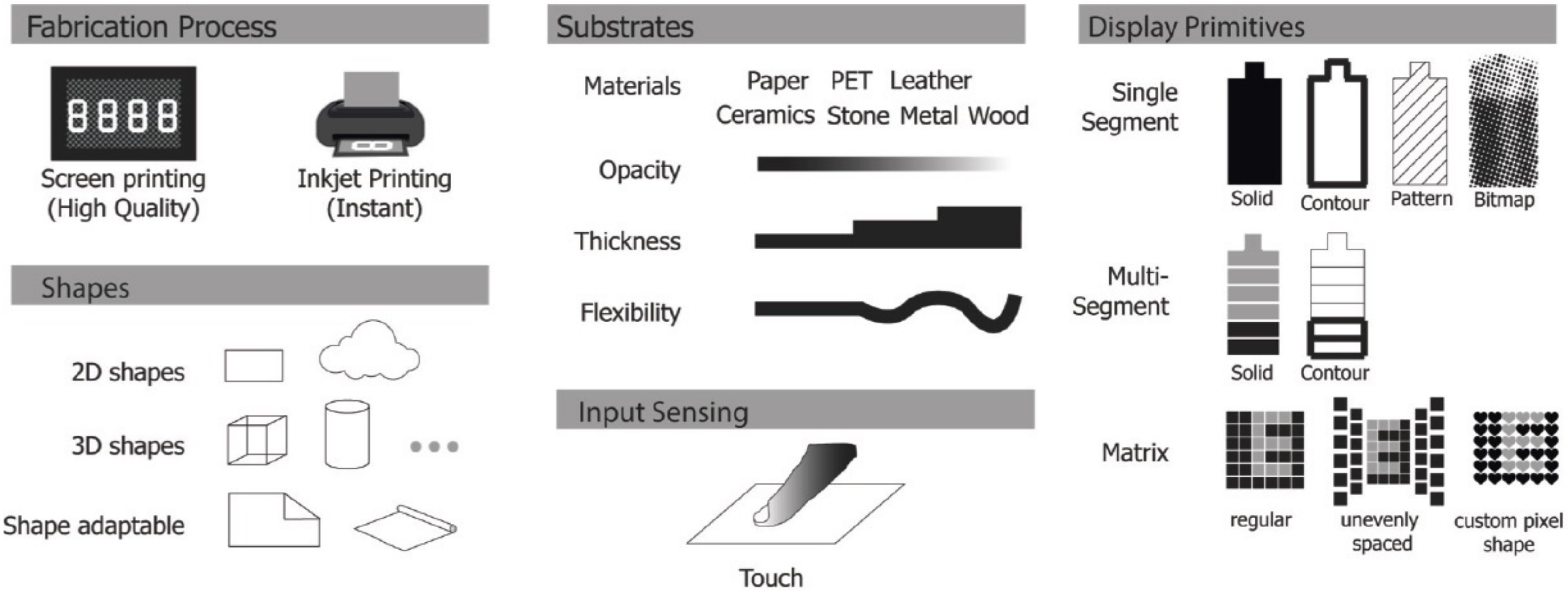
ABSTRACT

PrintScreen is an enabling technology for digital fabrication of customized flexible displays using thin-film electroluminescence (TFEL). It enables inexpensive and rapid fabrication of highly customized displays in low volume, in a simple lab environment, print shop or even at home. We show how to print ultra-thin (120 μm) segmented and passive matrix displays in greyscale or multi-color on a variety of deformable and rigid substrate materials, including PET film, office paper, leather, metal, stone, and wood. The displays can have custom, unconventional 2D shapes and can be bent, rolled and folded to create 3D shapes. We contribute a systematic overview of graphical display primitives for customized displays and show how to integrate them with static print and printed electronics. Furthermore, we contribute a sensing framework, which leverages the dis-

INTRODUCTION

Printed electronics is becoming a powerful and affordable enabling technology for fabricating functional devices and HCI prototypes that have very thin and deformable form factors. For many years already, printing has been a powerful means allowing end-users to produce customized *static* print products rapidly, inexpensively and in high quality. Recent work has contributed methods for easily printing custom *interactive* components on thin and flexible substrates. While sensing of user *input* has been successfully demonstrated [7, 13], it has not been possible so far to print customized flexible *displays* rapidly and inexpensively. Printing flexible displays, such as OLEDs or Electronic Paper, required a high-end print lab, complex machinery and expert skills, making it prohibitive to fabricate custom displays in low volume.

UIST 14
Olberding et.al.



