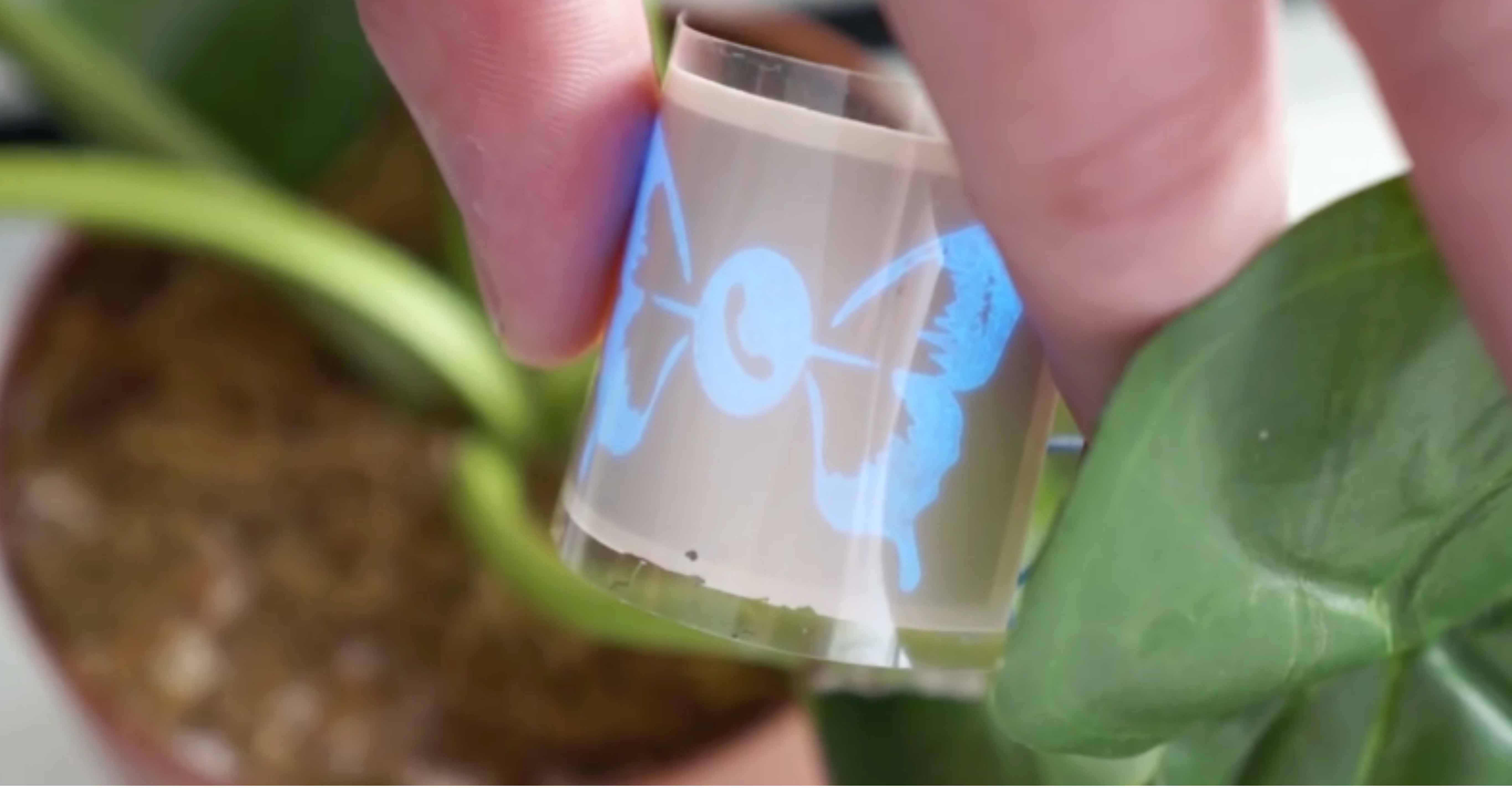


Display technology

6.S063 Engineering Interaction Technologies

Prof. Stefanie Mueller | HCI Engineering Group

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

Claytronics Vision

since we don’t have the tech yet,
how can prototype this to **make everything in our surrounding appear to be a display?**

<30 sec brainstorming>

projection

as a place holder for freeform screens

paper + projector + mocap

DisplayObjects: Prototyping Functional Physical Interfaces on 3D Styrofoam, Paper or Cardboard Models

Eric Akaoka, Tim Ginn and Roel Vertegaal
Human Media Lab
Queen's University
Kingston, ON K7L 3N6
Canada
info@hml.queensu.ca

ABSTRACT
This paper introduces DisplayObjects, a rapid prototyping workbench that allows functional interfaces to be projected onto real 3D physical prototypes. DisplayObjects uses a Vicon motion capture system to track the location of physical models. 3D software renditions of the 3D physical model are then texture-mapped with interactive behavior and projected back onto the physical model to allow real-time interactions with the object. We discuss the implementation of the system, as well as a selection of one and two-handed interaction techniques for DisplayObjects. We conclude with a design case that comments on some of the early design experiences with the system.

Author Keywords
Early Prototyping, Physical User Interfaces, Augmented Reality, Organic User Interfaces.

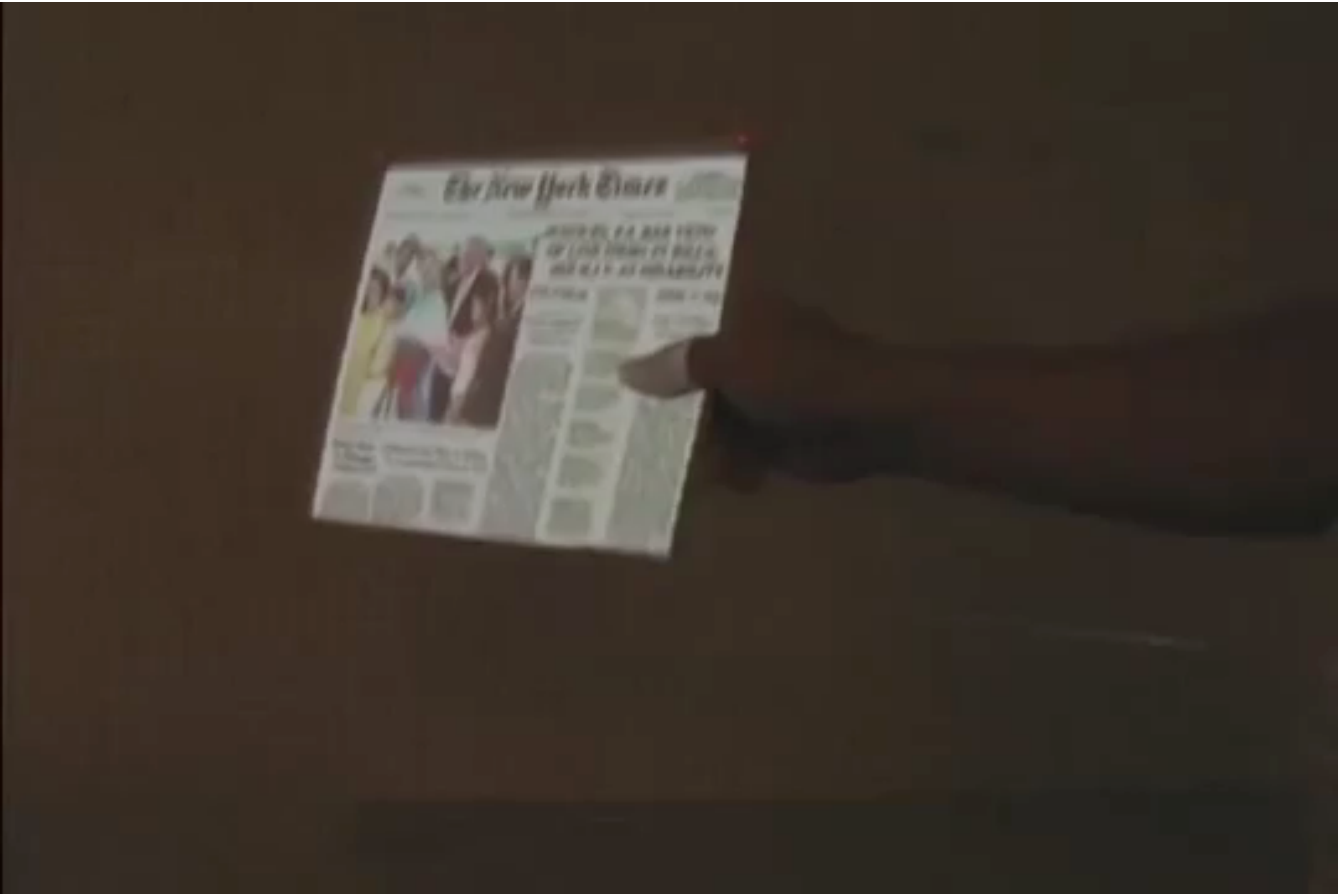
ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Human Factors.

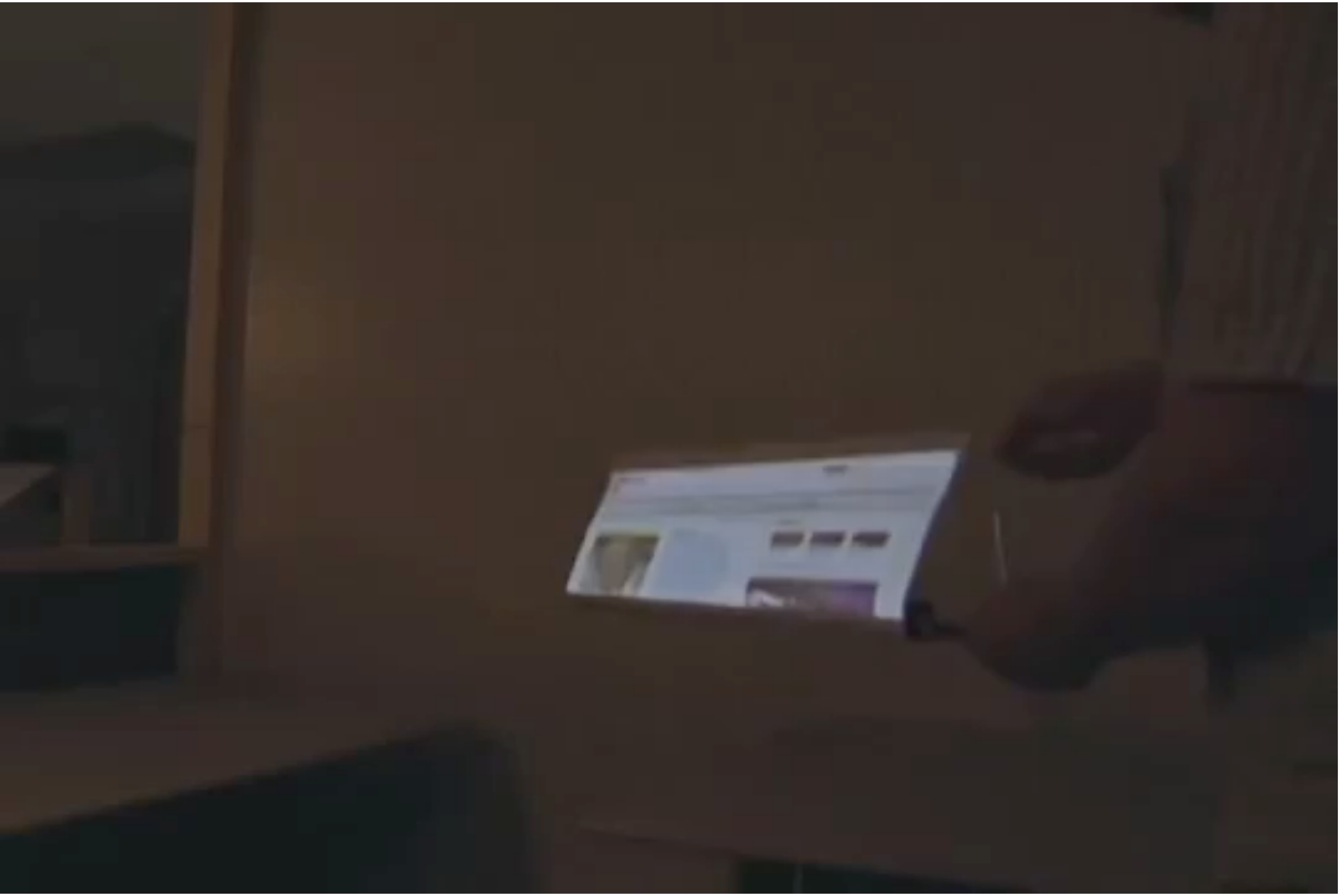
INTRODUCTION
Physical mockups have always played an important role in design phases are typically passive vehicles. Users are either provided with a Wizard of Oz style simulation during early evaluations, or a graphical computer user interface that provides simulations of the final functionality of the device on a computer. In this paper, we argue that one of the problems with this approach is that early user experiences remain disjoint: users experience the functionality of a device without being fully able to fuse their haptic and visual perceptions of the interface.

According to Hudson and Mankoff [9], this means designers are often constrained to either creating prototypes that look like the final product (physical mockups), or work like the final product (on-screen software). To alleviate this problem, they proposed augmenting physical mockups with sensors that capture the interaction styles of physical inputs such as button presses in physical cardboard and Styrofoam prototypes [12]. While workbenches like d.tools [6] and VoodoIO [23] support rapid prototyping of hardware interfaces with relative ease, the use of actual hardware in prototyping can make it difficult to simulate a seamless experience at early stages of the design process. This is because it is difficult to smoothly integrate hardware controls, like buttons or dials, into a product's display at this stage. This problem becomes more pressing when the surface

2008 foldable interactive displays



2008 foldable interactive displays



2008 foldable interactive displays

Foldable Interactive Displays

Johnny Chung Lee, Scott E. Hudson
Human-Computer Interaction Institute
Carnegie Mellon University
5000 Forbes Ave., Pittsburgh, PA 15213
{johnny, scott.hudson}@cs.cmu.edu

Edward Tse
Smart Technologies
1207-11 Avenue SW, Suite 300
Calgary, Alberta, Canada T3C 0M5
edwardtse@smarttech.com

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.

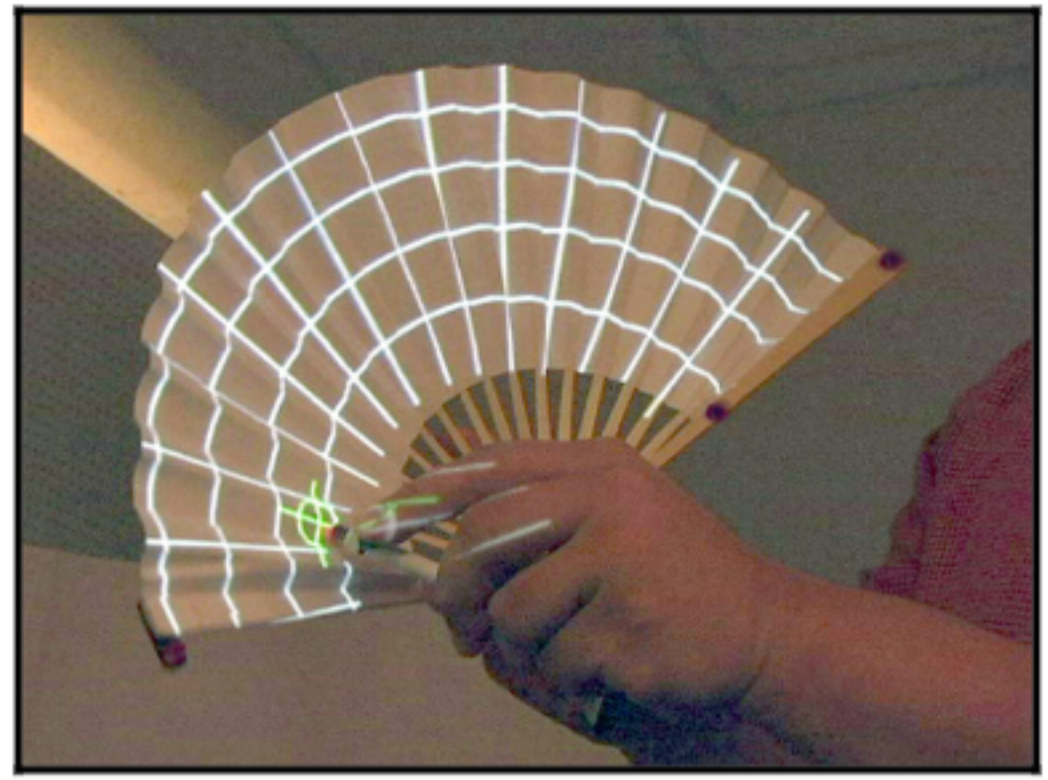


Figure 1 – Foldable fan display with stylus input.

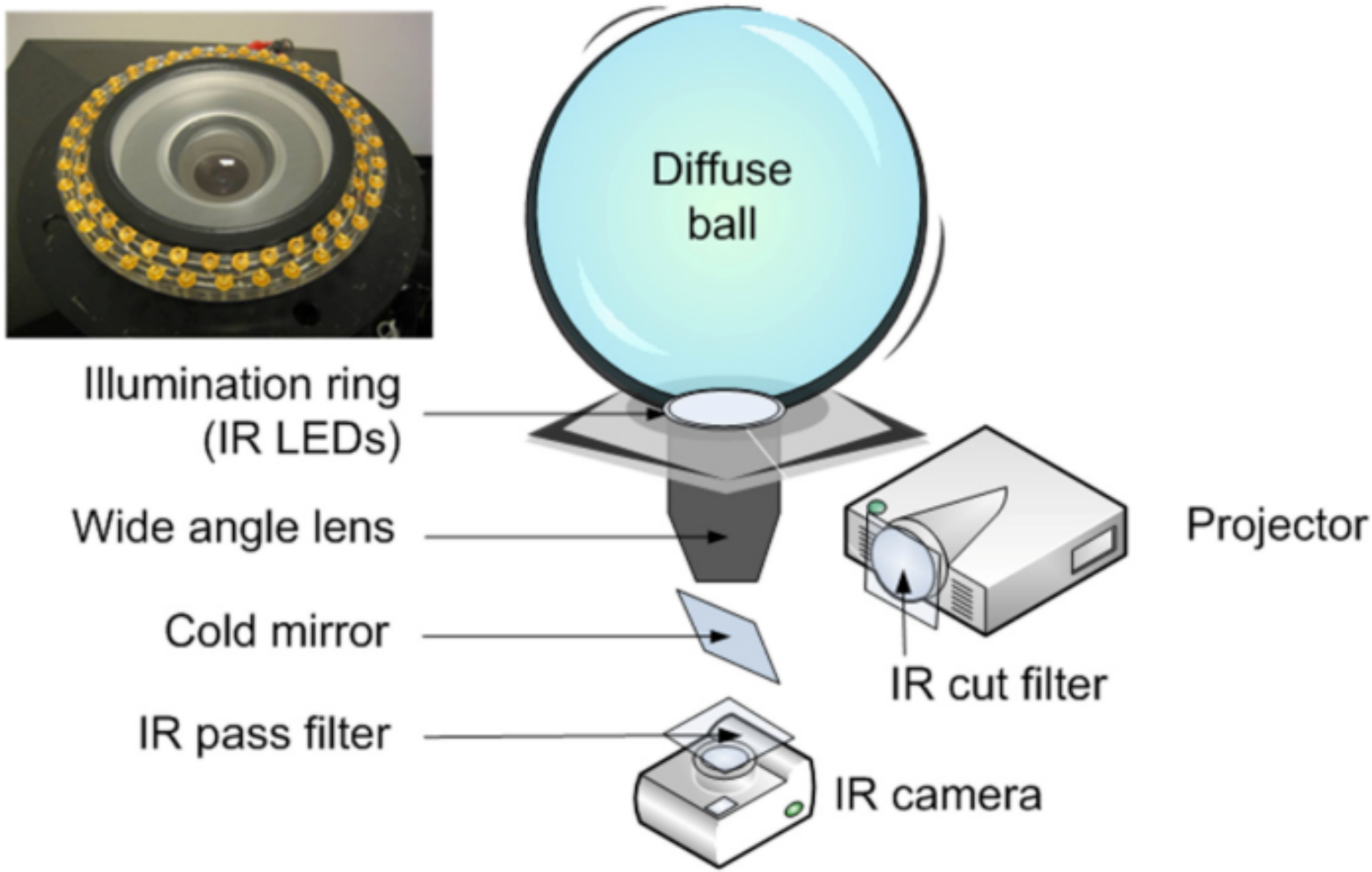
this paper, we explore this concept of inactive foldable displays and create a number of working prototypes such as the one shown in Figure 1.

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

2008: non-planar touch screens (Sphere, Benko)

how does this work?

<30 sec brainstorming>



Diffuse ball
Illumination ring (IR LEDs)
Wide angle lens
Cold mirror
IR pass filter
Projector
IR cut filter
IR camera

Sphere: Multi-Touch Interactions on a Spherical Display

Hrvoje Benko[1], Andrew D. Wilson[1], and Ravin Balakrishnan[1,2]

[1]Microsoft Research
One Microsoft Way, Redmond, WA, USA
{benko | awilson}@microsoft.com

[2]Department of Computer Science
University of Toronto, Toronto, ON, Canada
ravin@dgp.toronto.edu

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

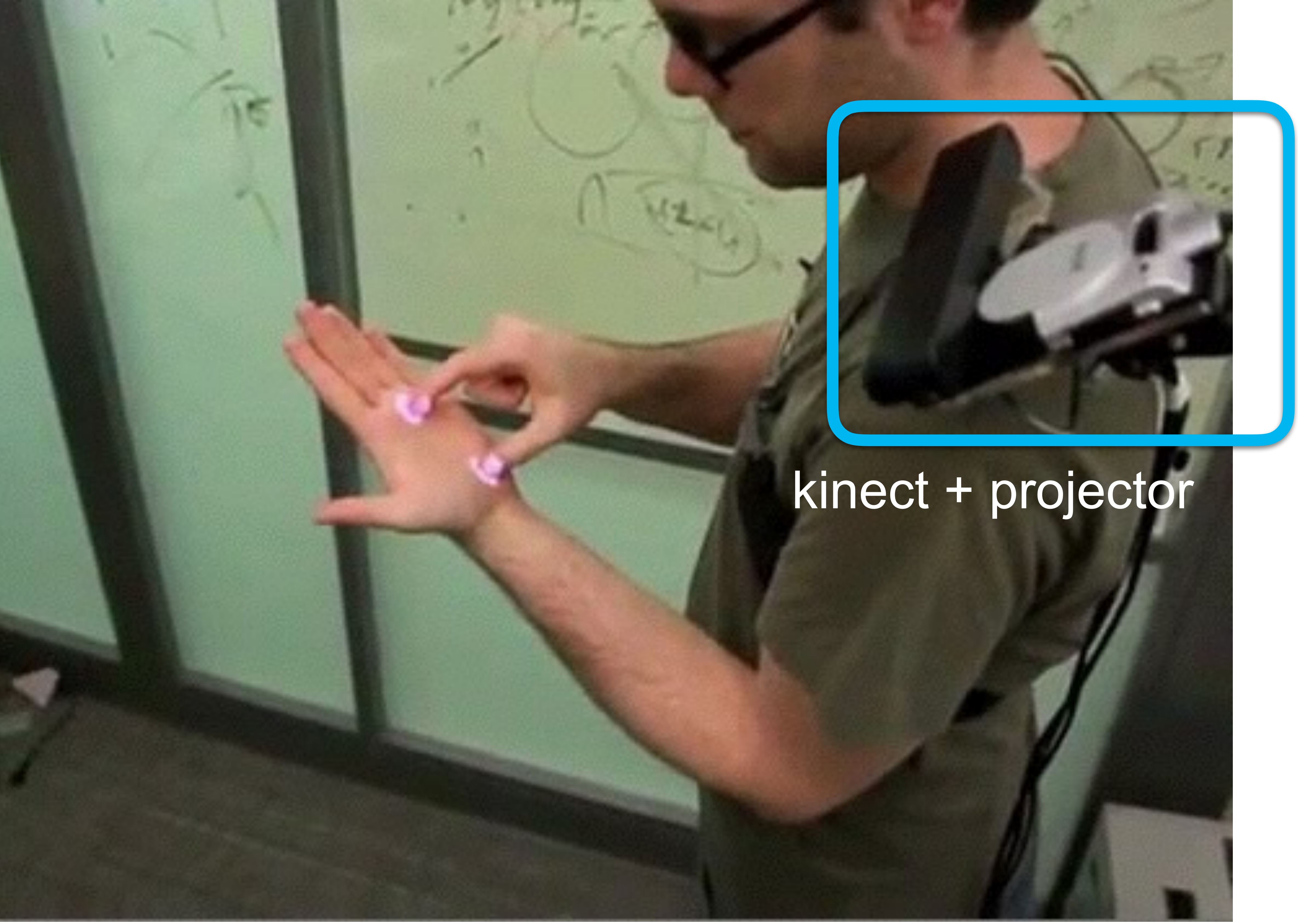
In this paper, we present an implementation of a novel, multi-touch-sensitive, spherical display prototype called *Sphere* (Figure 1). We use Sphere to explore the interactive and collaborative possibilities of spherical interfaces through the development of several concept applications. Our work makes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

2011 skin as display?