Fabrication Process

Screen printing
(High Quality)

Inkjet Printing
(Instant)

Shapes

2D shapes

3D shapes

Shape adaptable

Substrates

Materials: Paper PET Leather Ceramics Stone Metal Wood

Opacity

Thickness

Flexibility

Input Sensing

Touch

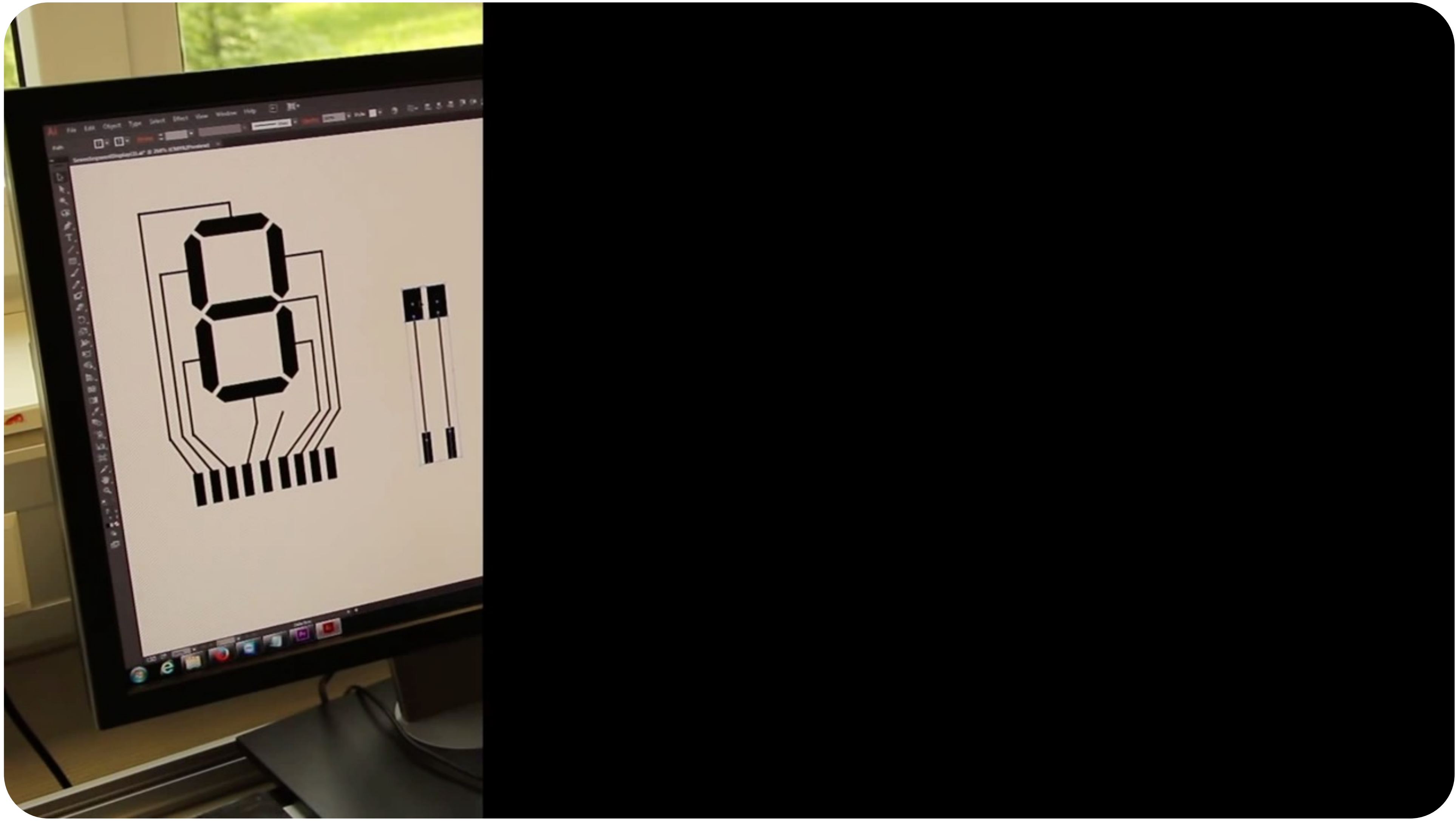
Display Primitives

Single Segment: Solid, Contour, Pattern, Bitmap