2011 skin as display?

OmniTouch: Wearable Multitouch Interaction Everywhere

Chris Harrison[1,2] *Hrvoje Benko*[1] *Andrew D. Wilson*[1]

[1]Microsoft Research
One Microsoft Way
Redmond, WA 98052
{benko,awilson}@microsoft.com

[2]Human-Computer Interaction Institute
Carnegie Mellon University
5000 Forbes Avenue, Pittsburgh PA 15213
chris.harrison@cs.cmu.edu

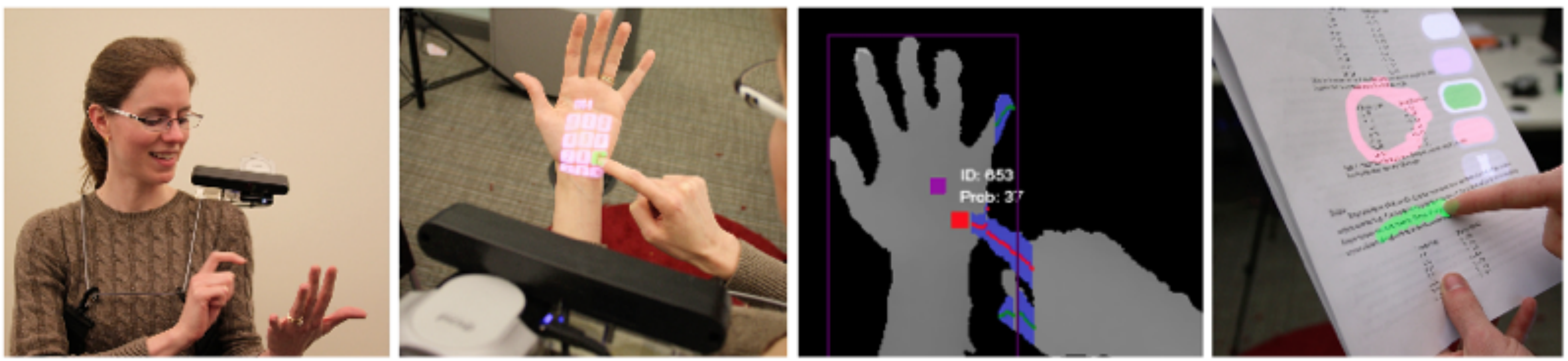


Figure 1. *OmniTouch* is a wearable depth-sensing and projection system that allows everyday surfaces - including a wearer's own body - to be appropriated for graphical multitouch interaction.

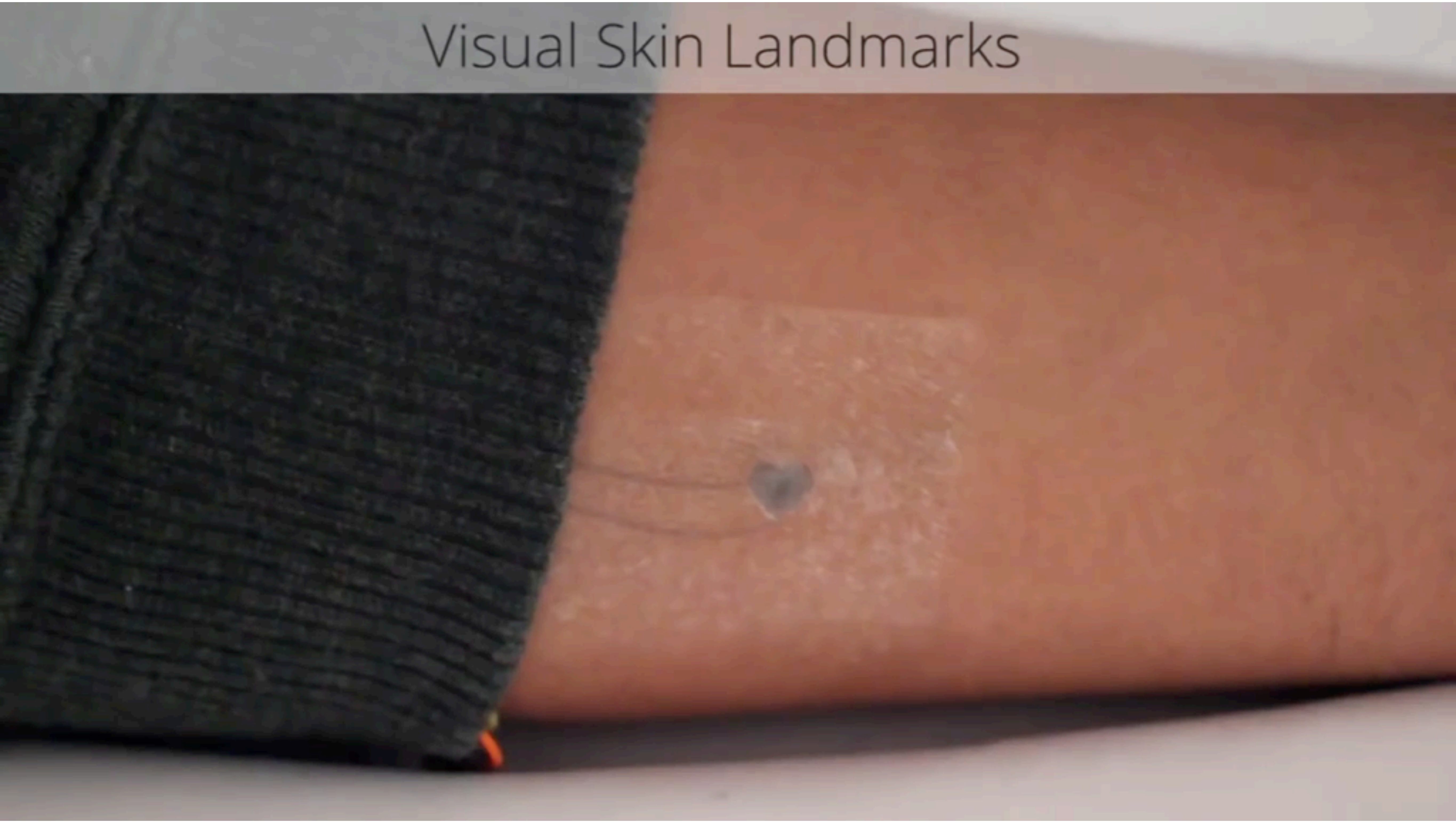
ABSTRACT

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"

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 sur-



yes it’s happening:
2017 simple electro-luminescent skin displays

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

we move very quickly…

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

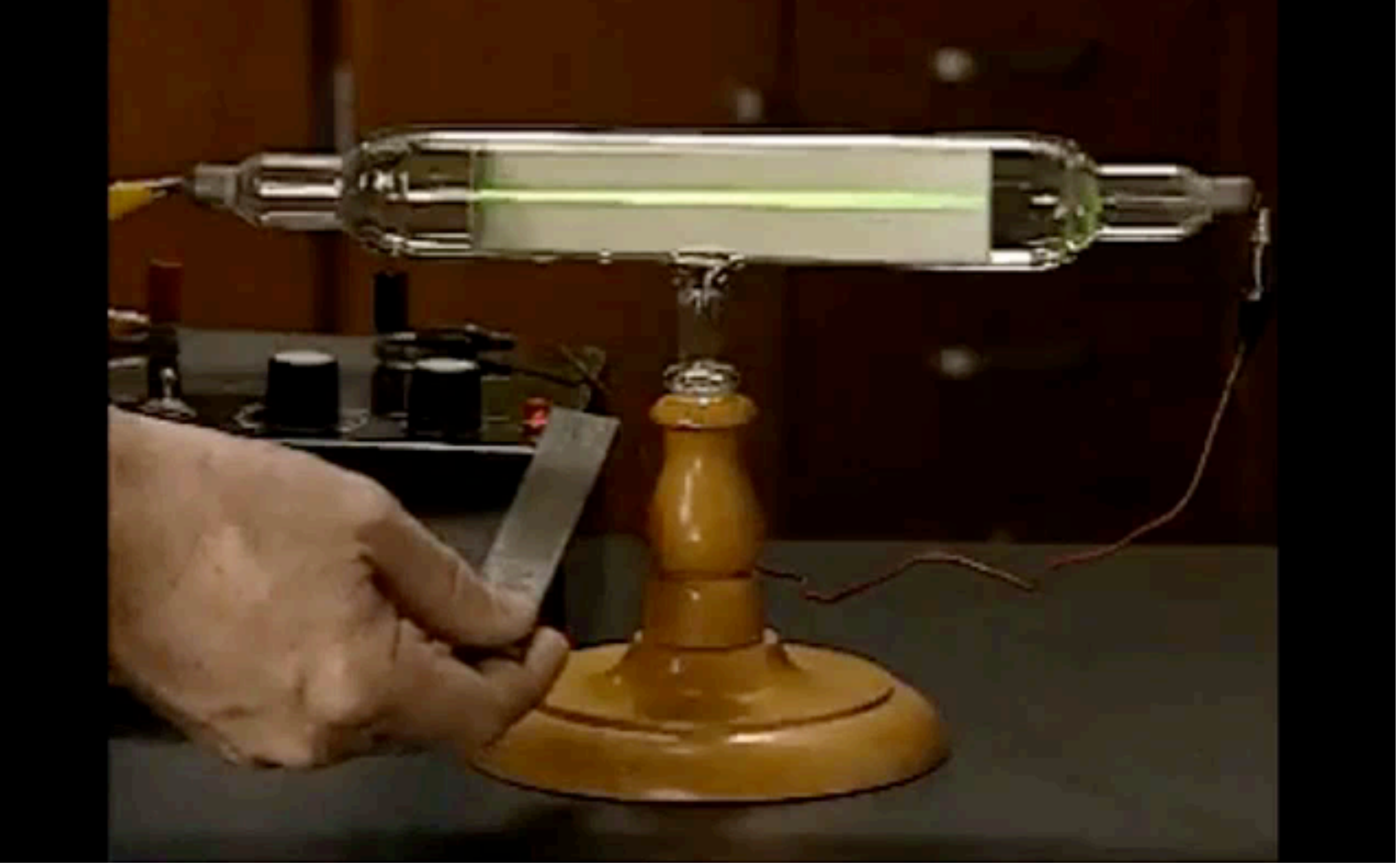
so **how far** are we with display tech?

let’s look at where we came from…

(1957)

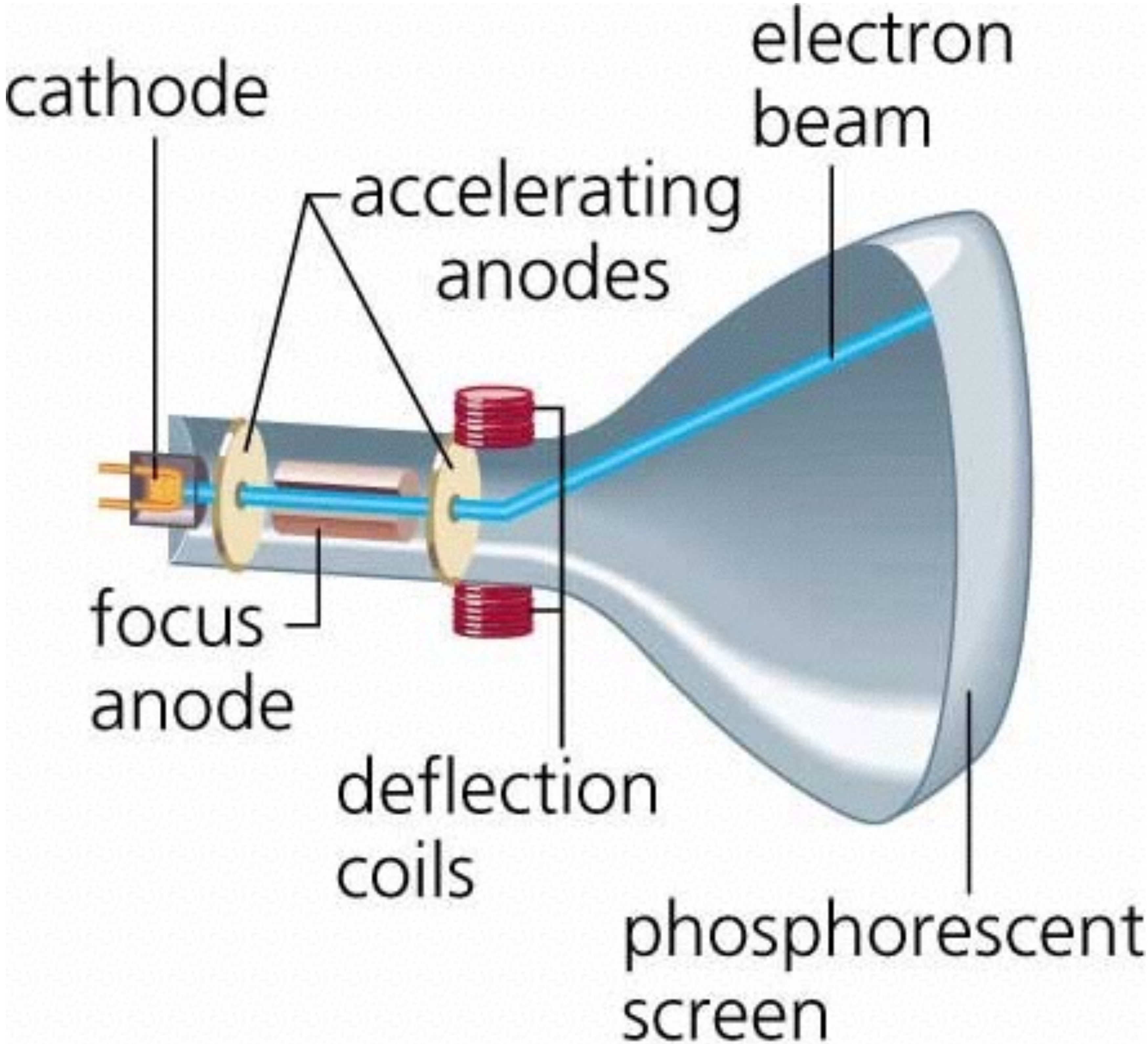
cathode ray tube (CRT)

1922 monochrome cathode ray tubes



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
- only lights up when intensity of beam (charge) high enough
- you needed space for the tube, no flat panel TV



cathode
electron beam
accelerating anodes
focus anode
deflection coils
phosphorescent screen

line-by-line: CRT filmed with a high speed camera

1963: Ivan Sutherland’s Light Pen on CRT

any idea how the pen detection works?

<30 sec brainstorming>

- light sensor on pen
- when CRT beam hits the light pen, the pen 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

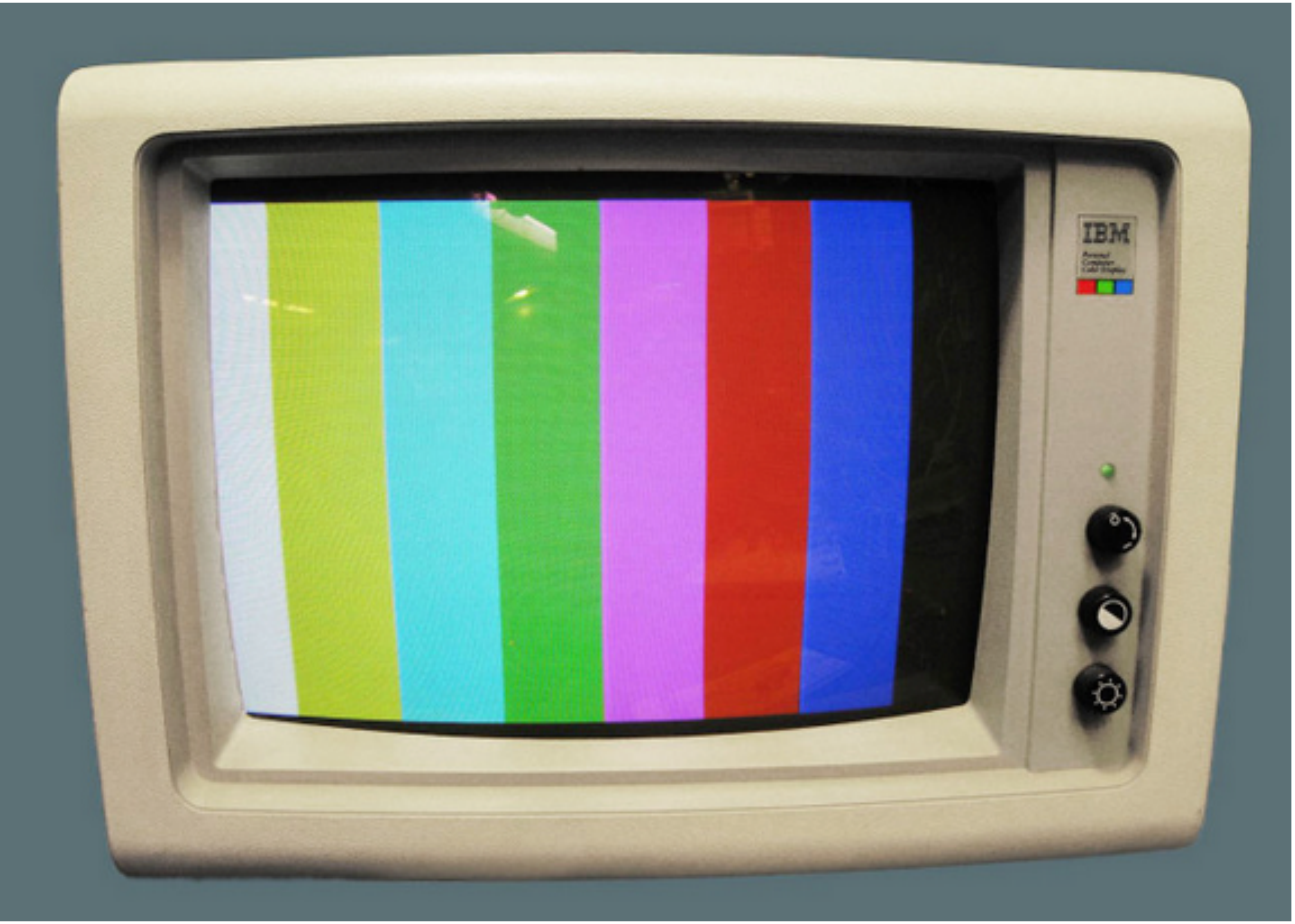
the light pen does no longer work on today's screen,
but the **interaction concept** remains!

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

they just need to be **adapted for each platform**
(e.g. pen for capacitive)

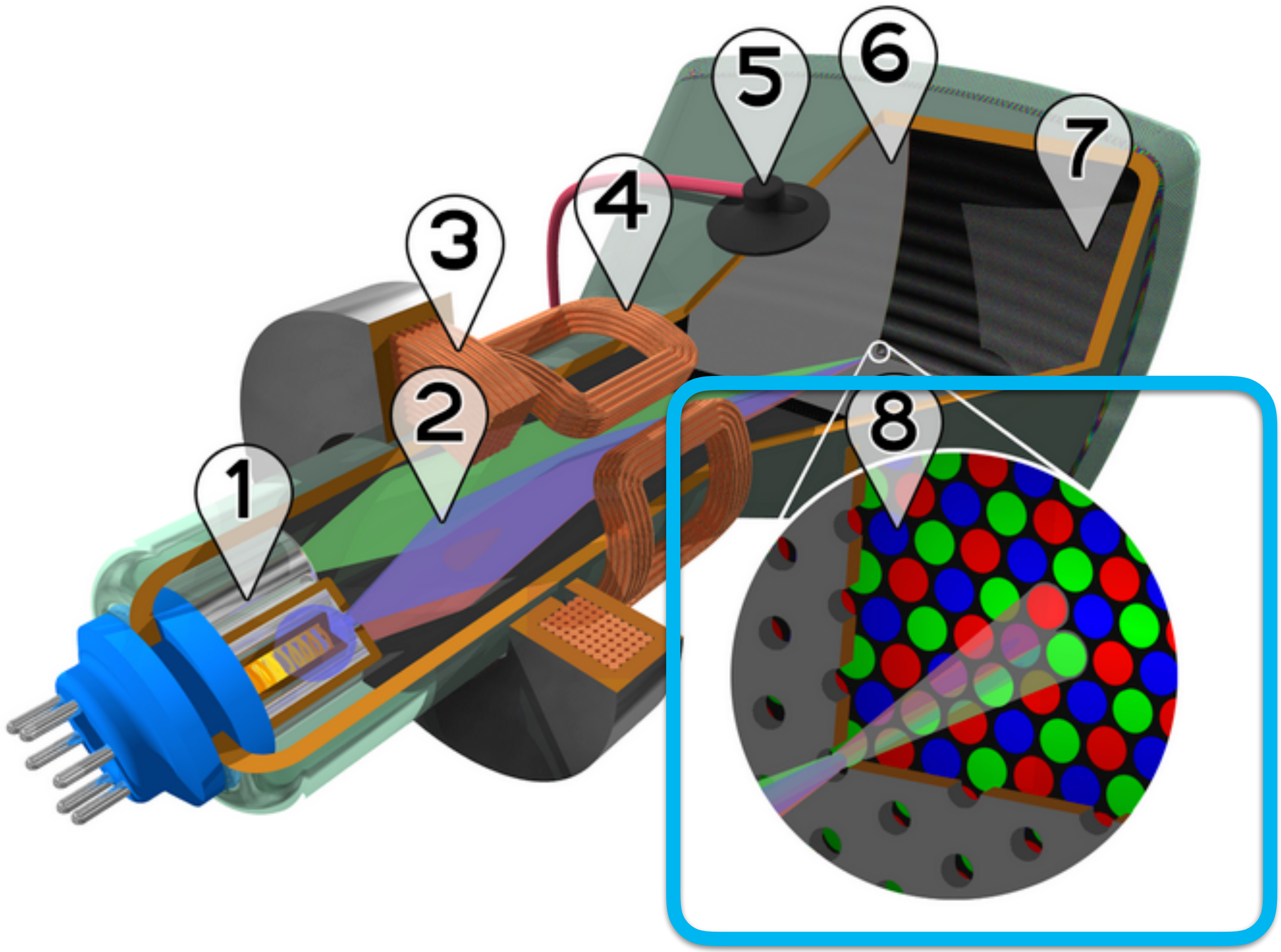
did CRT exist in multi-color?
and if yes, how did they do it?

<30 sec brainstorming>



[IBM CRT 1981)

1954 multi-color cathode ray tubes

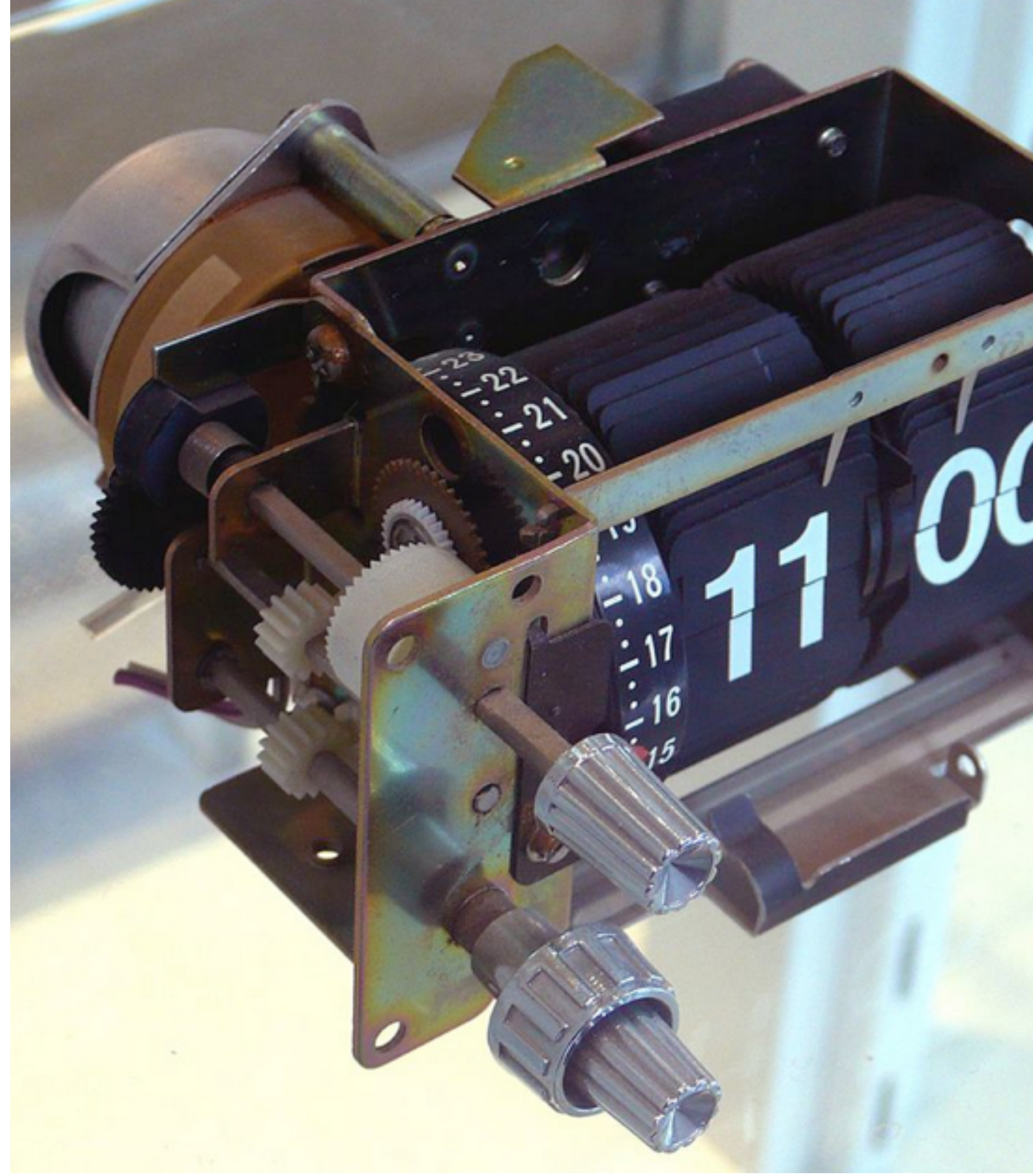


- different phosphor colors coated on screen

(1957)

split-flap display

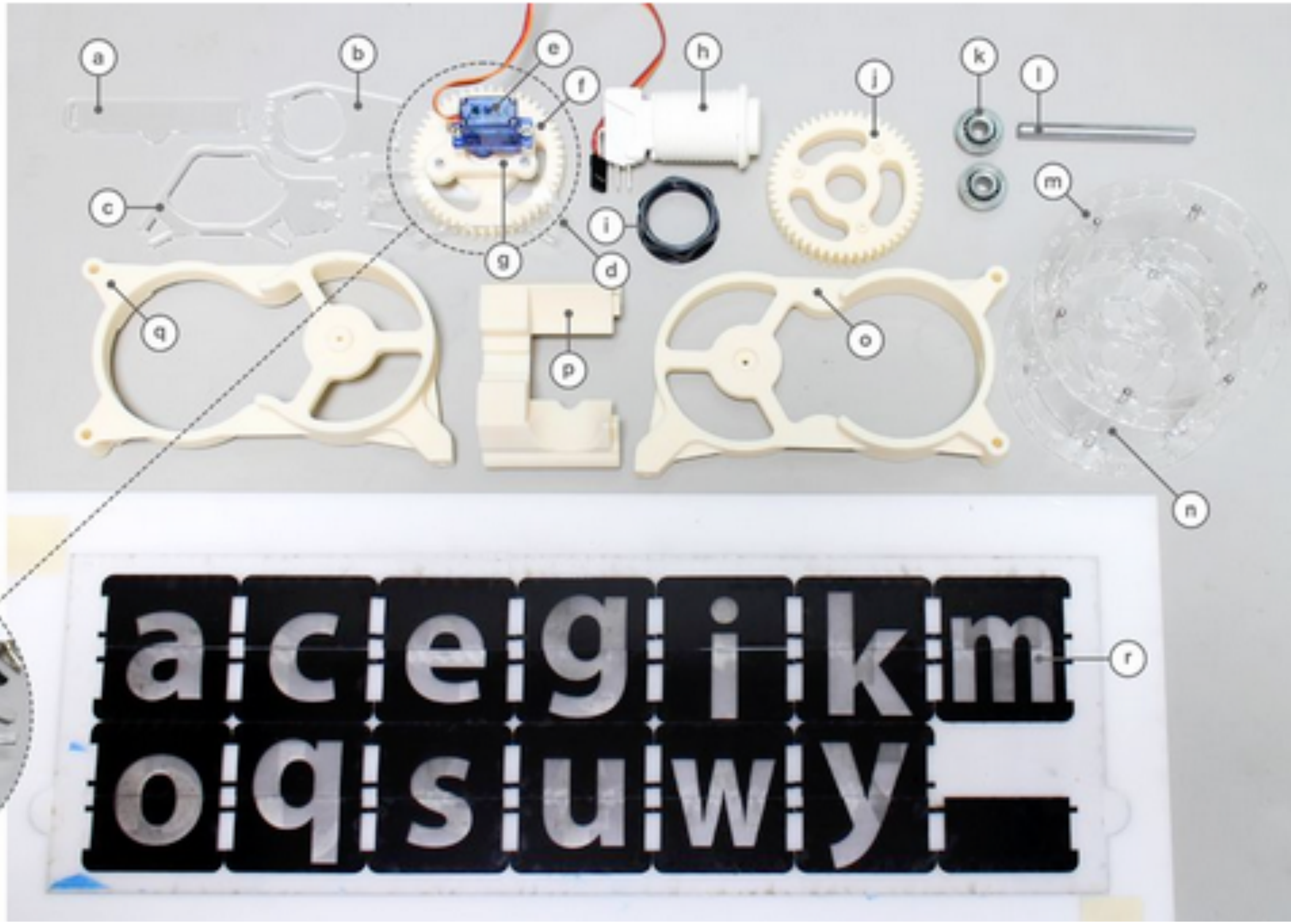
1957 split flap display (electro-mechanical)



1957 split flap display (electro-mechanical)

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

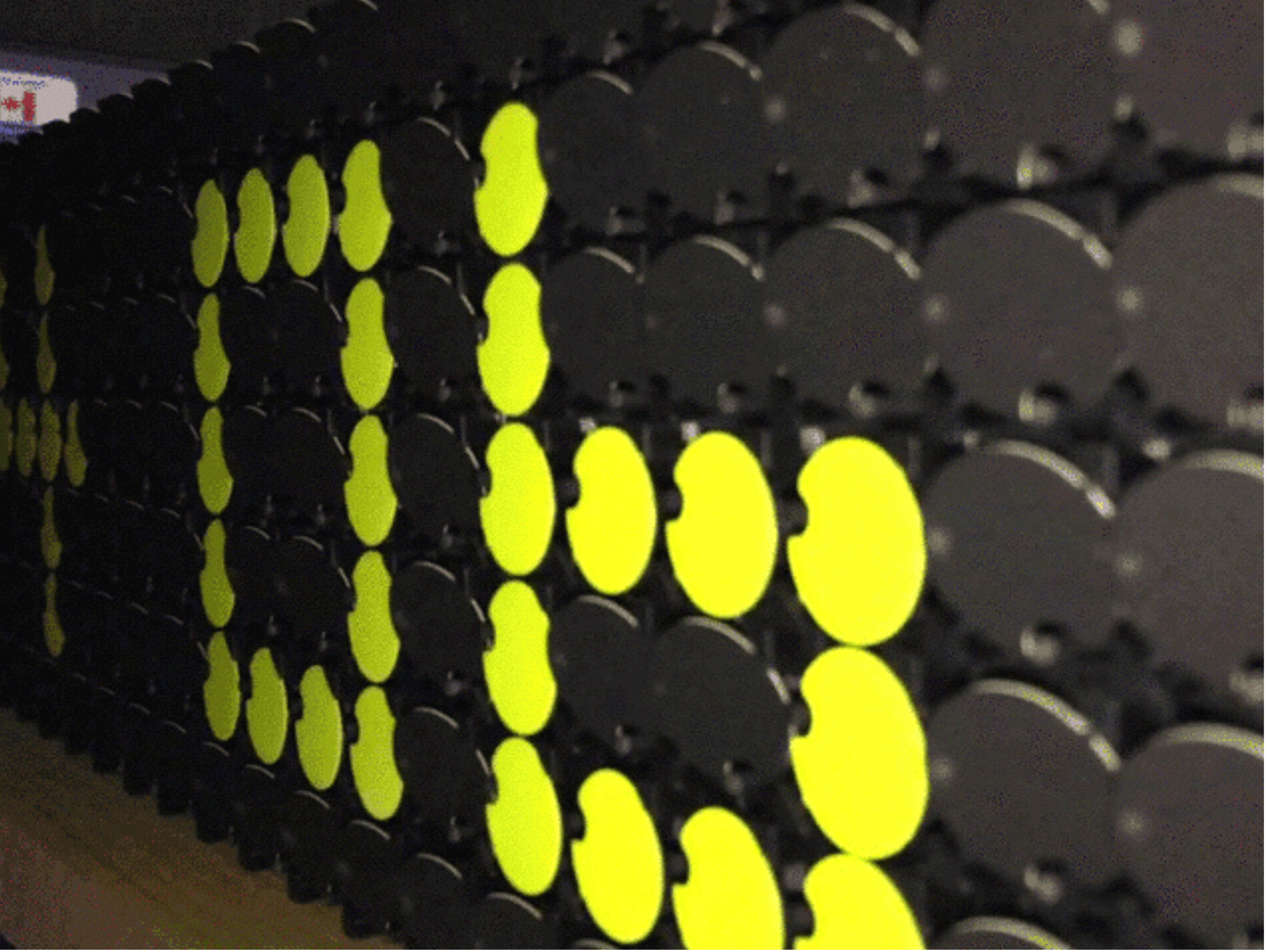
a. tongue
b. button bracket
c. side bracket
d. motor bracket
e. servo motor
f. active gear
g. motor mount
h. arcade button
i. arcade button nut
j. passive gear
k. 1/4" Ø bearing (2)
l. 1/4" X 3" shaft
m. wheel (2)
n. wheel spar (6)
o. end cap (right)
p. bottom bracket
q. end cap (left)
r. flaps (27)



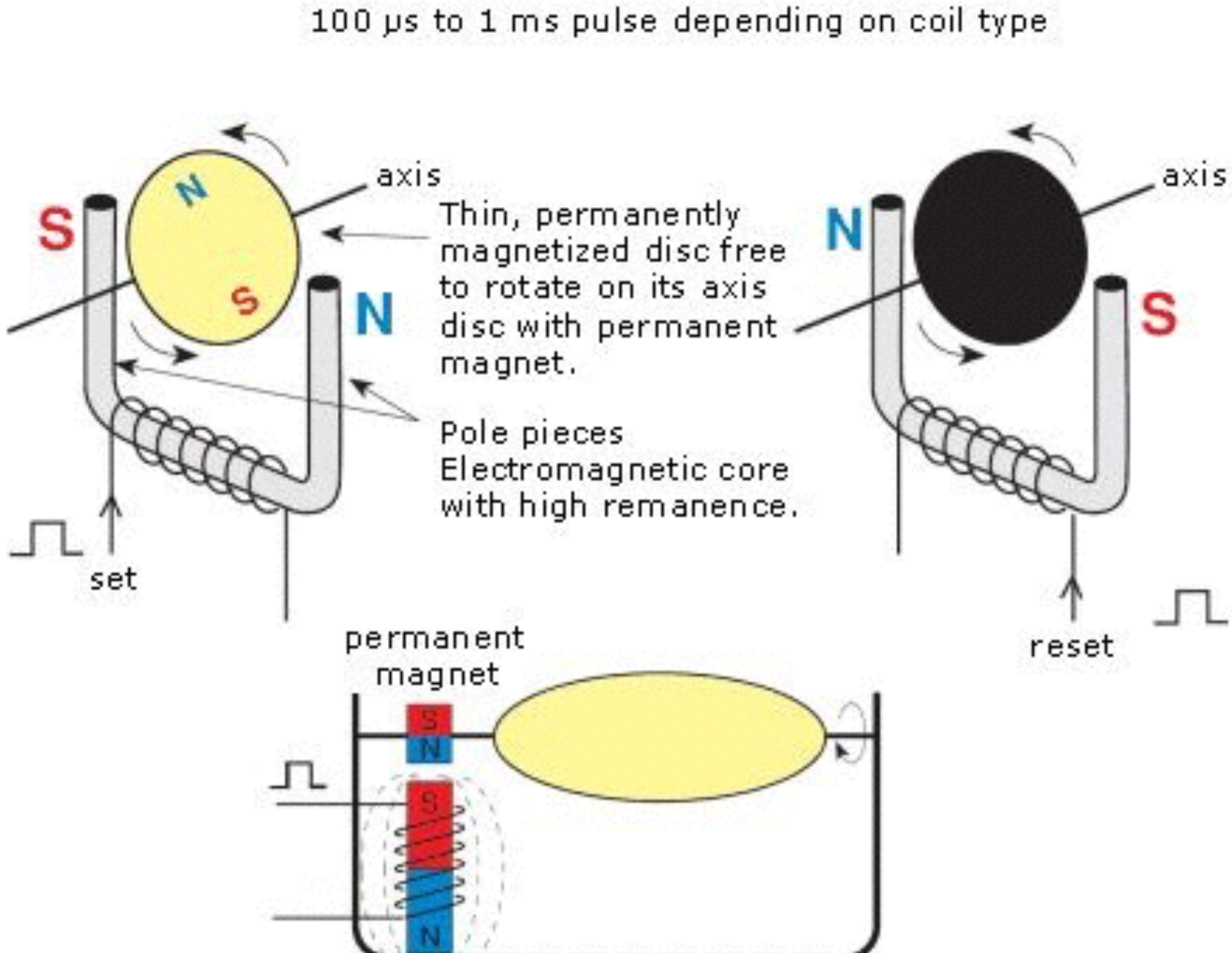
http://www.instructables.com/id/Split-Flap-Display/

(1961)

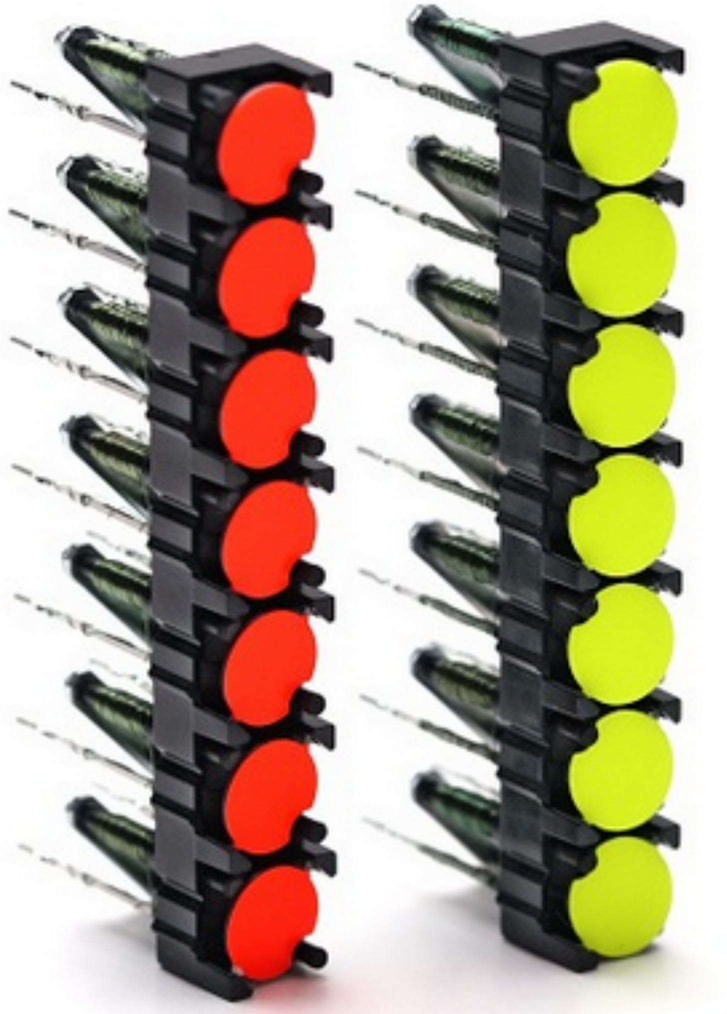
flip-disc display

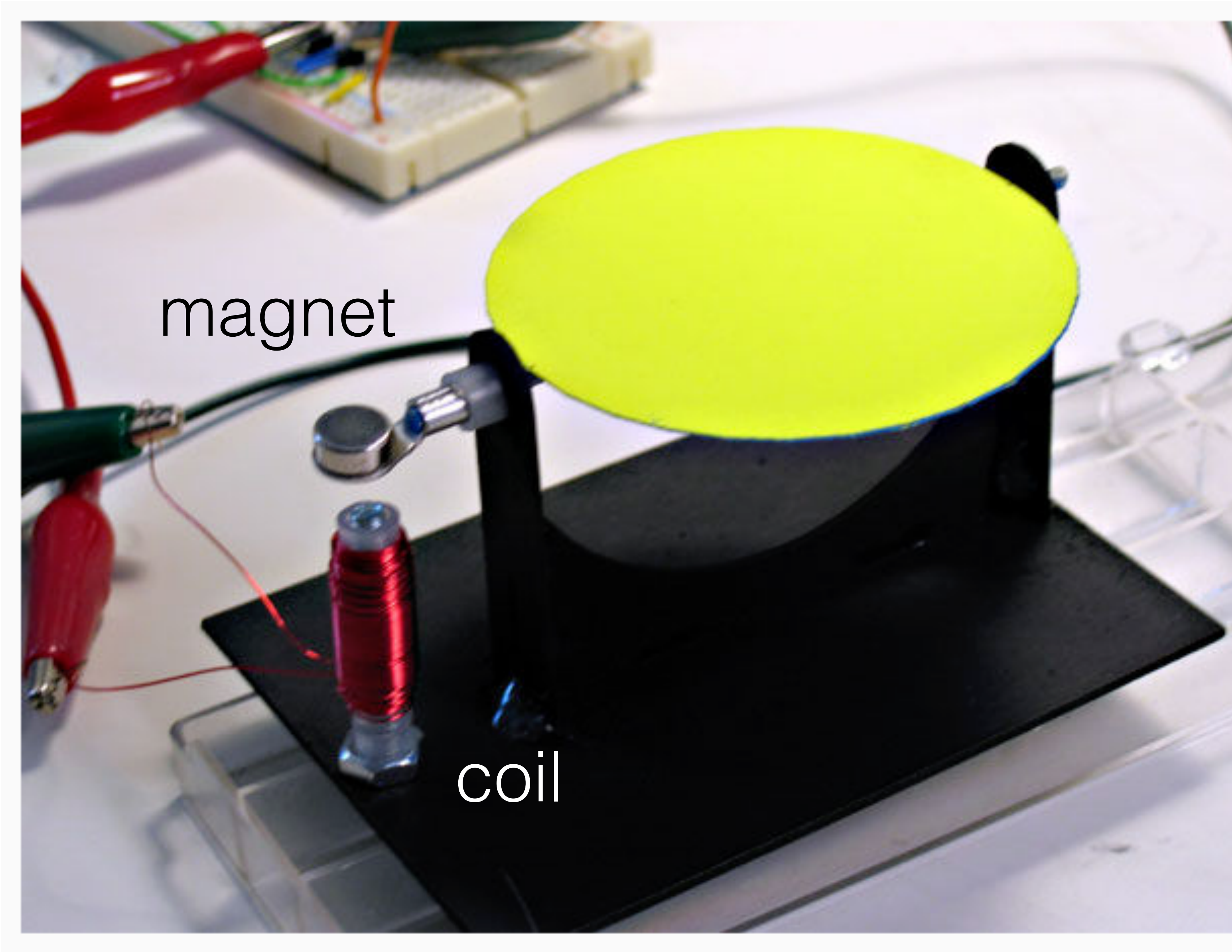


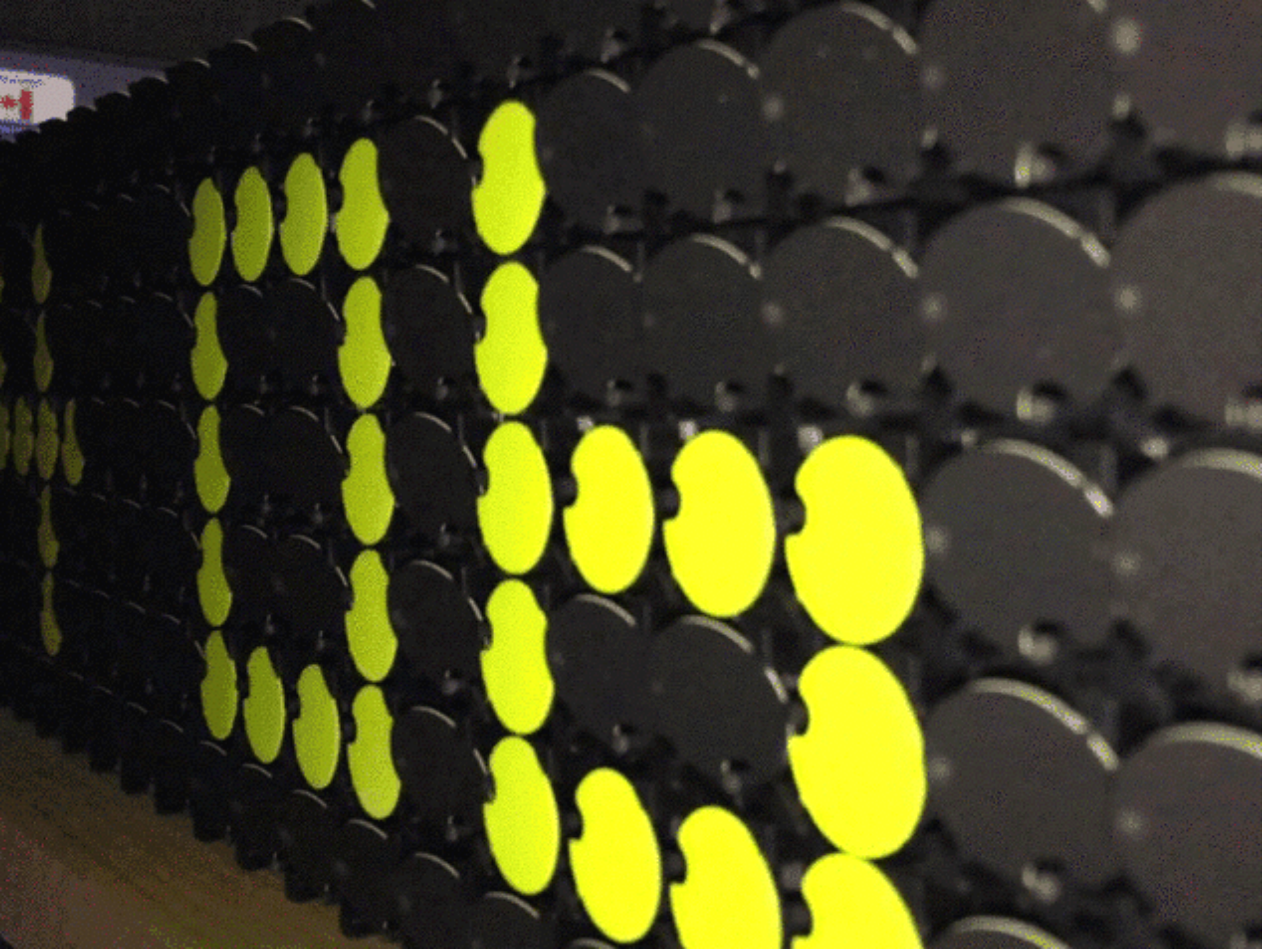
1961 flip-disc display (electro-magnetic)



Residual magnetism provides memory.