Multi-Segment: Solid, Contour

Matrix: regular, unevenly spaced, custom pixel shape

Prototyping **ubiquitous display**

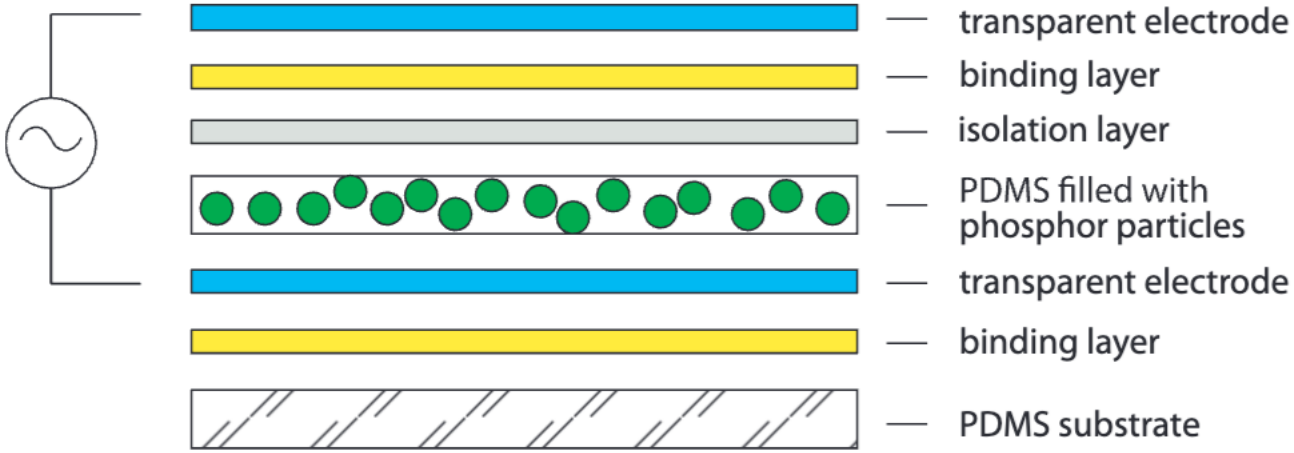


Prototyping **ubiquitous display ->** **Printing on-skin display**

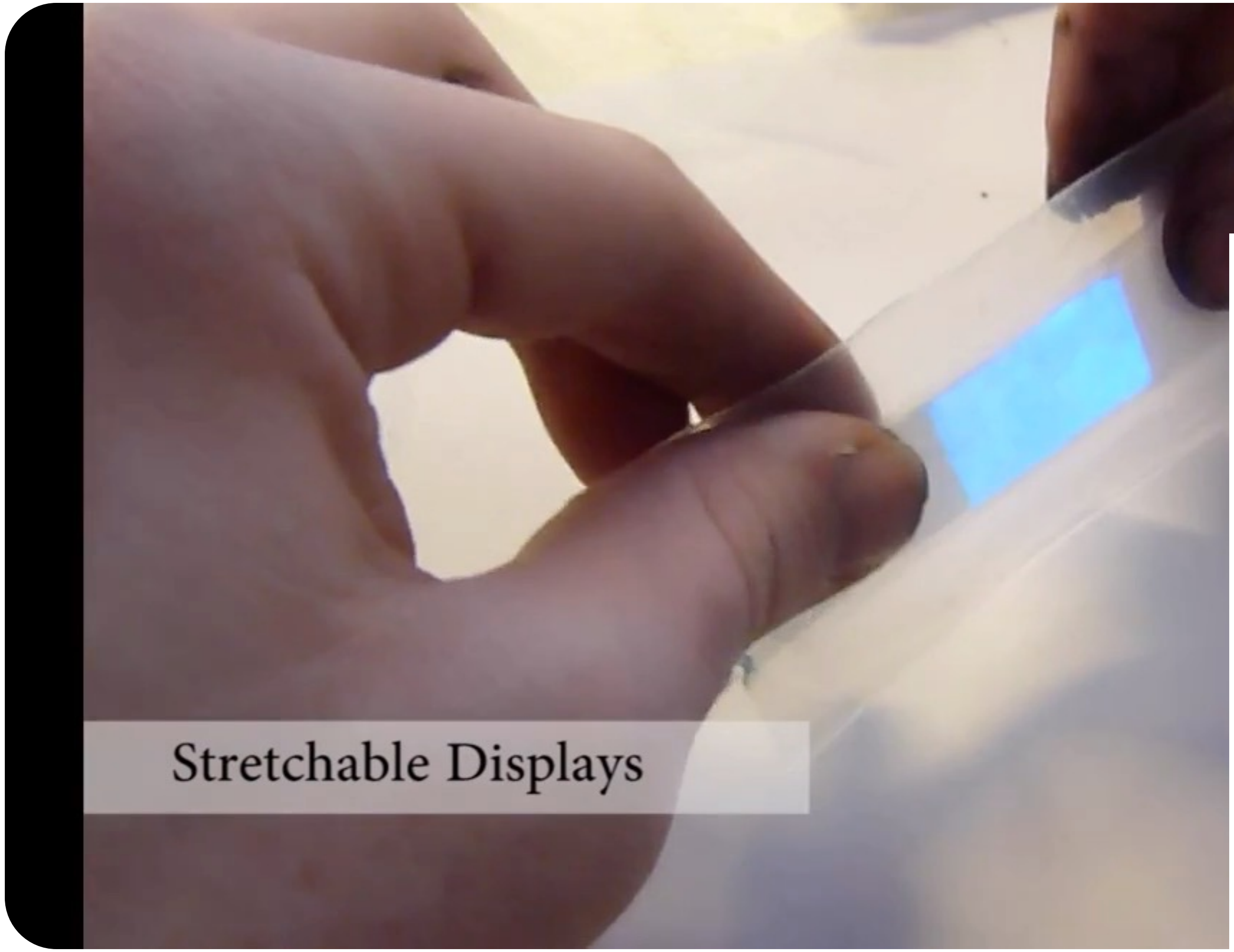
Need to be:
Flexible & Stretchable
(Ultra) thin