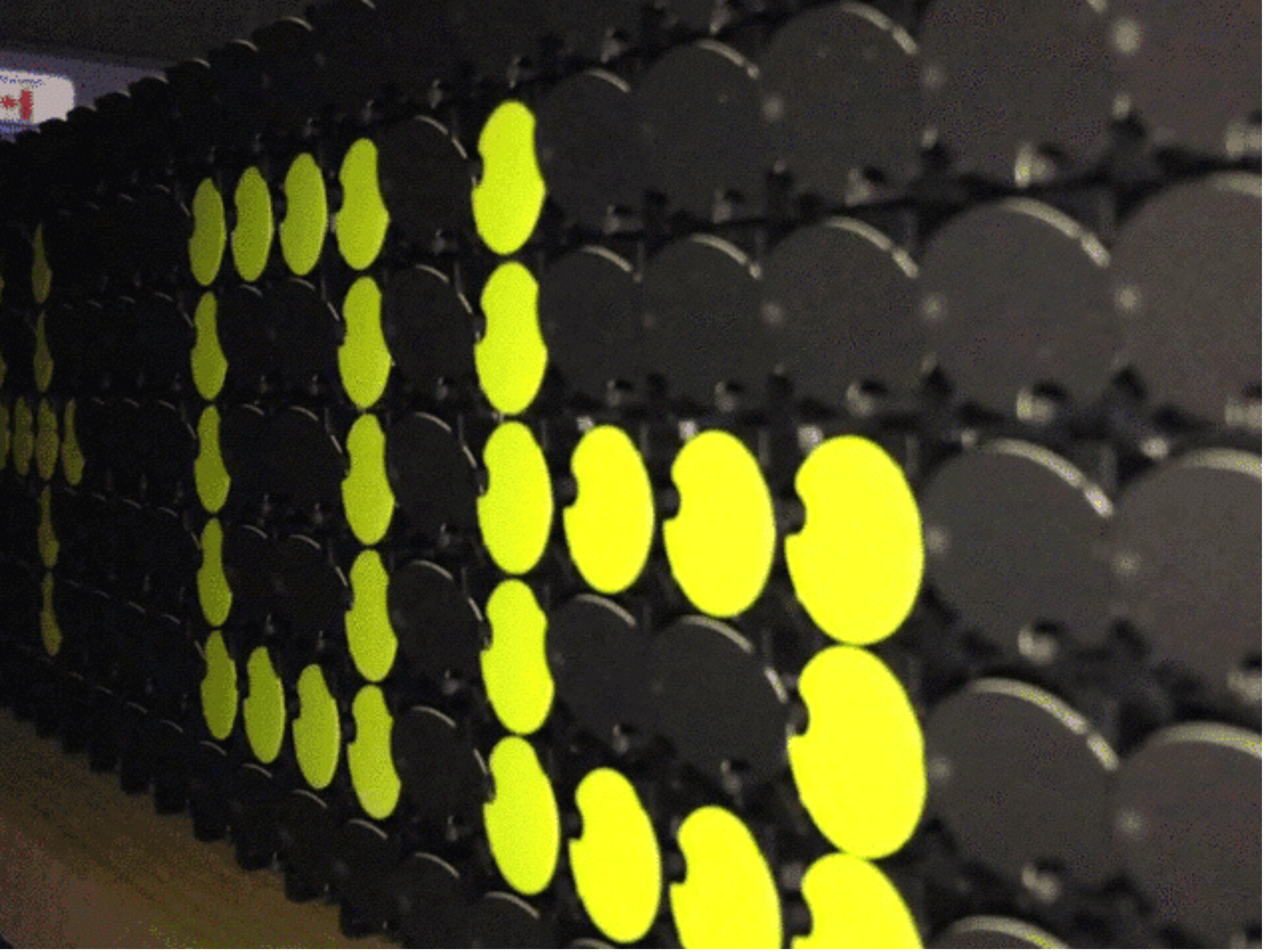



magnet
coil



how would you build user input for this?
e.g. touch input or pen input to set the color of a region?

<30 sec brainstorming>



how would you build user input for this?
e.g. touch input or pen input to set the color of a region?

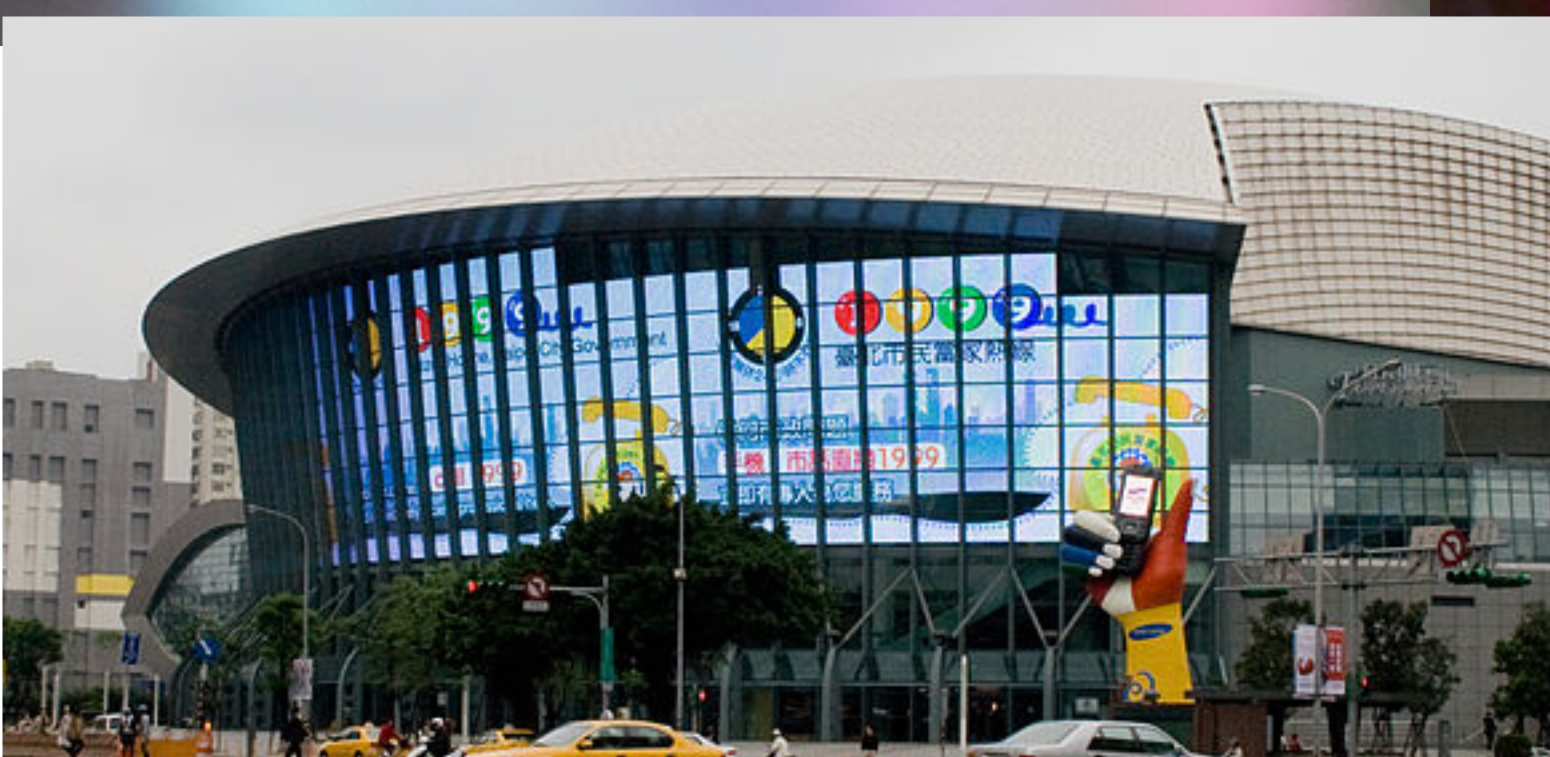
change the magnetic field
e.g. electro-magnetic finger marker.
e.g. electro-magnetic pen.

(1968)

light-emitting diode (LED)

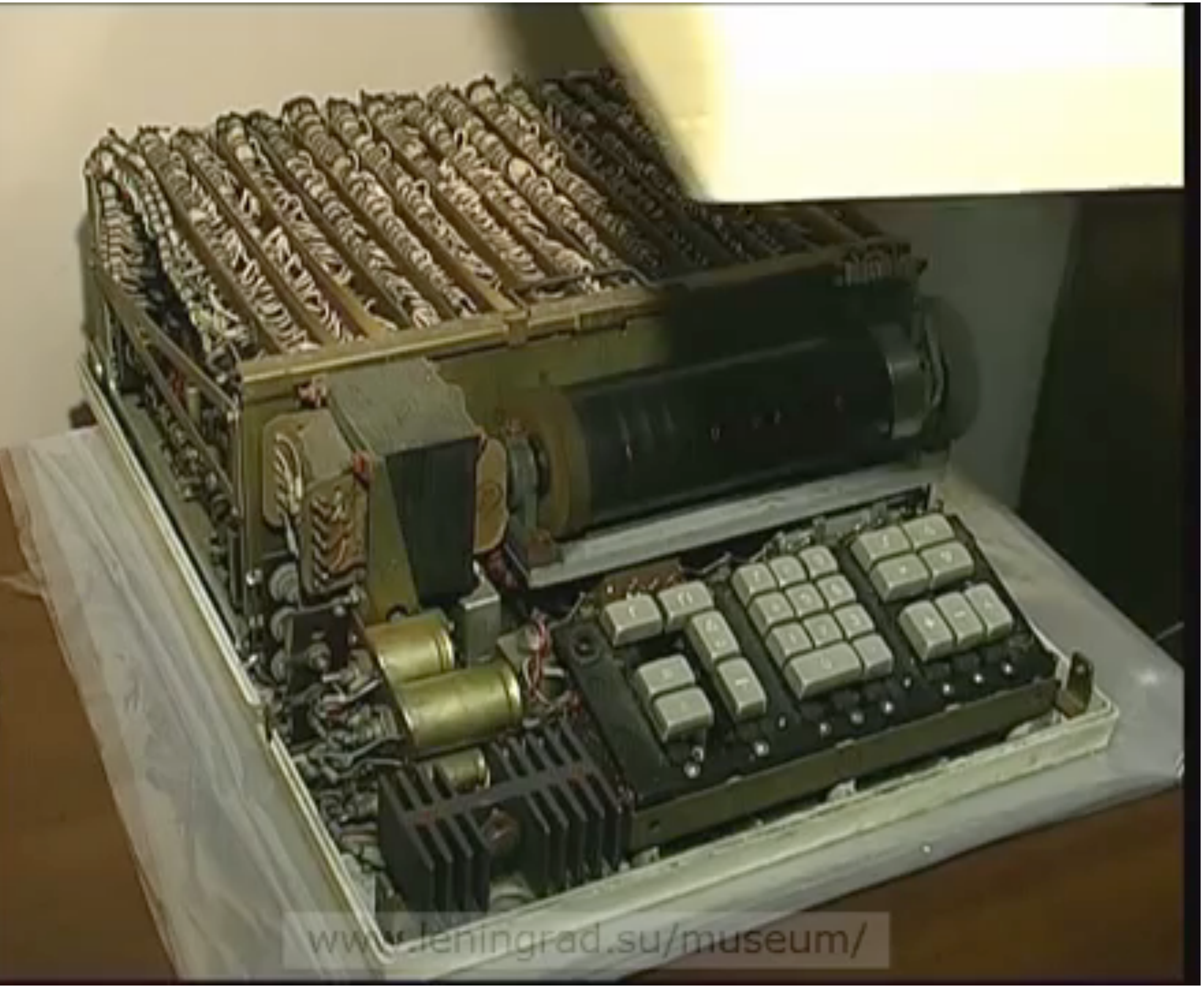
1968 light emitting diode

- billboard signs
- advertisement

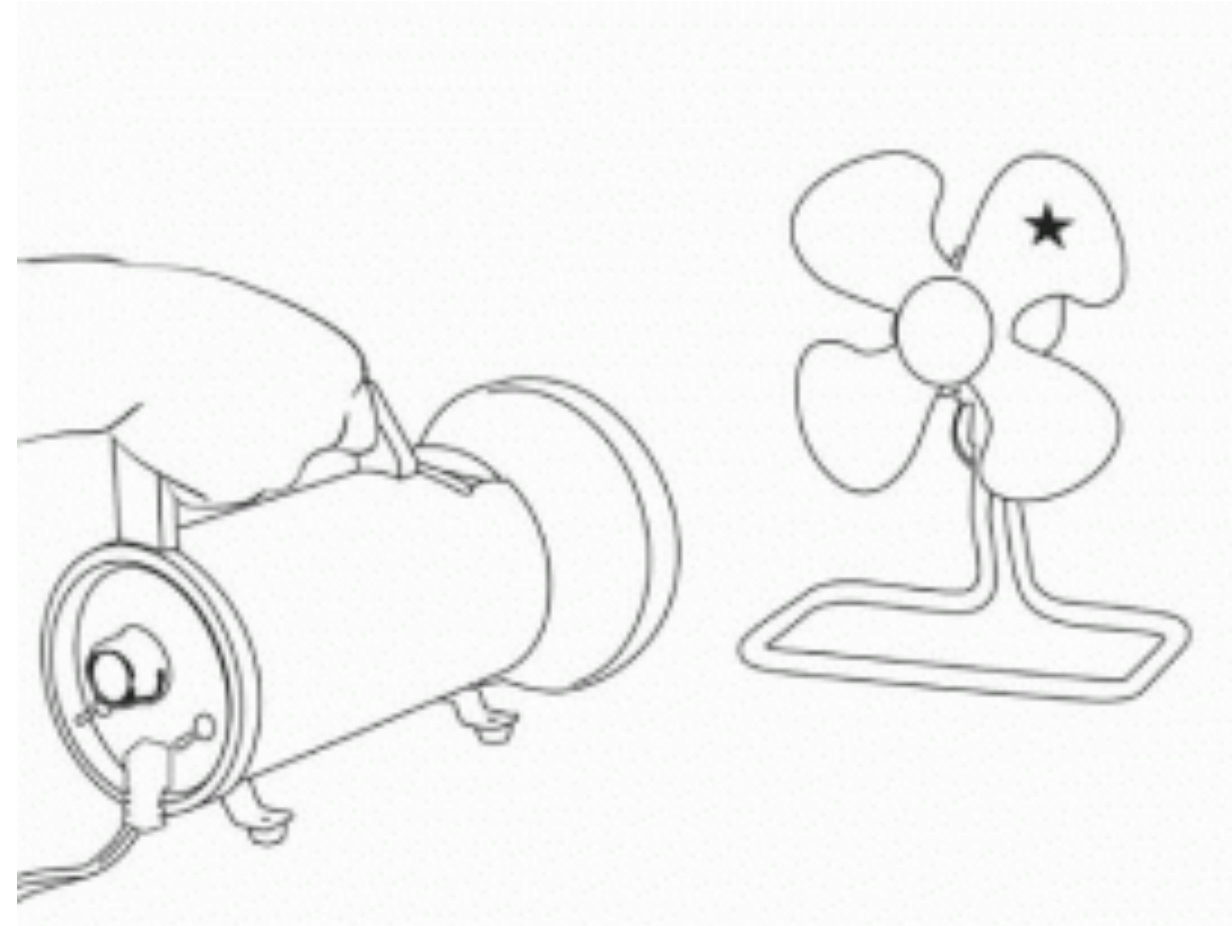


(1968)

stroboscopic display

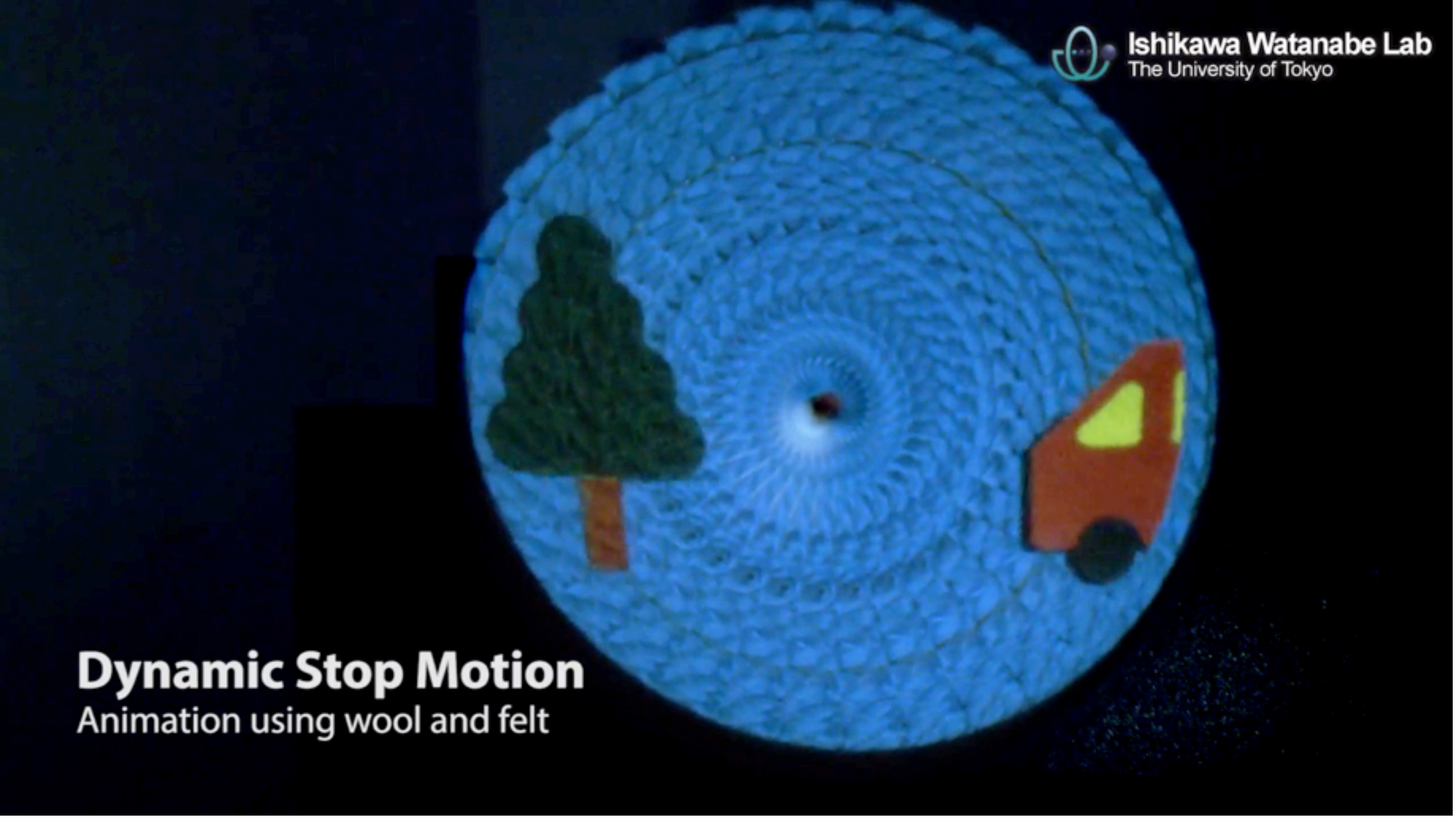


1960s stroboscopic displays:
rotating cylinder, but it appears to be standing still!



stroboscopic effect:

- series of intense light flashes at specific intervals
- emitted onto an object rotating 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



let's apply this,
any idea how this works?
yes this is real wool and real felt.