Polydimethylsiloxane of **PDMS**

- Flexibility and Elasticity
- Biocompatibility
- Transparency



Stretchable display
EL embedded in silicone



Stretchis: Fabricating Highly Stretchable User Interfaces

Michael Wessely
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Theophanis Tsandilas
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Wendy E. Mackay
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Inria; Univ Paris-Sud & CNRS (LRI); Université Paris-Saclay
F-91405 Orsay, France

Figure 1. *Stretchis* **are highly stretchable user interfaces that include touch and proximity sensors and electroluminescent displays (a).** *Stretchis* **are transparent (b); can be stretched to fit to the geometry of different physical objects (c); and can act as on-skin user interfaces (d).**

ABSTRACT

Recent advances in materials science research have enabled the production of highly stretchable sensors and displays. However, such technologies are not yet accessible to non-expert makers. We present a novel and inexpensive fabrication method for creating *Stretchis*, highly stretchable user interfaces that combine sensing capabilities and visual output. We use Polydimethylsiloxan (PDMS) as the base material for a *Stretchi* and show how to embed stretchable touch and proximity sensors and stretchable electroluminescent displays. Stretchis can be ultra-thin ($\approx 200\ \mu m$), flexible, and fully customizable, enabling non-expert makers to add interaction to elastic physical objects, shape-changing surfaces, fabrics, and the human body. We demonstrate the usefulness of our approach with three application examples that include ubiquitous computing, wearables and on-skin interaction.

Author Keywords
Stretchable interfaces; personal fabrication; sensing technologies; custom-shaped displays; wearables.

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation

tablets combine input and output, allowing users to interact directly via multi-touch displays. Unfortunately, these technologies are rigid, expensive and complex to manufacture.

What if we could create inexpensive, lightweight, interactive surfaces that can be embedded in or attached to nearly any physical object? We are particularly interested in ultra-thin, *stretchable* user interfaces that can embed rich interaction onto a wide variety of objects. To this end, we need ultra-flexible and stretchable substrate materials that can adapt to complex object geometries, doubly curved and shape-changing surfaces, and fabrics. We also need highly deformable sensors and displays that remain functional even when the underlying substrates are under strain.

Recent research on printed electronics has made considerable progress in this direction, but has not yet reached a complete solution. For example, iSkin [28] sensors allow limited stretching, up to 30%, but do not provide visual output. Other research [20] demonstrates how to print flexible electroluminescent displays, but the fabrication approach does not support stretchable substrates.

This paper offers a set of key innovations toward our goal of creating inexpensive, ultra-thin, *stretchable* user inter-

UIST 16
Wessely et.al.

conformal displays

temporary tattoo paper
(Tattoo Decal Paper)

SkinMarks

Enabling Interactions on Body
Using Conformal Skin Elec

Martin Weigel[1], Aditya Nittala[1], Alex Olwal[2], Jürg
[1] Saarland University, Saarland Informatics Camp
[2] Google Inc., USA

ACM CHI 2017

Haptics on Skin CHI 2017, May 6–11, 2017, Denver, CO, USA

SkinMarks: Enabling Interactions on Body Landmarks Using Conformal Skin Electronics

Martin Weigel[1] Aditya Shekhar Nittala[1] Alex Olwal[2] Jürgen Steimle[1]
[1] Saarland University, Saarland Informatics Campus, Germany
[2] Google Inc., Mountain View, California, United States
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Figure 1: SkinMarks are conformal on-skin sensors and displays. They enable interaction on five types of body landmarks: (a) skeletal landmarks, (b) skin microstructures, (c) elastic landmarks, (d) visual skin landmarks, and (e) accessories.