<30 sec brainstorming>


Ishikawa Watanabe Lab
The University of Tokyo


Ishikawa Watanabe Lab
The University of Tokyo
3D Shape Mixture
Recomposition of multiple objects

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

Takatoshi Yoshida
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku,
Tokyo, Japan
takatoshi_yoshida@ipc.i.u-tokyo.ac.jp

Yoshihiro Watanabe
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku,
Tokyo, Japan
yoshihiro_watanabe@ipc.i.u-tokyo.ac.jp

Masatoshi Ishikawa
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku,
Tokyo, Japan
masatoshi_ishikawa@ipc.i.u-tokyo.ac.jp

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-

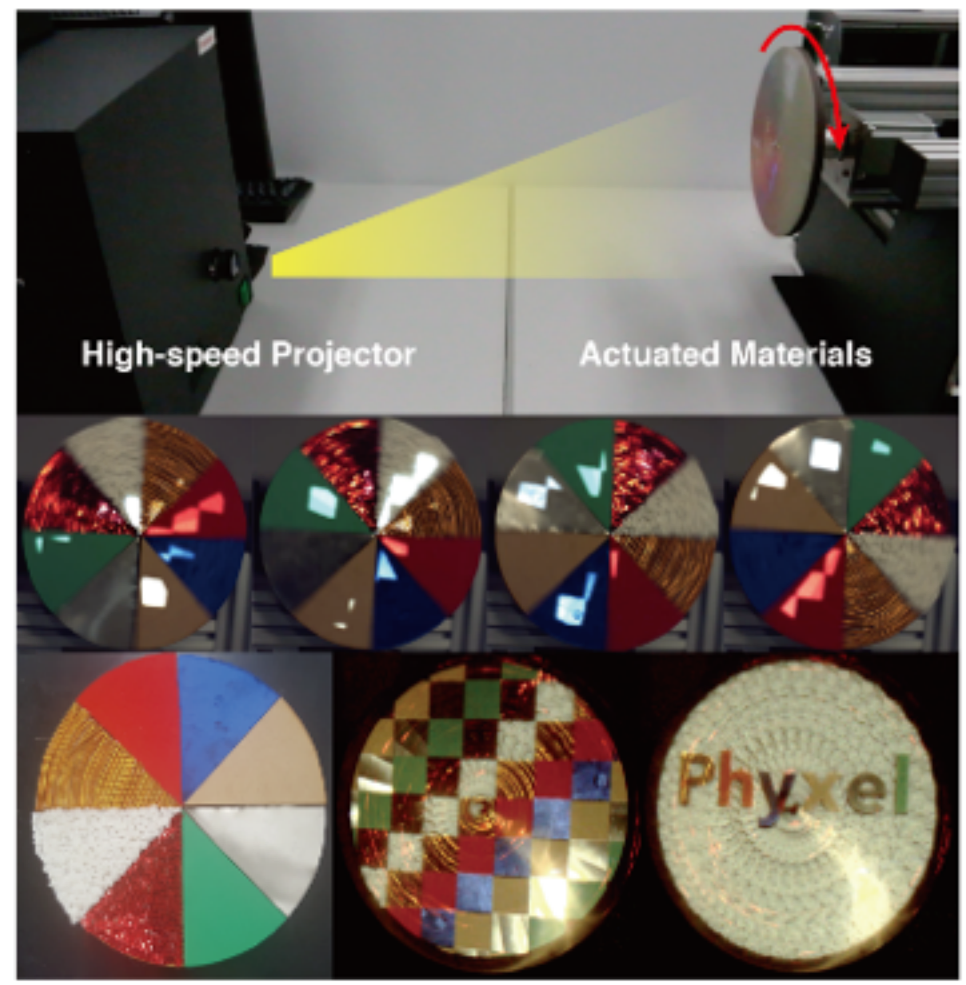
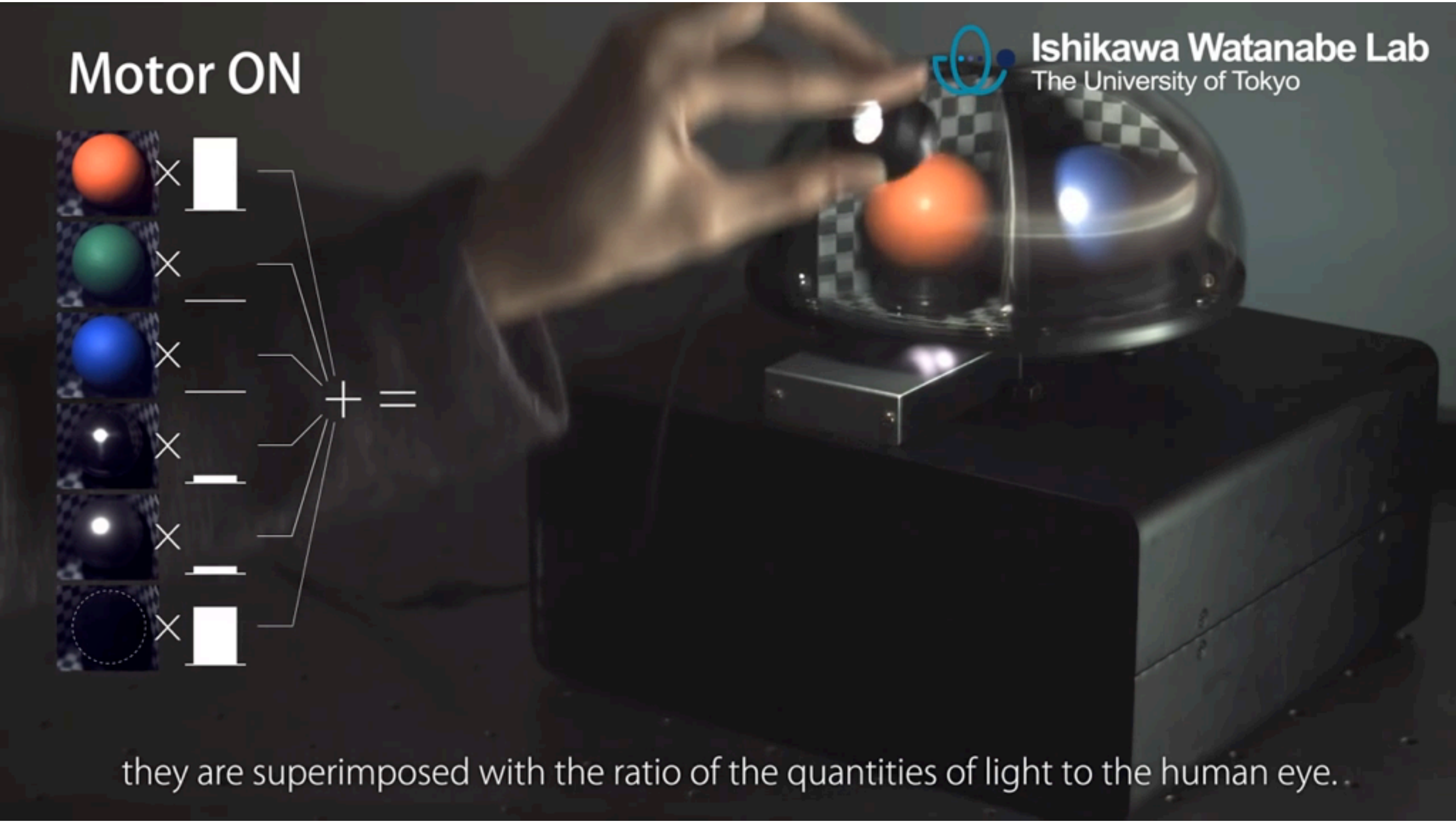


Figure 1. (top) Photograph of the proposed system: adaptive lighting patterns are projected at high speed onto actuated physical materials. (middle) A decomposed sequence captured by a high-speed camera (actuating materials are illuminated by pixelated lighting, and the pattern changes with rotation). (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.



same principle…

ZoeMatrope: A System for Physical Material Design

Leo Miyashita, University of Tokyo
Kota Ishihara, PKSHA Technology Inc.
Yoshihiro Watanabe, University of Tokyo
Masatoshi Ishikawa, University of Tokyo

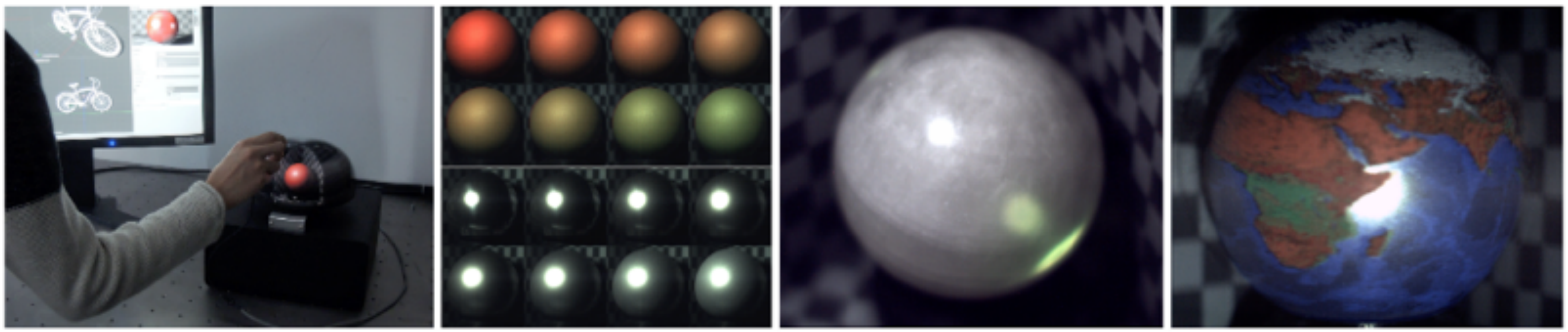


Figure 1: *We introduce a novel material display based on a zoetrope and a thaumatrope. (left) The system can represent a variety of realistic materials and assist physical material design. (left center) Material animation. (right center) Augmented material composed of marble and green glass. (right) Spatially-varying material formed by combining many materials.*

Abstract

Reality is the most realistic representation. We introduce a material display called ZoeMatrope that can reproduce a variety of materials with high resolution, dynamic range and light field reproducibility by using compositing and animation principles used in a zoetrope and a thaumatrope. With ZoeMatrope, the quality of the material is equivalent to that of real objects and the range of expressible materials is diversified by overlaying a set of base materials in a linear combination. ZoeMatrope is also able to express spatially-varying materials, and even augmented materials such as materials with an alpha channel. In this paper, we propose a method for selecting the optimal material set and determining the weights of the linear combination to reproduce a wide range of target materials properly. We also demonstrate the effectiveness of this approach with the developed system and show the results for various materials.

Keywords: zoetrope, strobe light, thaumatrope, material composition, diffuse, specular

Concepts: •Human-centered computing → Systems and tools

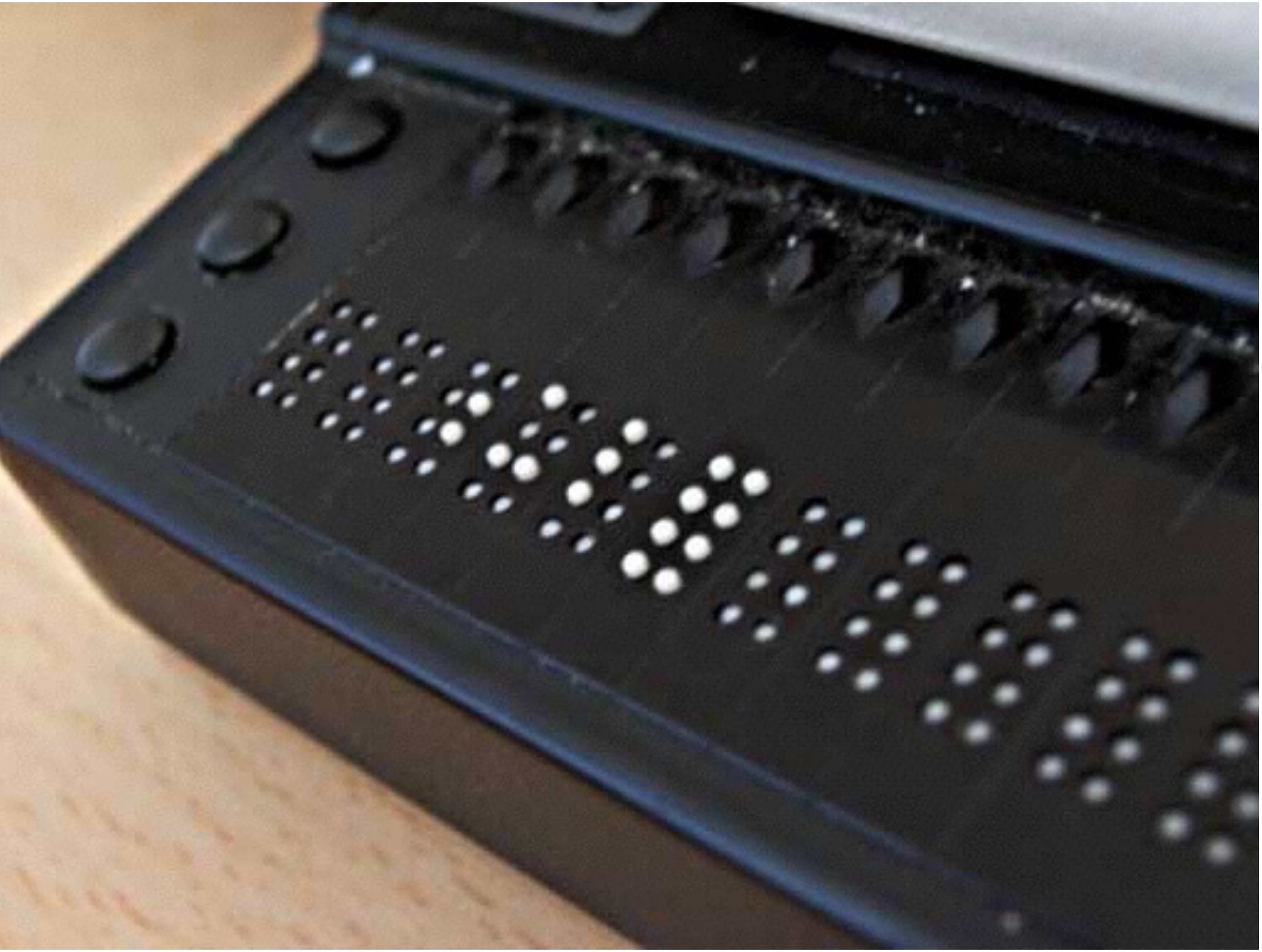
and users can utilize these images for checking whether the materials perform as intended. The realistic presentation of materials is essential for not only designing a material but also confirming the color and gloss in internet shopping. In addition, it enhances various immersive experiences in art, media, and augmented reality.

However, conventional displays cannot represent realistic materials due to their limitations, including resolution, dynamic range and freedom of the viewing and lighting directions. Some research has attempted to improve these issues by using technologies such as projection mapping techniques and specialized displays; however, the results are still far behind reality, or the kinds of expressible materials are limited.

Our key concept to display a realistic material is to use real materials. Display devices using real objects have been developed over a long period of time; the zoetrope and the thaumatrope are two examples of them. The zoetrope is a device that can animate pictures or 3D objects by apparent motion with a rotating base and cut slits or strobe light, as shown in Fig. 2 (a). The thaumatrope is a device that can composite pictures switched at high speed by exploiting

(1969)

braille display / pin screen



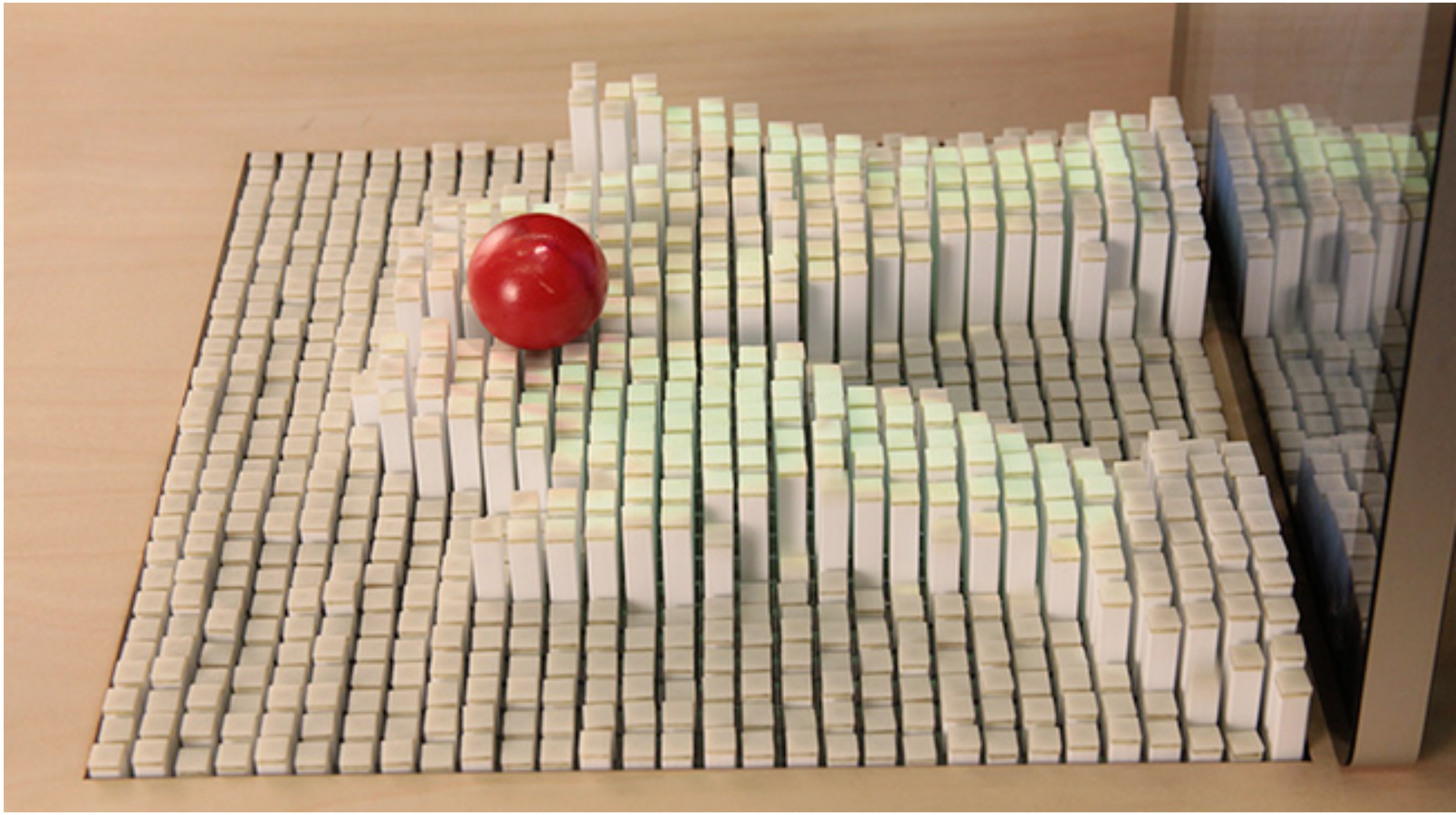
1969 braille display for the blind and visually impaired

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

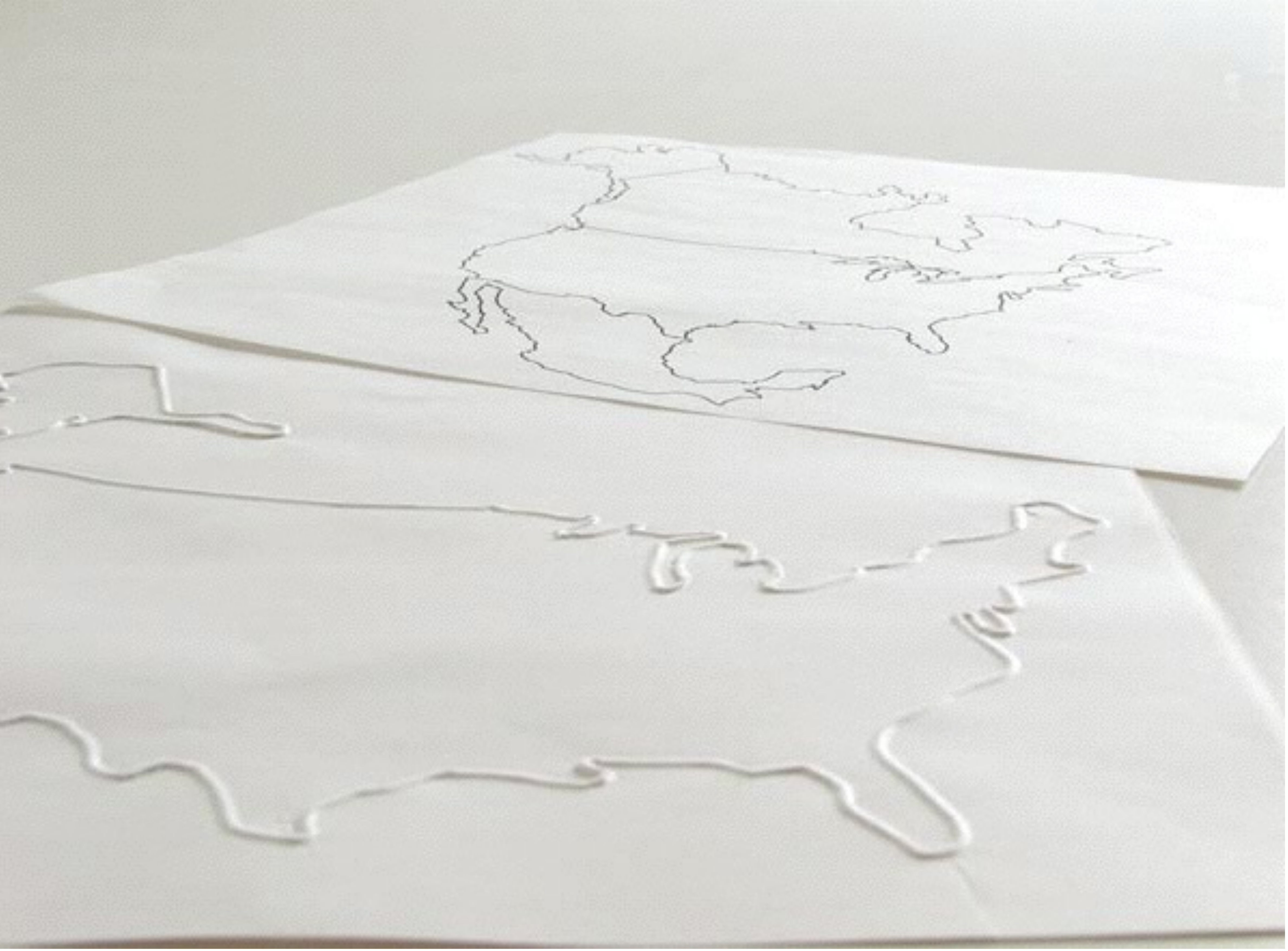
much later 1994: HyperBraille
(allows blind users to browse the internet)



was the inspiration for some newer tech…

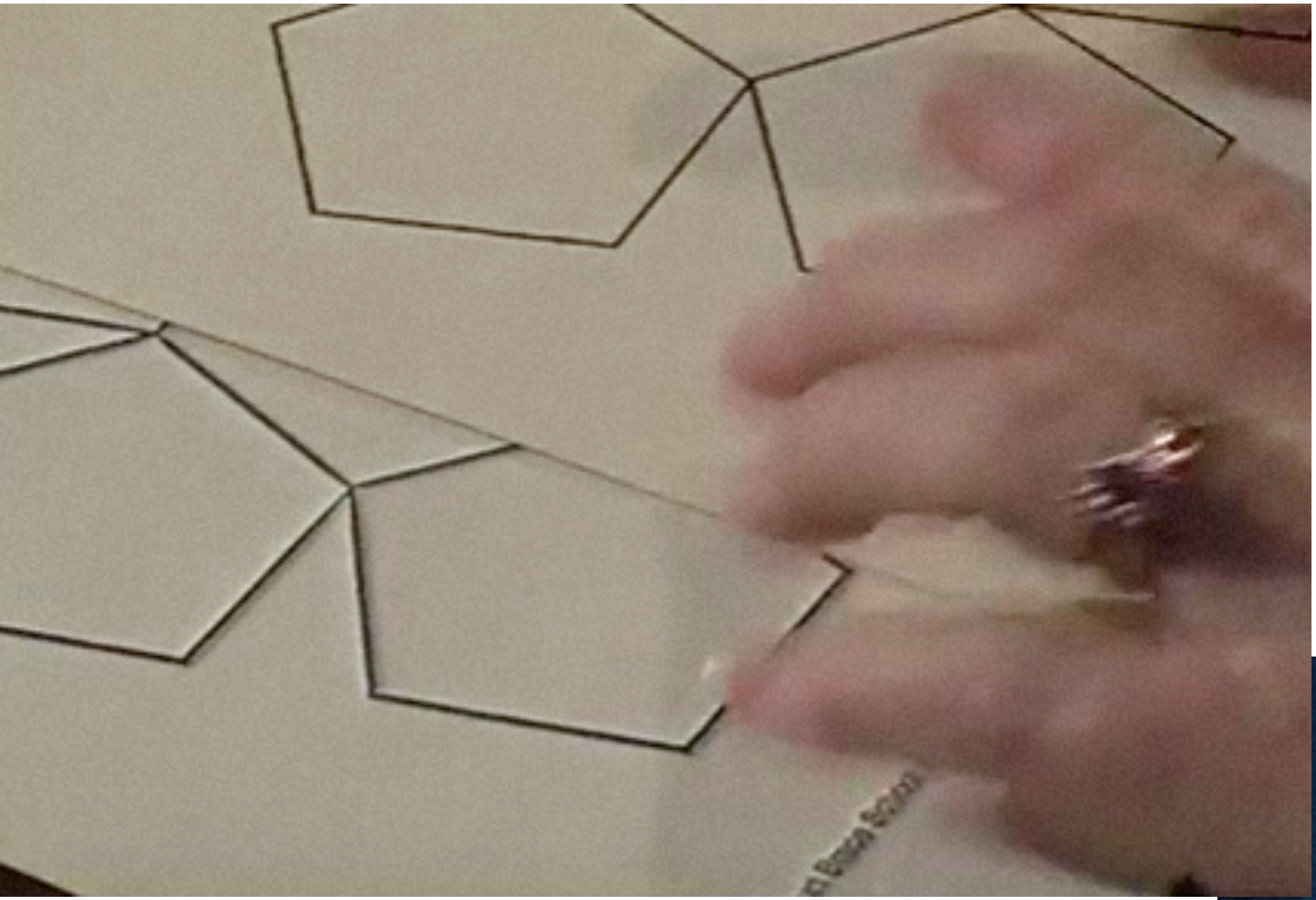
this is very expensive… $10,000+
how would you build a cheaper tactile interactive display?