ABSTRACT

The body provides many recognizable landmarks due to the underlying skeletal structure and variations in skin texture, elasticity, and color. The visual and spatial cues of such body landmarks can help in localizing on-body interfaces, guide input on the body, and allow for easy recall of mappings. Our main contribution are SkinMarks, *novel skin-worn I/O devices* for precisely localized input and output on fine body landmarks. SkinMarks comprise skin electronics on temporary rub-on tattoos. They conform to fine wrinkles and are compatible with strongly curved and elastic body locations. We identify *five types of body landmarks* and demonstrate novel interaction techniques that leverage SkinMarks' unique touch, squeeze and bend sensing with integrated visual output. Finally, we detail on the conformality and evaluate sub-millimeter electrodes for touch sensing. Taken together, SkinMarks expands the on-body interaction space to more de-

INTRODUCTION

The body is recognized as a promising input surface for mobile computing, as it offers a large and quickly accessible area for interaction. Prior research contributed input [11, 12, 14, 16, 17, 26, 27, 29, 41, 45] and output devices [11, 43] for on-body interactions. However, they mostly assume interactive elements to be rather large and only slightly curved.

The human body has various types of landmarks which are distinct from their surroundings. It offers unique possibilities for interaction due to their tactile properties and visual appearance. For example, protruding skeletal landmarks, like the knuckles, provide physical affordances for touching and circling around them. Prior work in human-computer interaction has briefly explored the potential of such unique landmarks. Gustafson et al. [8, 9], for example, suggested using the segments of the finger as distinct input buttons. However, thus

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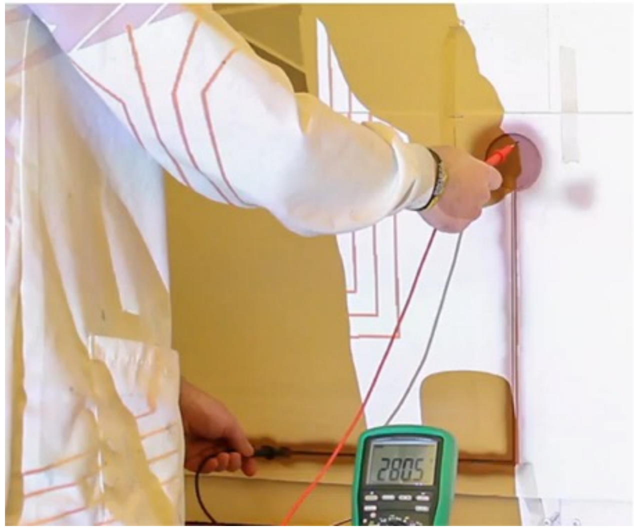
Weigel et.al.

How to scale up? (like for room-scale interactions?)



Sprayable User Int

Prototyping Large-

Surfaces with Sens

Michael Wessely, Ticha Sethapakdi, Carlo
Jackson C Snowden, Ollie Hanton, Isabel
Mike Fraser, Anne Roudaut, Stefanie Mu

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

Sprayable User Interfaces: Prototyping Large-Scale Interactive Surfaces with Sensors and Displays

**Michael Wessely[1], Ticha Sethapakdi[1], Carlos Castillo[1], Jackson C. Snowden[1], Ollie Hanton[2]
Isabel P.S. Qamar[12], Mike Fraser[3], Anne Roudaut[2], Stefanie Mueller[1]**

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[2] University of Bristol, Bristol, UK
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[3]University of Bath
Bath, UK, BA2 7AY
mcf35@bath.ac.uk

Figure 1. Sprayable User Interfaces enable makers to create large-scale interactive surfaces on various materials and curved geometries. After designing an interactive artwork (a), our tool supports their fabrication with auto-generated stencils (b) enabling novel user interfaces that cover entire rooms (c), integrate in interactive architecture (d), and smart cities (e).

ABSTRACT

We present Sprayable User Interfaces: room-sized interactive surfaces that contain sensor and display elements created by airbrushing functional inks. Since airbrushing is inherently mobile, designers can create large-scale user interfaces on complex 3D geometries where existing stationary fabrication methods fail.

To enable Sprayable User Interfaces, we developed a novel design and fabrication pipeline that takes a desired user interface layout as input and automatically generates stencils for airbrushing the layout onto a physical surface. After fabricating stencils from cardboard or projecting stencils digitally, designers spray each layer with an airbrush, attach a microcontroller to the user interface, and the interface is ready to be used.

Our technical evaluation shows that Sprayable User Interfaces work on various geometries and surface materials, such as porous stone and rough wood. We demonstrate our system with several application examples including interactive smart home applications on a wall and a soft leather sofa, an interactive smart city application, and interactive architecture in public office spaces.

Author Keywords

Spraying; fabrication; printed electronics; ubiquitous computing; airbrush

CHI '20, April 25–30, 2020, Honolulu, HI, USA

ACM ISBN 978-1-4503-6708-0/20/04…$15.00
https://doi.org/10.1145/3313831.3376249

CSS Concepts

• **Human-centered computing~Human computer interaction (HCI)**; *Human-centered computing*

INTRODUCTION

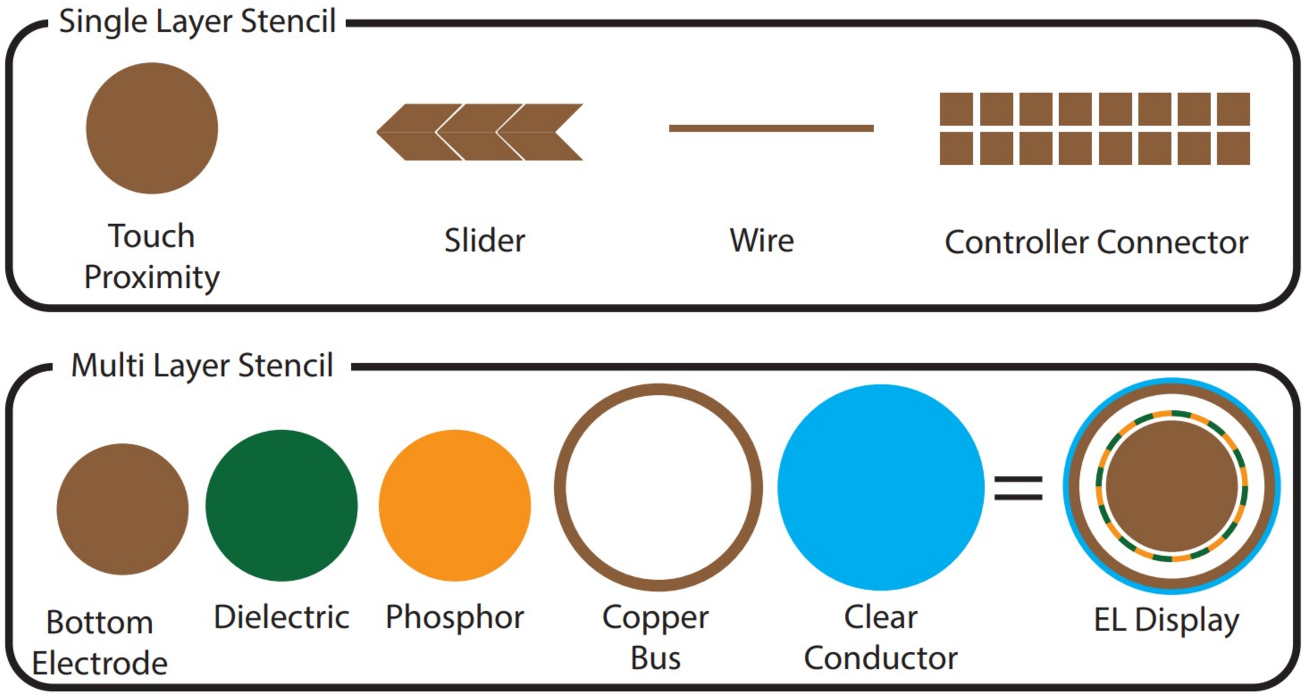
Since the early 1990s, Human-Computer Interaction researchers have envisioned a world in which digital user interfaces are seamlessly integrated with the physical environment until the two are indistinguishable from one another *(Computer of the 21st century* [29]).

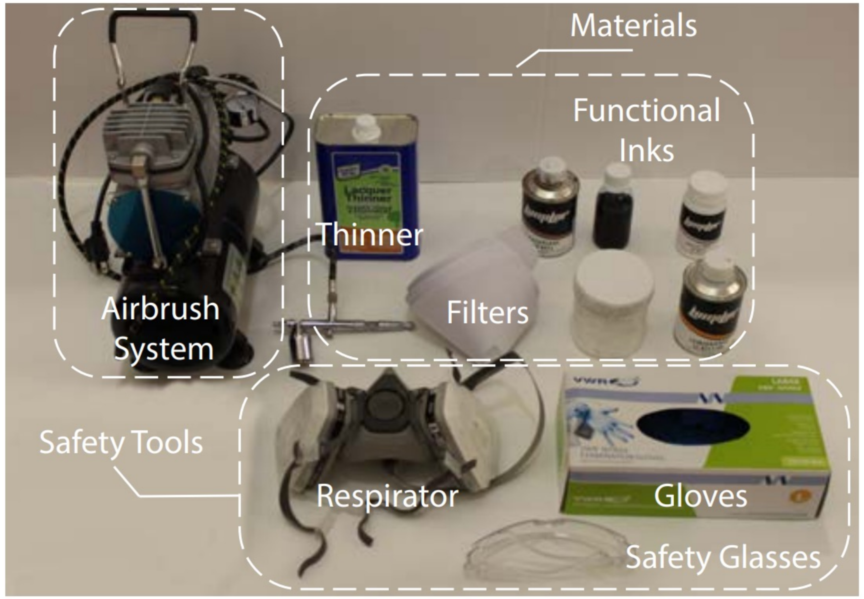
One of the greatest challenges in enabling this future is the integration of sensors and display elements with the physical environment, since the fabrication of interactive surfaces requires many design considerations, including how to adhere the elements to different materials and how to apply them onto irregular surface geometries in a manner accessible to novice users.