<30 sec brainstorming>

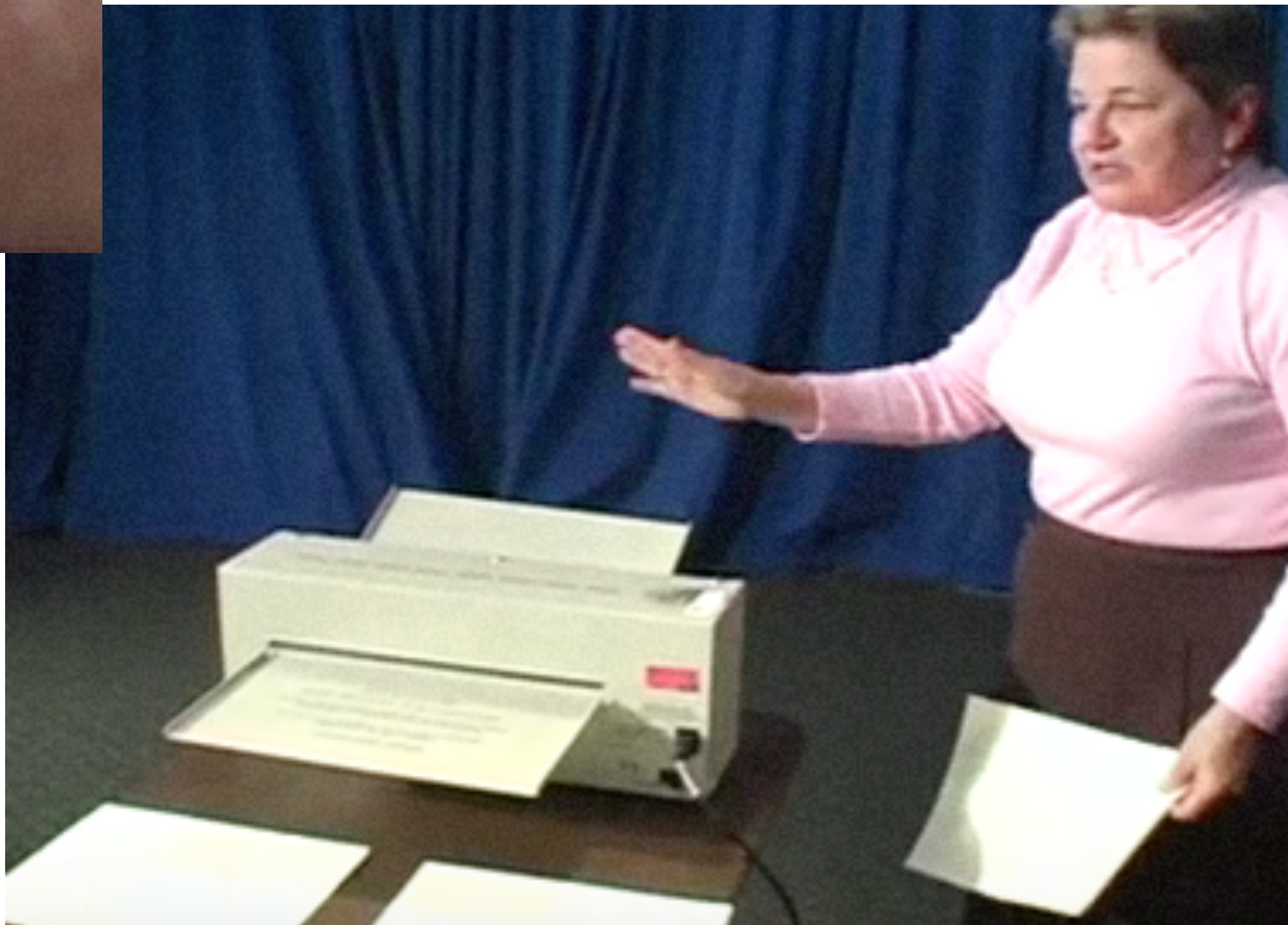


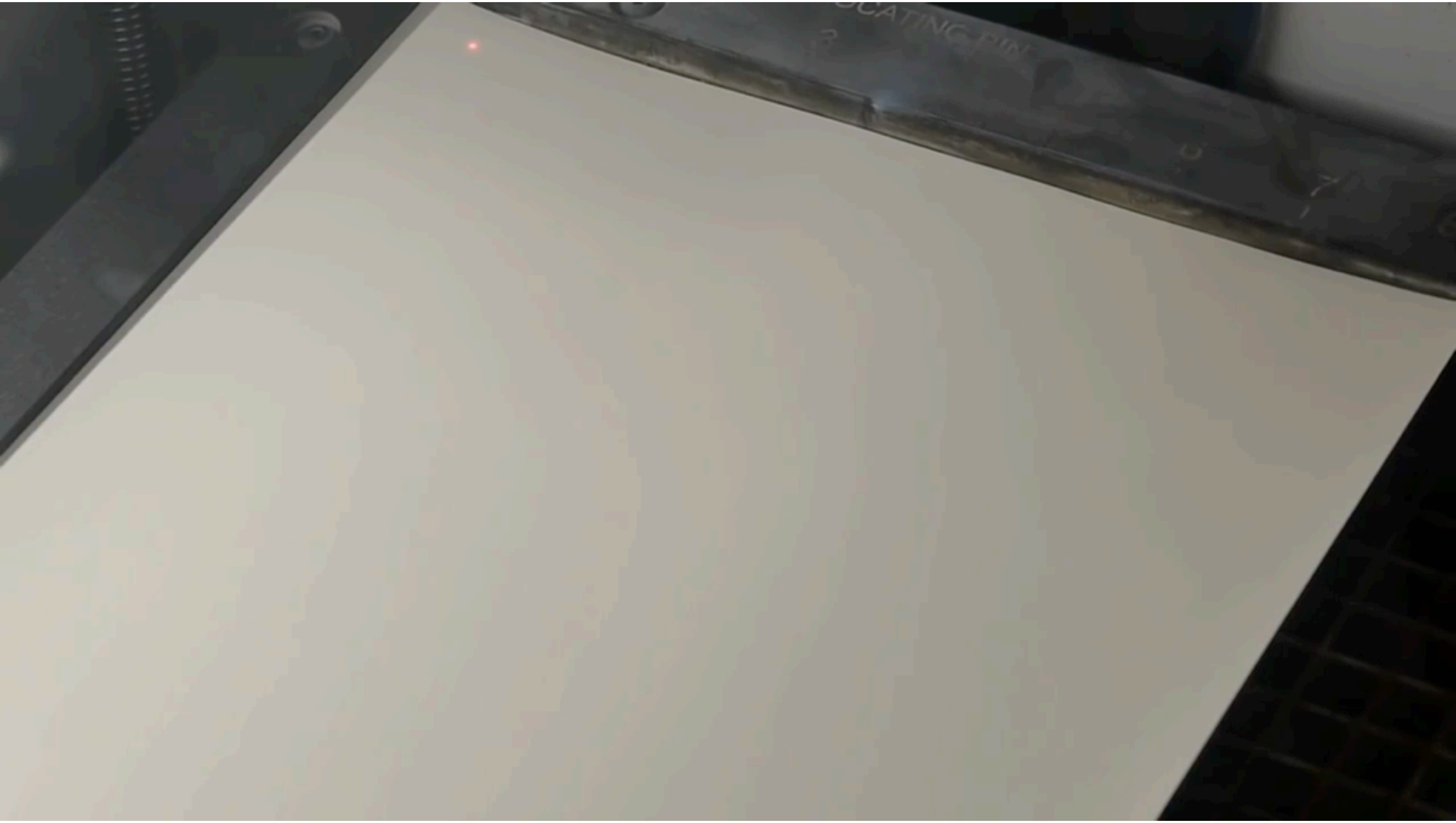
swell paper

create black line drawing



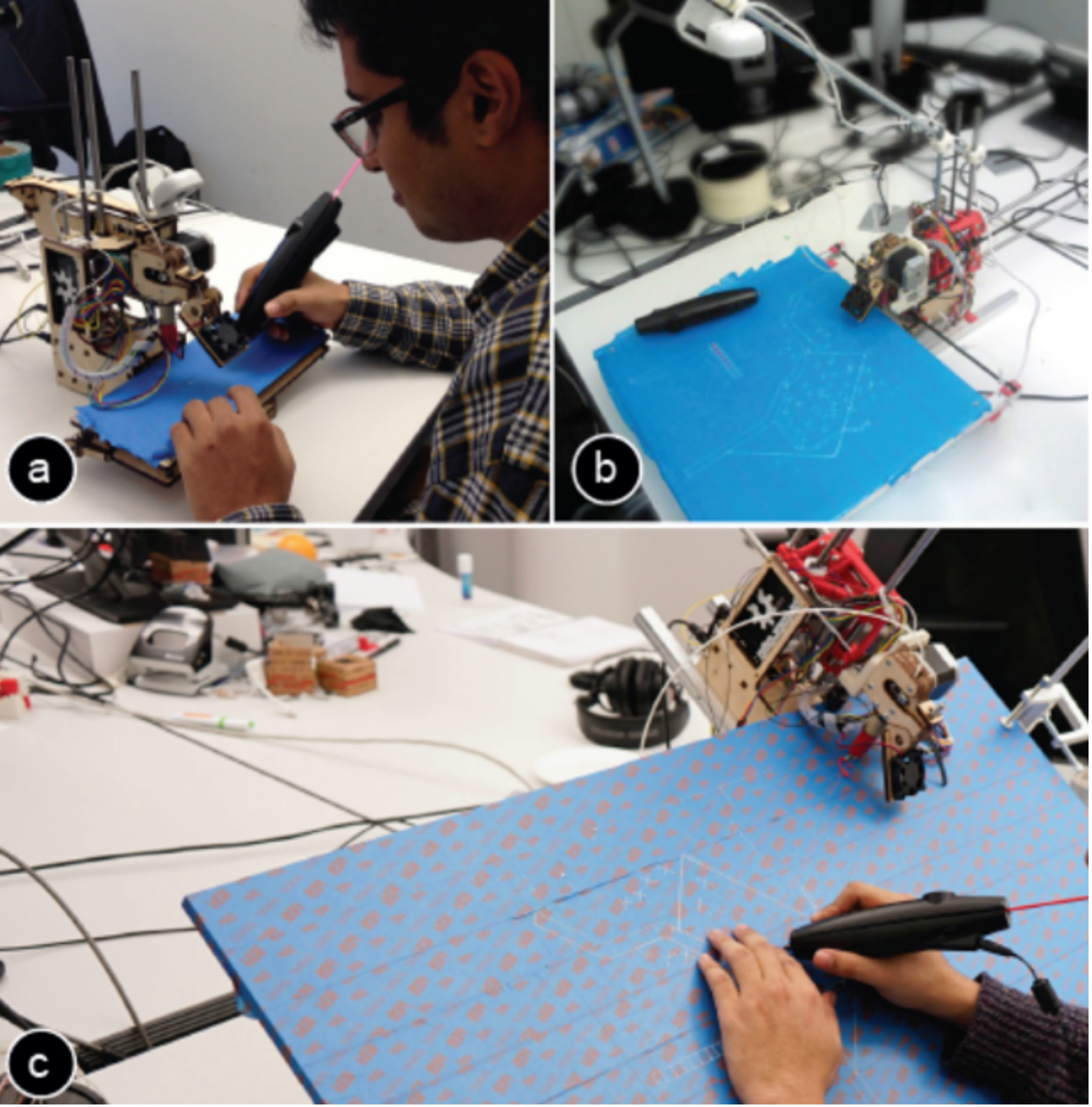
put in heater
-> only black lines
attract heat & swell



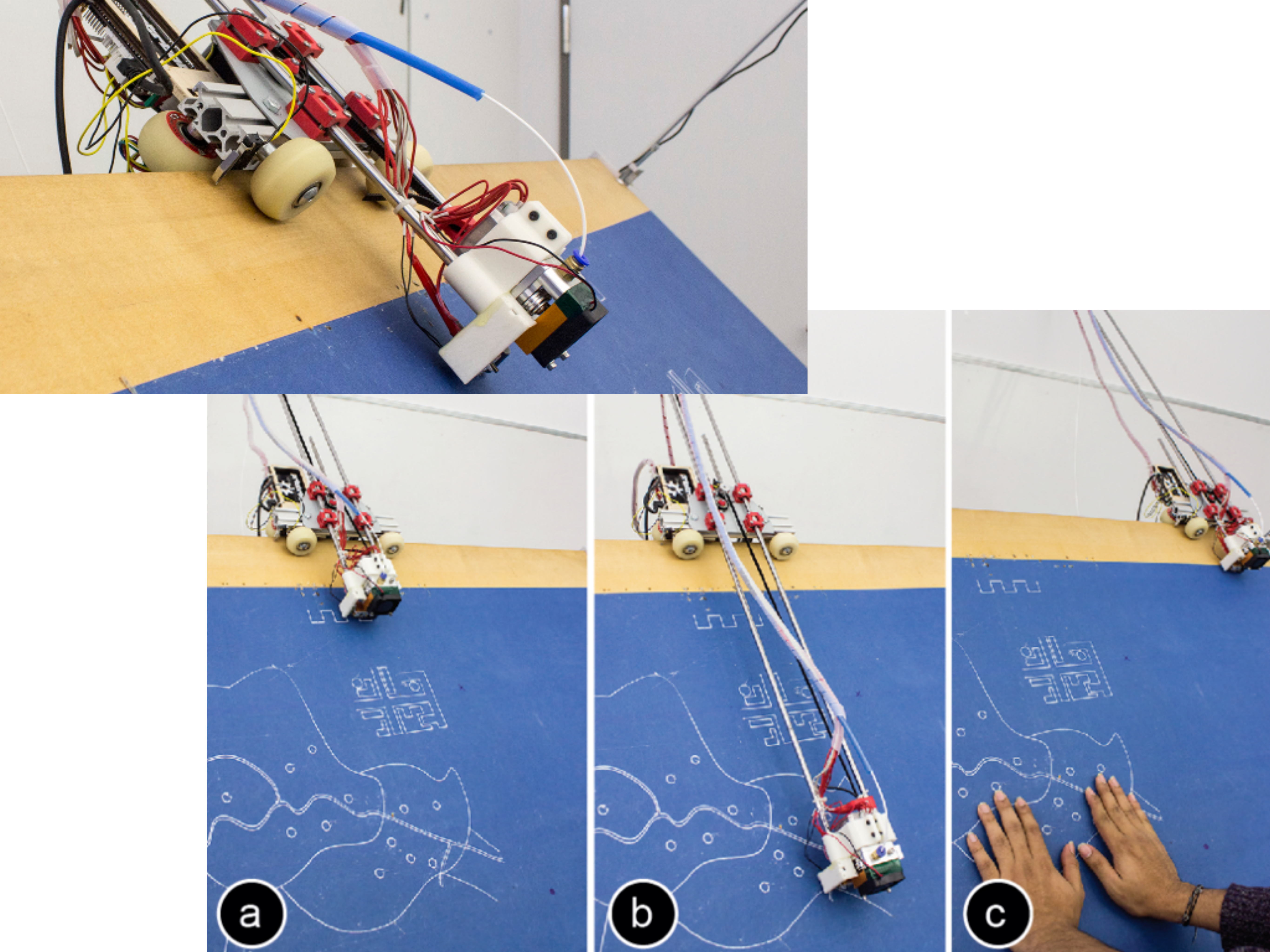


swell paper + laser cutter (almost 0% power + defocus)

other method… use a 3D printer!



good prototyping: test concept first, then iterate


a
b
c

Linespace: A Sensemaking Platform for the Blind

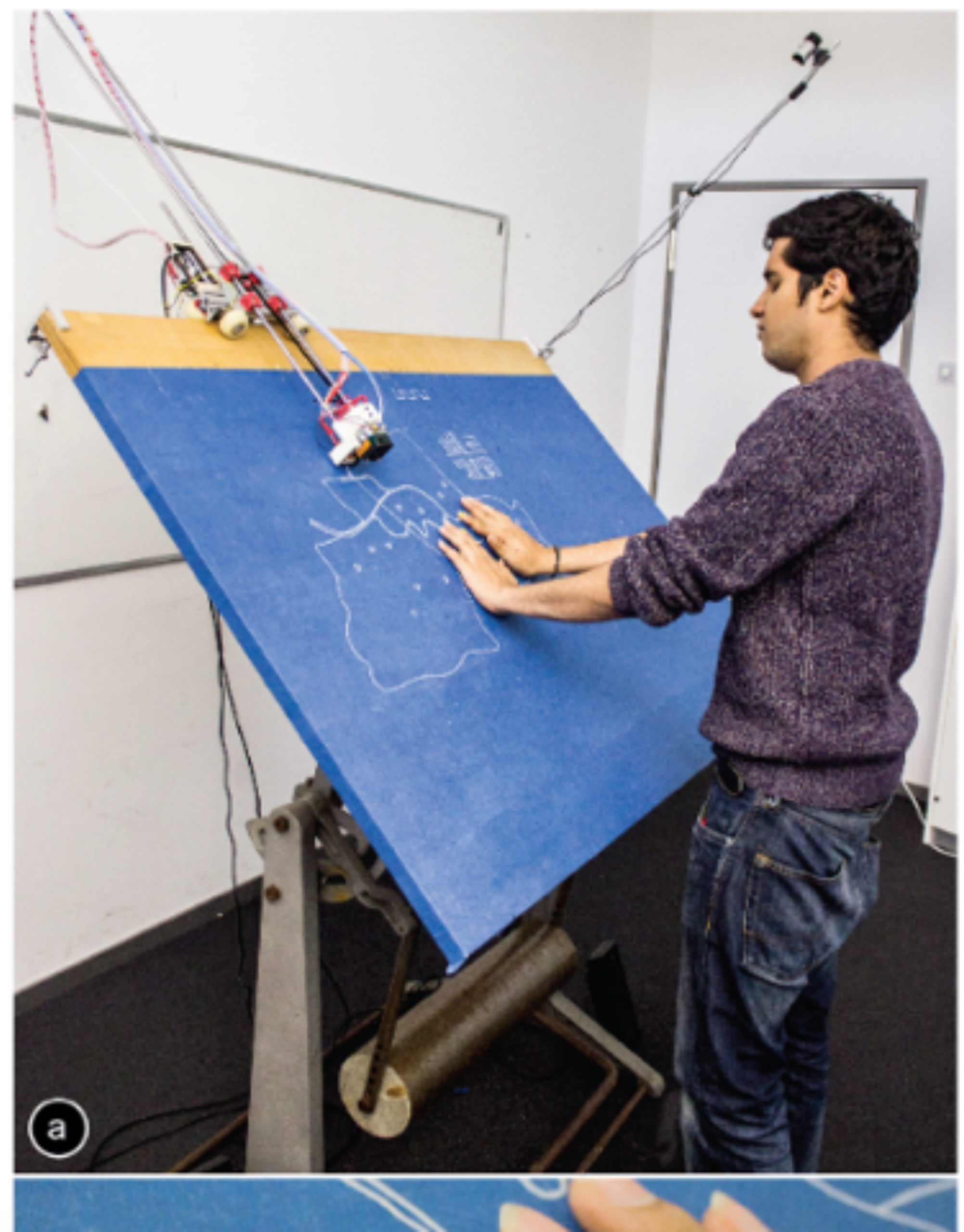
Saiganesh Swaminathan, Thijs Roumen, Robert Kovacs,
David Stangl, Stefanie Mueller, and Patrick Baudisch
Hasso Plattner Institute, Potsdam, Germany
{firstname.lastname}@hpi.de

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

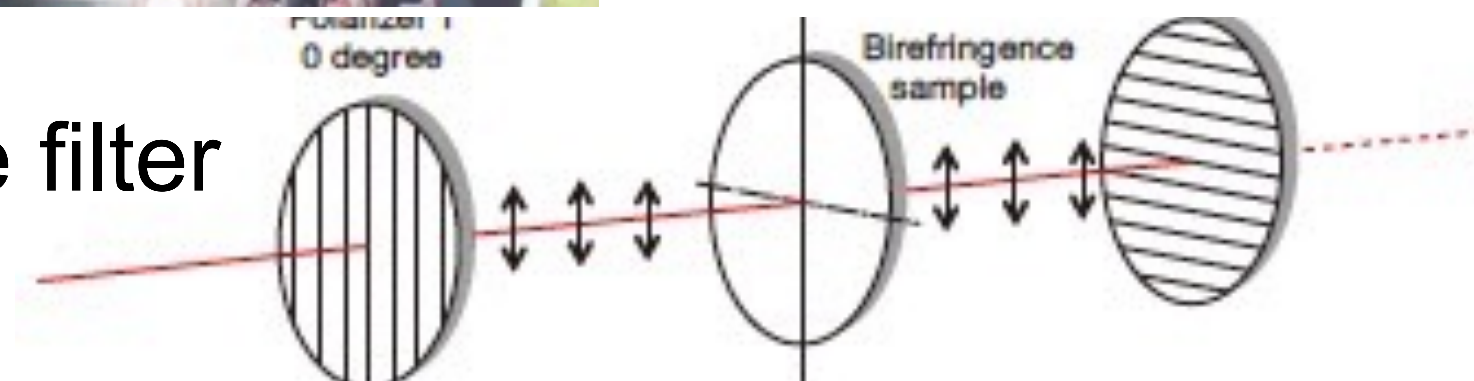
(1971)

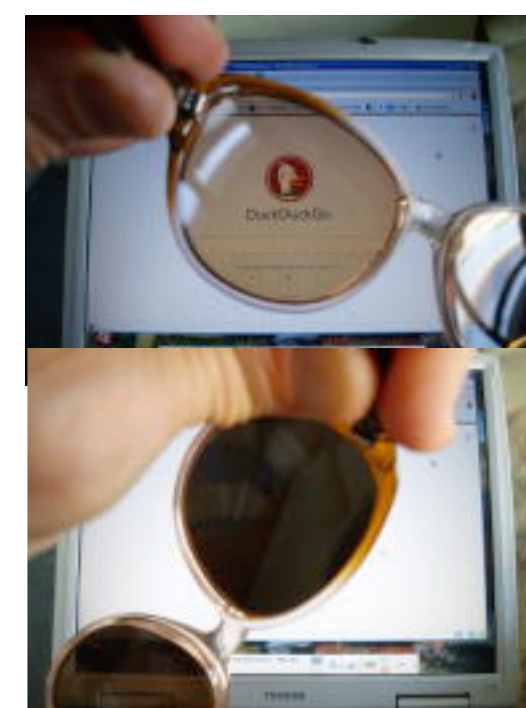
liquid crystal display

liquid crystal display

your screen

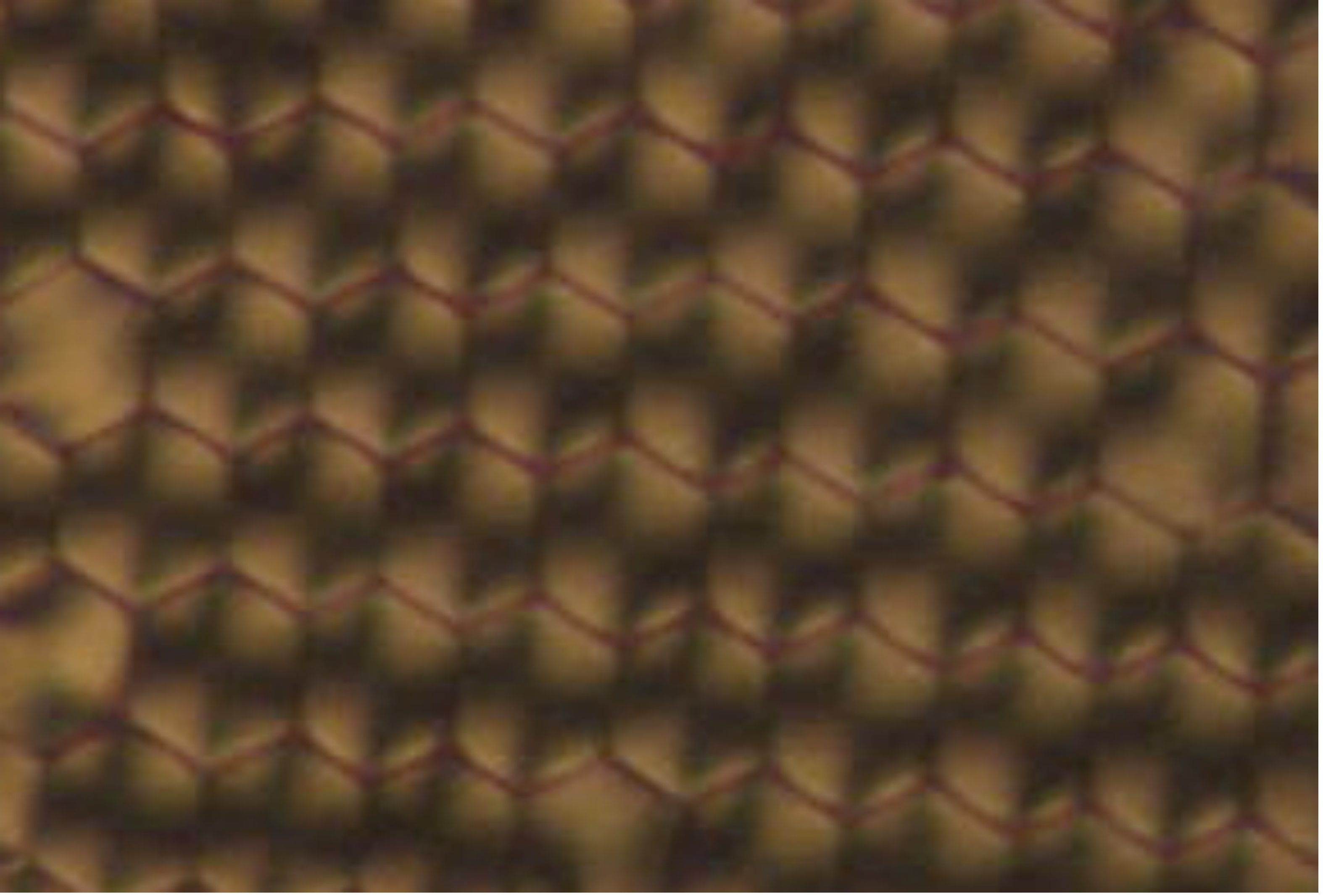
the filter





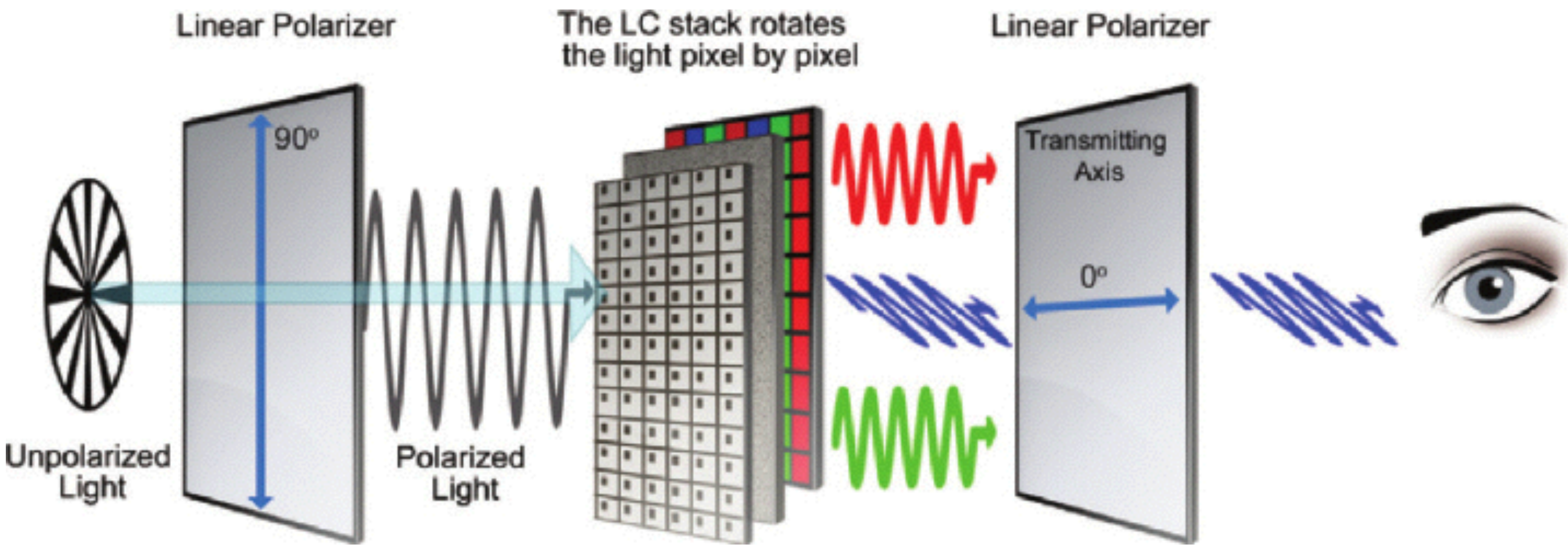
polarizer:

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



liquid crystals:

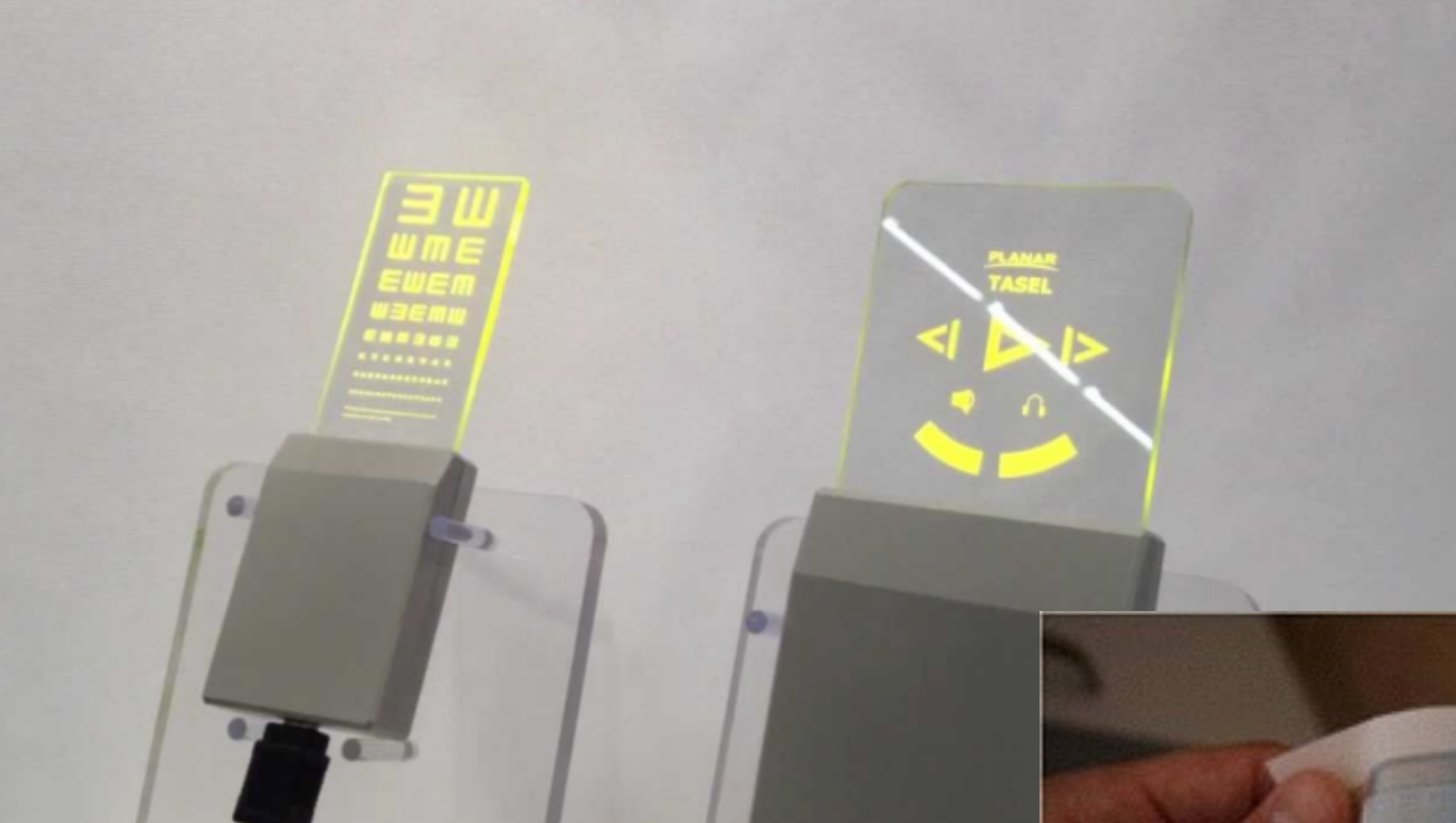
- act as a polarizer filter!
- no electricity: crystals move around freely (smectic phase)
- when electricity is applied, molecules all point in the same direction and let light pass through (nematic phase)



color pixels get lit up when light passes through the liquid crystal

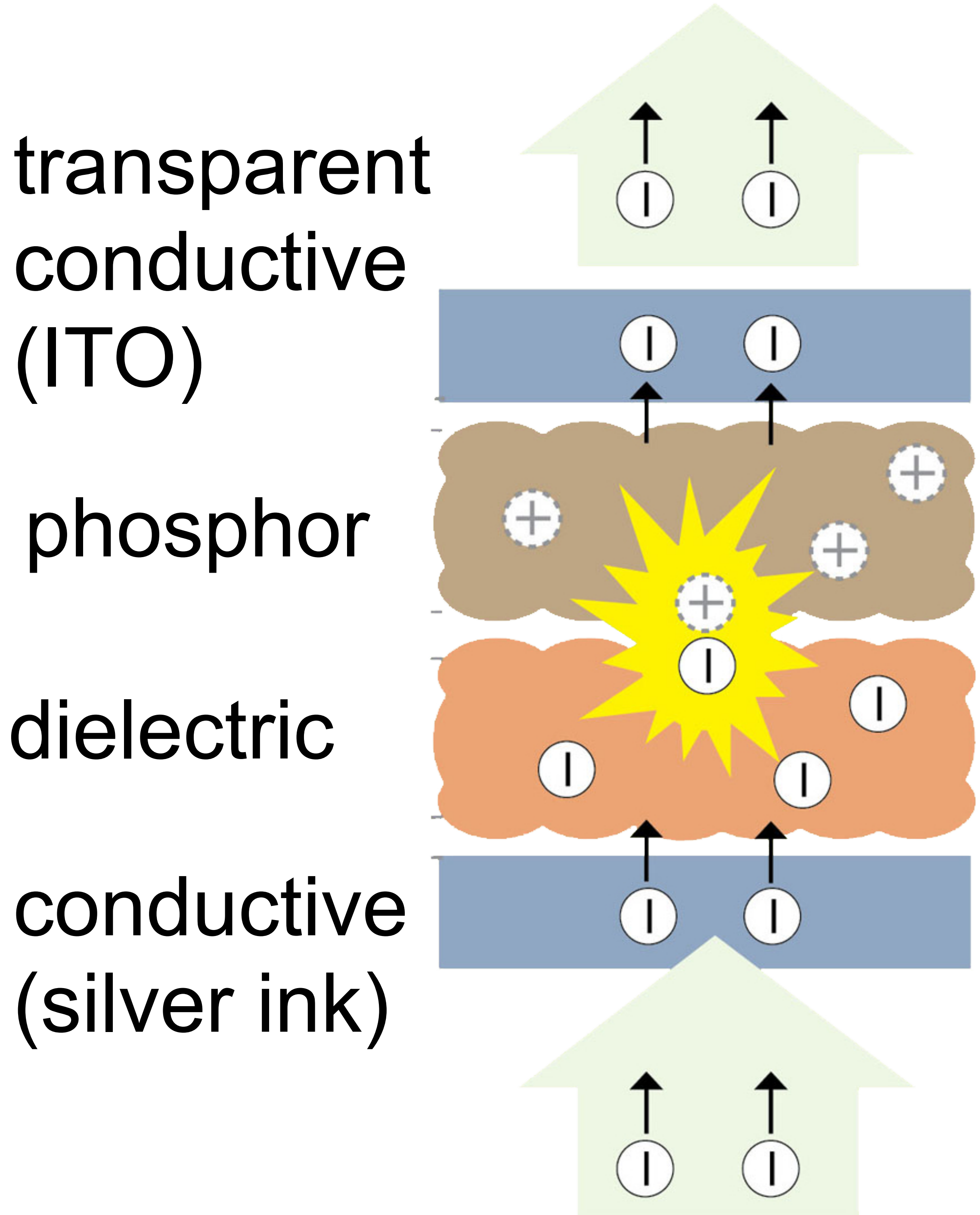
(1974)

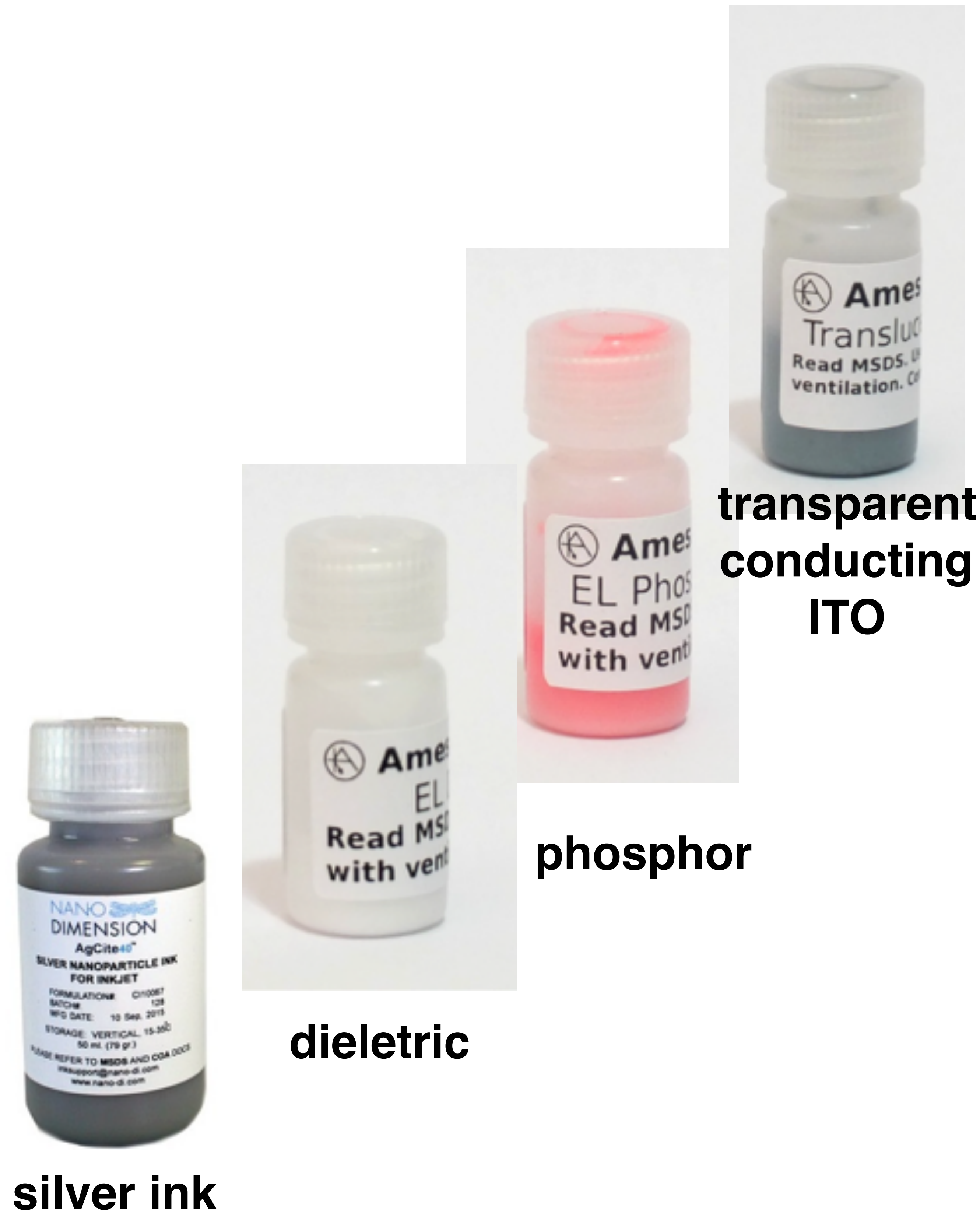
electro-luminescent (EL)



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

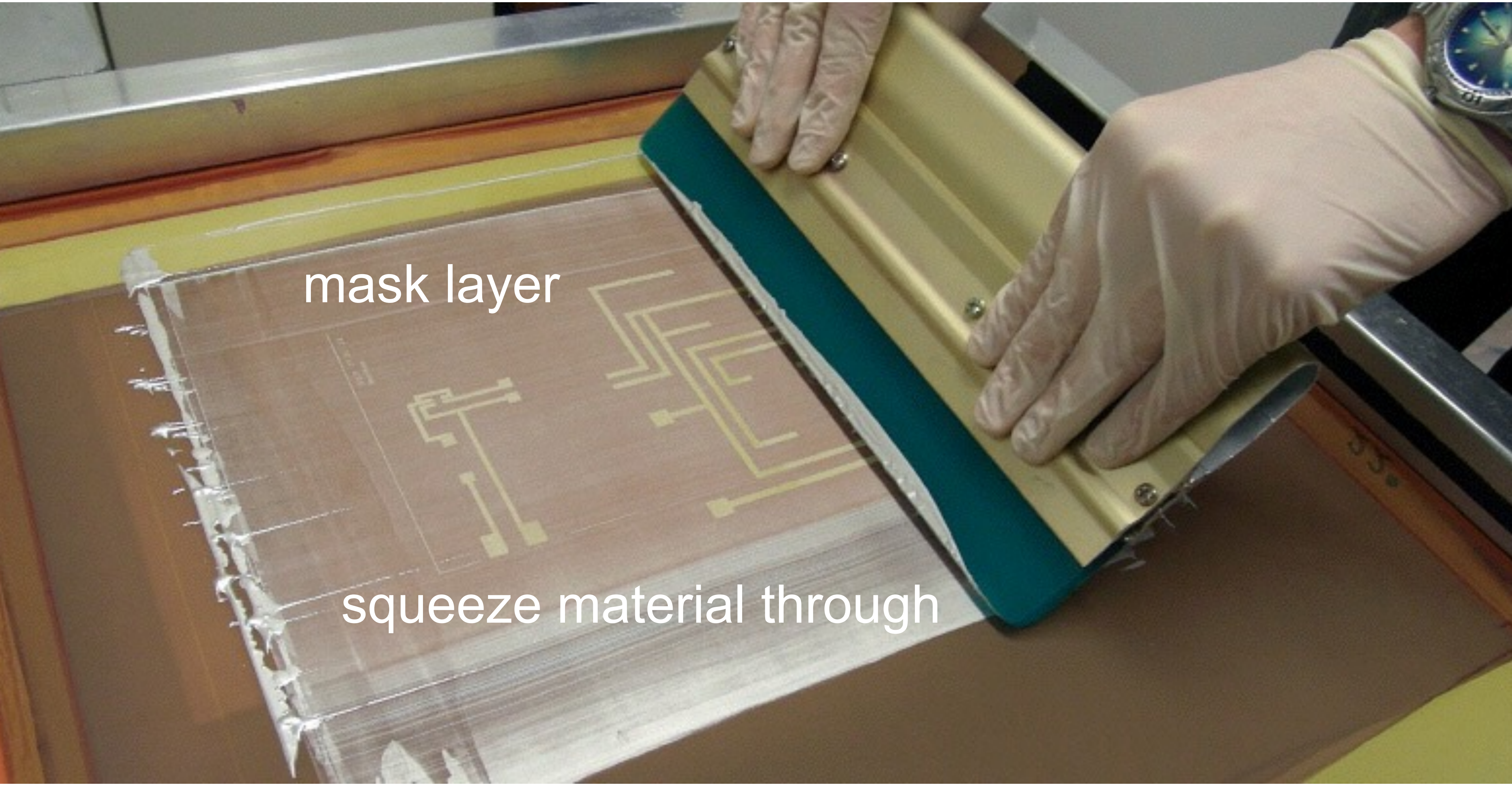
very easy to make! hand painted in our lab