Over the last few years, novel fabrication methods have been developed that enable the fabrication of displays and sensors using inkjet- and screen-printing (*PrintScreen* [19]) as well as hydrographics (*ObjectSkin* [6]). However, all of these methods are limited to small-scale geometries, i.e. they are bound by the volume of the fabricating device, such as the size of the printer, the area of the screen-printing net, or the size of the hydrographic bath.

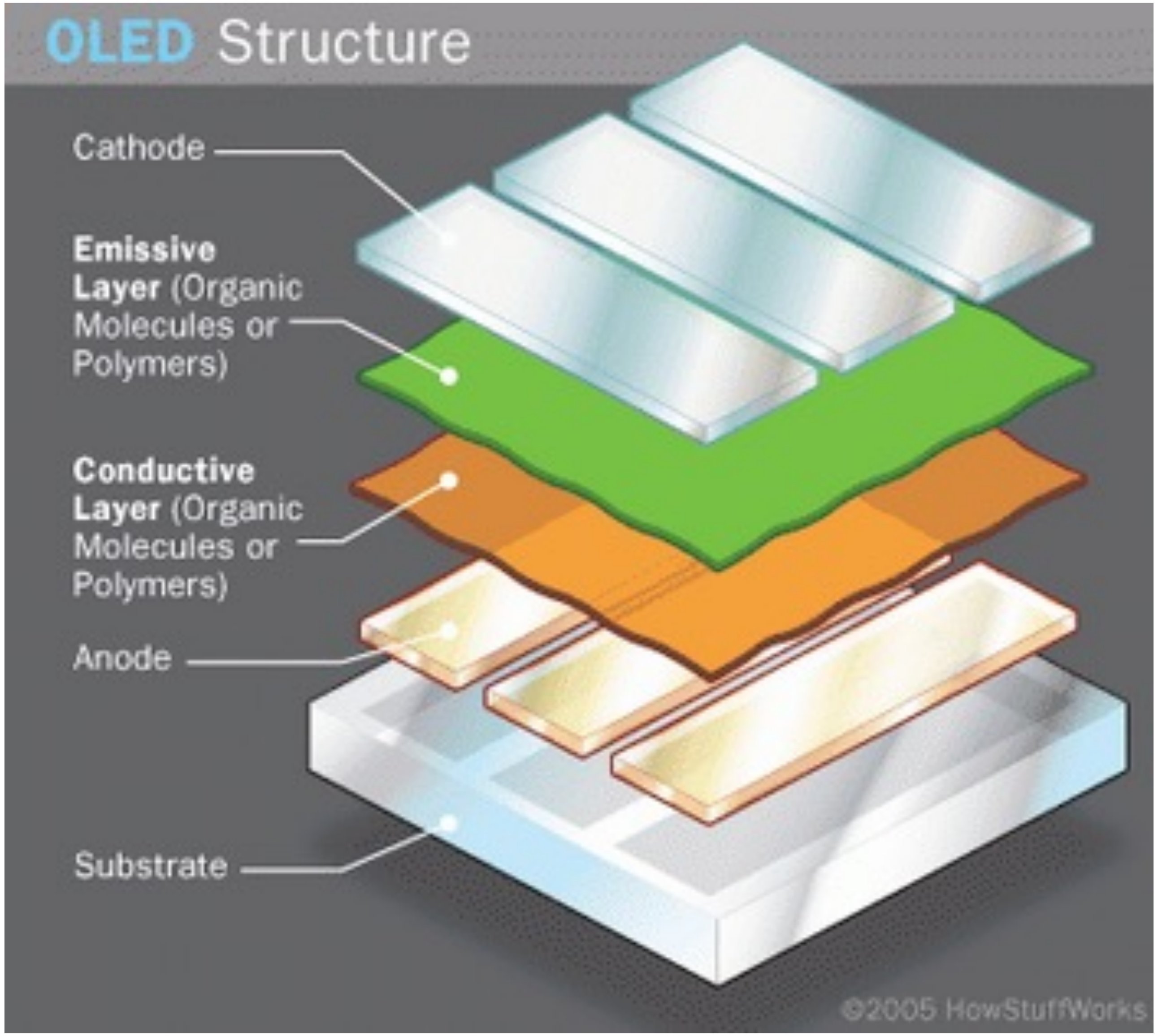
In this paper, we explore how to make large-scale user interfaces using spraying as the fabrication method. Unlike many existing techniques, such as 3D printing, screen printing or inkjet printing, spraying is not bound to a specific volume and, as often demonstrated by graffiti artwork, can create output that covers entire walls and even building facades. In addition, since spraying is a non-contact method, it works well on various surface textures (wallpaper, concrete, wood, bathroom tiles) and surface geometries, such as those with

CHI 20
Wessely et.al.


Single Layer Stencil
Touch Proximity
Slider
Wire
Controller Connector
Multi Layer Stencil
Bottom Electrode
Dielectric
Phosphor
Copper Bus
Clear Conductor
=
EL Display


Materials
Functional Inks
Thinner
Airbrush System
Filters
Safety Tools
Respirator
Gloves
Safety Glasses

electroluminescence is also used in **OLEDs**



EL displays concept, but organic instead of inorganic phosphors

zooming out…

ubiquitous computing:

computing is made to **appear anytime** and **anywhere**

if everything is a computer,
everything will also **sense** user input
and everything will be a **display** for output

Special thanks to Prof. Stefanie Mueller. These slides are largely based on hers.

Optional readings

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

Sprayable User Interfaces: Prototyping Large-Scale Interactive Surfaces with Sensors and Displays

Michael Wessely[1], Ticha Sethapakdi[1], Carlos Castillo[1], Jackson C. Snowden[1], Ollie Hanton[2]
Isabel P.S. Qamar[12], Mike Fraser[3], Anne Roudaut[2], Stefanie Mueller[1]

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[2] University of Bristol, Bristol, UK
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[3] University of Bath
Bath, UK, BA2 7AY
mcf35@bath.ac.uk

Figure 1. Sprayable User Interfaces enable makers to create large-scale interactive surfaces on various materials and curved geometries. After designing an interactive artwork (a), our tool supports their fabrication with auto-generated stencils (b) enabling novel user interfaces that cover entire rooms (c), integrate in interactive architecture (d), and smart cities (e).

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Page 1

CHI 20
Wessely et.al.

Haptics on Skin
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SkinMarks: Enabling Interactions on Body Landmarks Using Conformal Skin Electronics

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Figure 1: SkinMarks are conformal on-skin sensors and displays. They enable interaction on five types of body landmarks: (a) skeletal landmarks, (b) skin microstructures, (c) elastic landmarks, (d) visual skin landmarks, and (e) accessories.

ABSTRACT

The body provides many recognizable landmarks due to the underlying skeletal structure and variations in skin texture, elasticity, and color. The visual and spatial cues of such body landmarks can help in localizing on-body interfaces, guide input on the body, and allow for easy recall of mappings. Our main contribution are SkinMarks, *novel skin-worn I/O devices* for precisely localized input and output on fine body landmarks. SkinMarks comprise skin electronics on temporary rub-on tattoos. They conform to fine wrinkles and are compatible with strongly curved and elastic body locations. We identify *five types of body landmarks* and demonstrate novel interaction techniques that leverage SkinMarks' unique touch, squeeze and bend sensing with integrated visual output. Finally, we detail on the conformality and evaluate sub-millimeter electrodes for touch sensing. Taken together, SkinMarks expands the on-body interaction space to more detailed, highly curved and challenging areas on the body.

Author Keywords

On-body interaction; on-skin sensing; on-skin display; epidermal electronics; electronic tattoos; fabrication; flexible display.

ACM Classification Keywords

H.5.2. User Interfaces: Input devices and strategies, Interaction Styles, Haptic I/O

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INTRODUCTION

The body is recognized as a promising input surface for mobile computing, as it offers a large and quickly accessible area for interaction. Prior research contributed input [11, 12, 14, 16, 17, 26, 27, 29, 41, 45] and output devices [11, 43] for on-body interactions. However, they mostly assume interactive elements to be rather large and only slightly curved.

The human body has various types of landmarks which are distinct from their surroundings. It offers unique possibilities for interaction due to their tactile properties and visual appearance. For example, protruding skeletal landmarks, like the knuckles, provide physical affordances for touching and circling around them. Prior work in human-computer interaction has briefly explored the potential of such unique landmarks. Gustafson et al. [8, 9], for example, suggested using the segments of the finger as distinct input buttons. However, thus far, the majority of potentially beneficial landmarks remain unexplored and unsupported. These include landmarks with highly curved geometries, tactile microstructures, or strong deformability.

This paper presents *SkinMarks*, an enabling technology for interaction on body landmarks. SkinMarks are highly conformal interactive tattoos, which enable precisely localized input and output on five types of body landmarks.

SkinMarks are inspired by recent research on slim, skin-worn sensors and displays [41, 17, 27, 43]. We extend beyond prior work by contributing highly conformal skin electronics with co-located input and output, which are compatible with strongly curved, elastic, and tiny body landmarks. These make it possible to use the plethora of tactile and visual cues on body landmarks for direct, eyes-free, and expressive interaction.

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