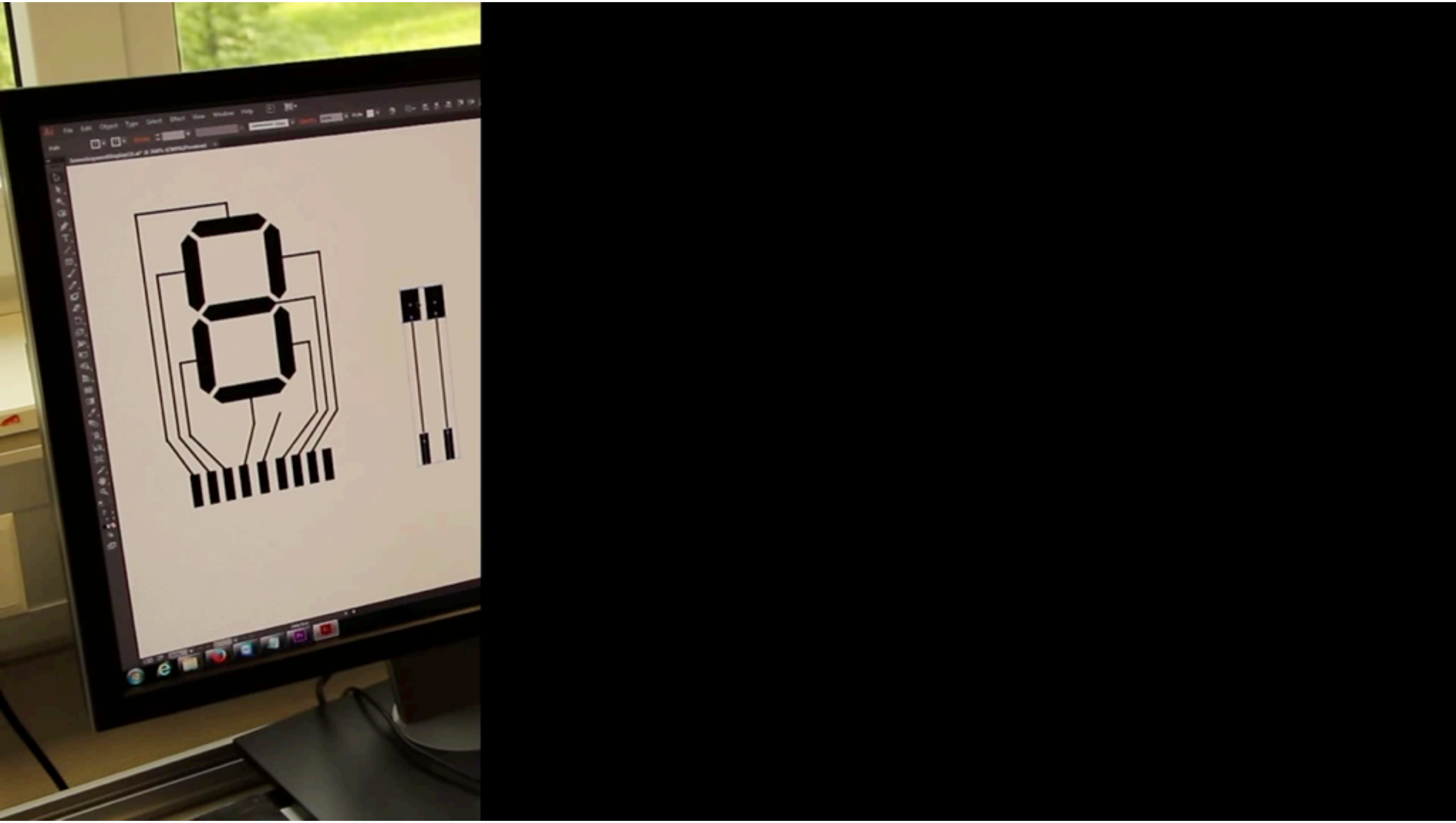


http://www.gwent.org/gem_electroluminescent_kit.html

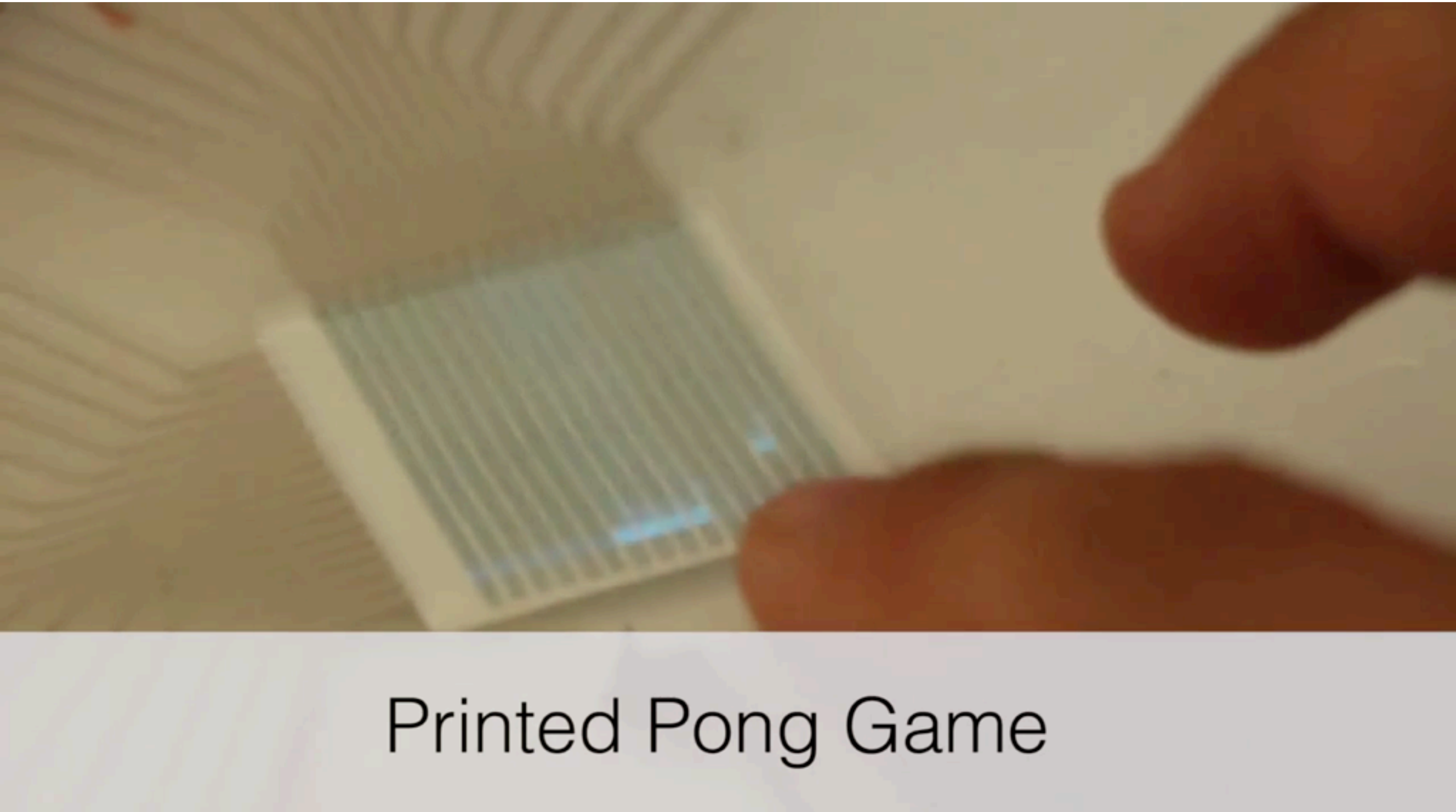
http://www.dupont.com/products-and-services/display-lighting-materials/electroluminescent-materials.html



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



screen printing or conductive inkjet printer



2014: flexible printed displays

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

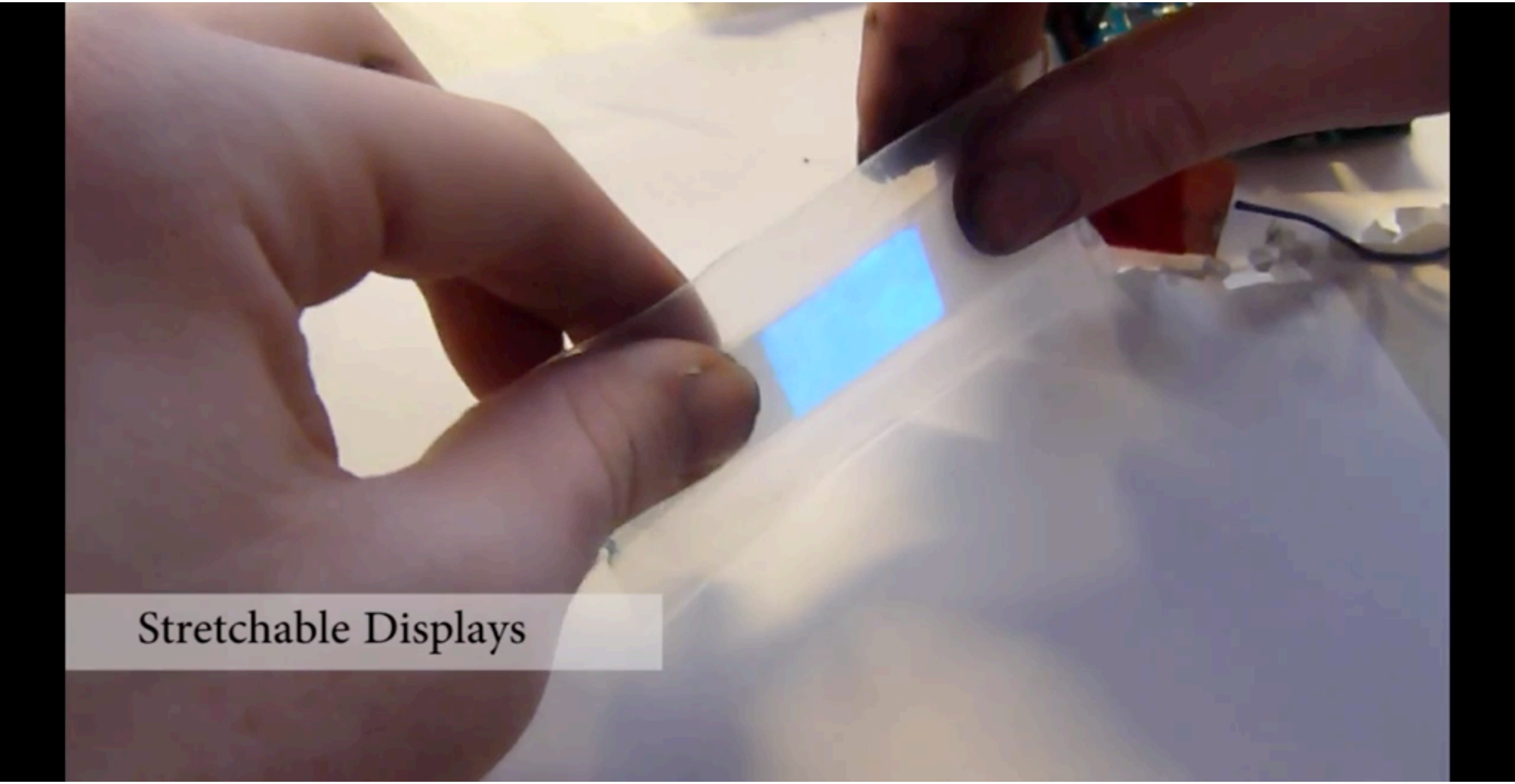
Figure 1. PrintScreen contributes a digital fabrication approach to enable non-experts to print custom flexible displays. They can be fully folded or rolled and enable manifold applications in ubiquitous, mobile and wearable computing.

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

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



2016 stretchable displays: EL embedded in silicone

Stretchis: Fabricating Highly Stretchable User Interfaces

Michael Wessely
michael.wessely@inria.fr

Theophanis Tsandilas
theophanis.tsandilas@inria.fr

Wendy E. Mackay
wendy.mackay@inria.fr

Inria; Univ Paris-Sud & CNRS (LRI); Université Paris-Saclay
F-91405 Orsay, France

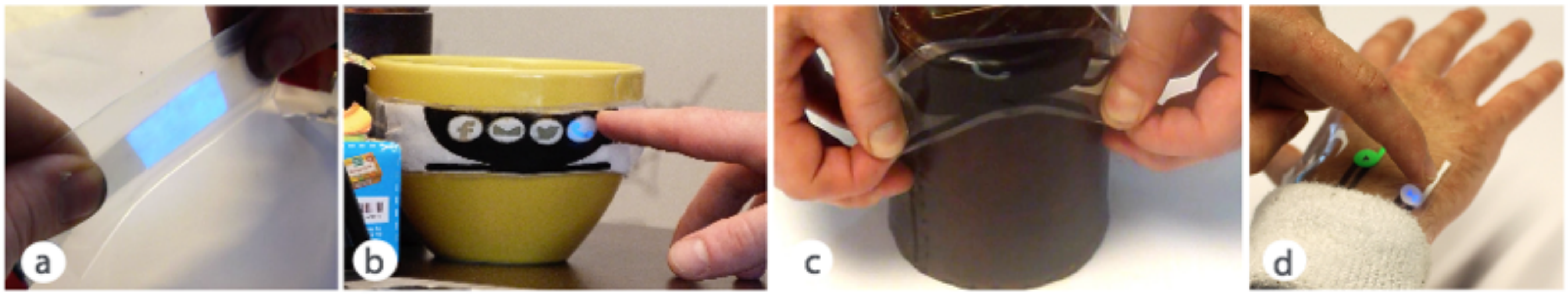


Figure 1. ***Stretchis*** **are highly stretchable user interfaces that include touch and proximity sensors and electroluminescent displays (a).** ***Stretchis*** **are transparent (b); can be stretched to fit to the geometry of different physical objects (c); and can act as on-skin user interfaces (d).**

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.

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.

2017 conformal displays

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
{weigel, nittala, steimle}@cs.uni-saarland.de, olwal@google.com

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.

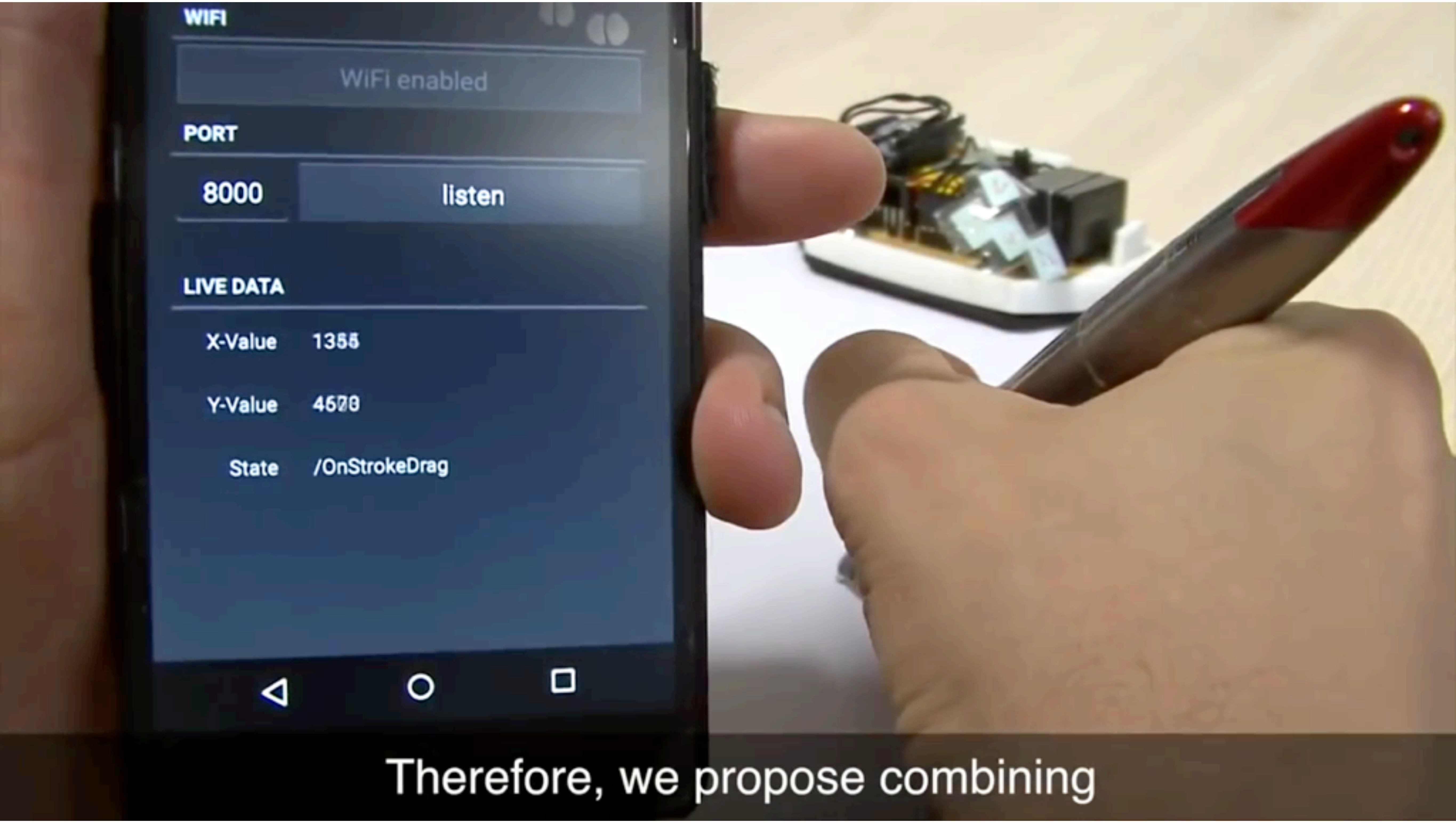
ABSTRACT

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

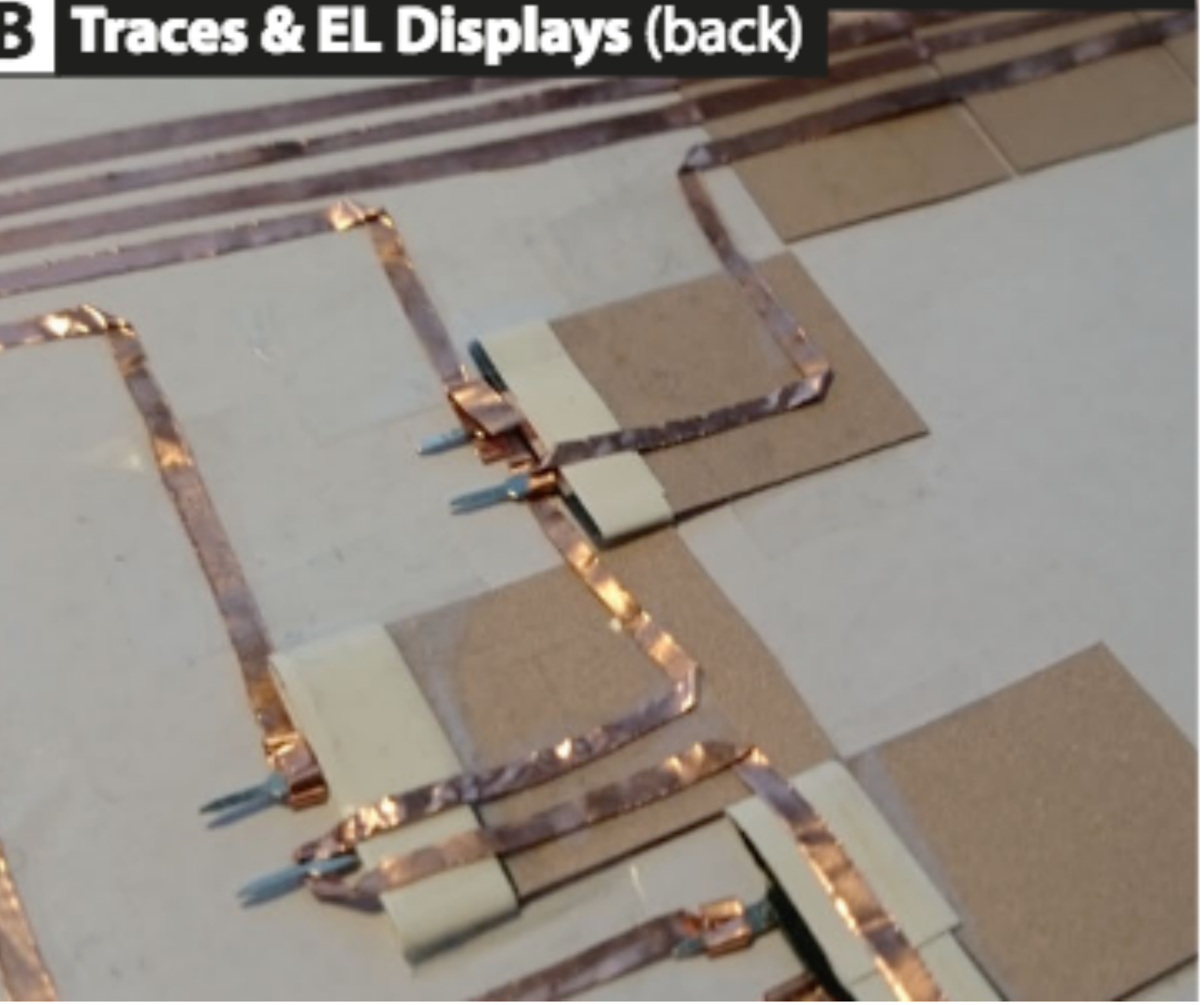
INTRODUCTION

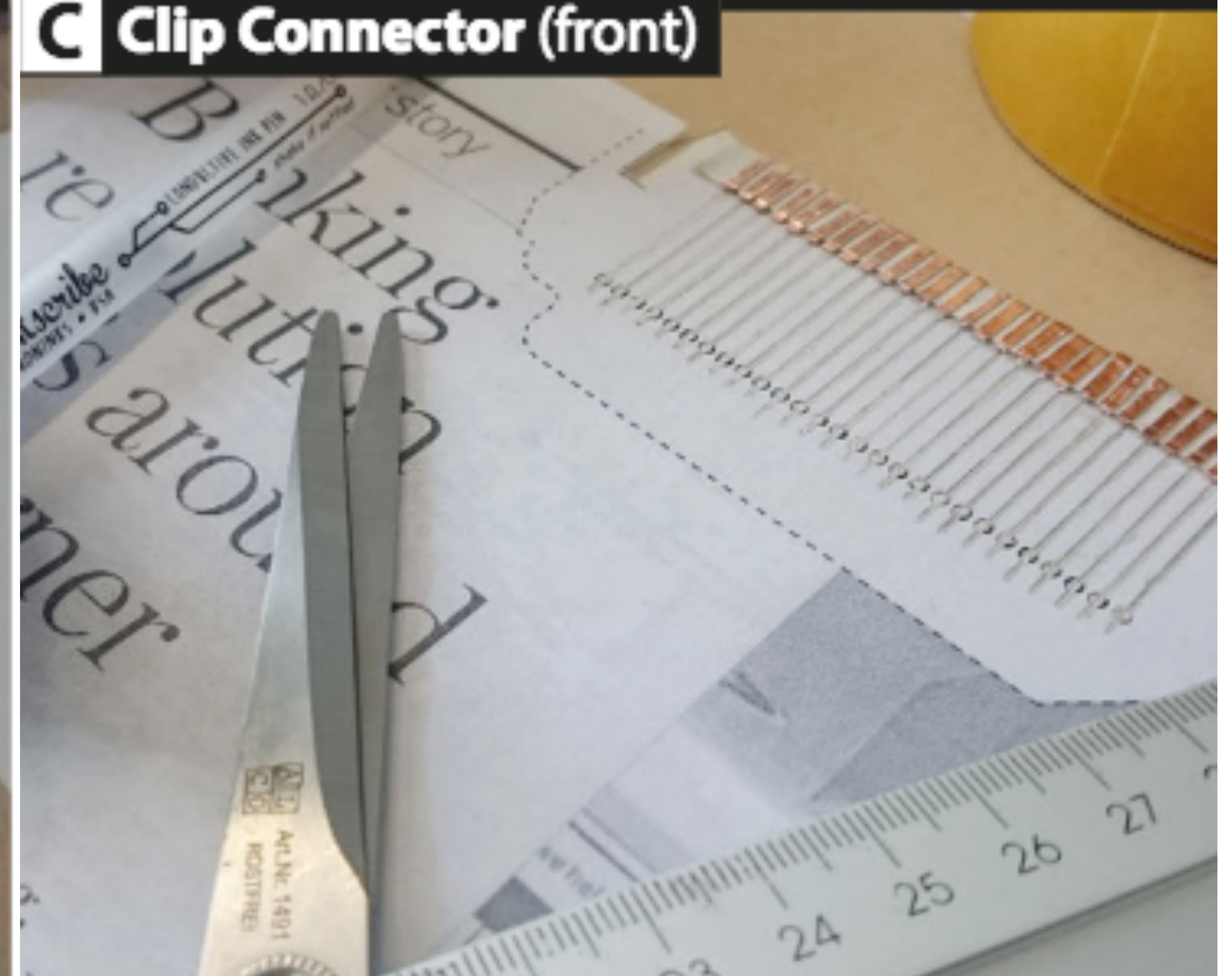
The body is recognized as a promising input surface for mobile computing, as it offers a large and quickly accessible area for interaction. Prior research contributed input [11, 12, 14, 16, 17, 26, 27, 29, 41, 45] and output devices [11, 43] for on-body interactions. However, they mostly assume interactive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

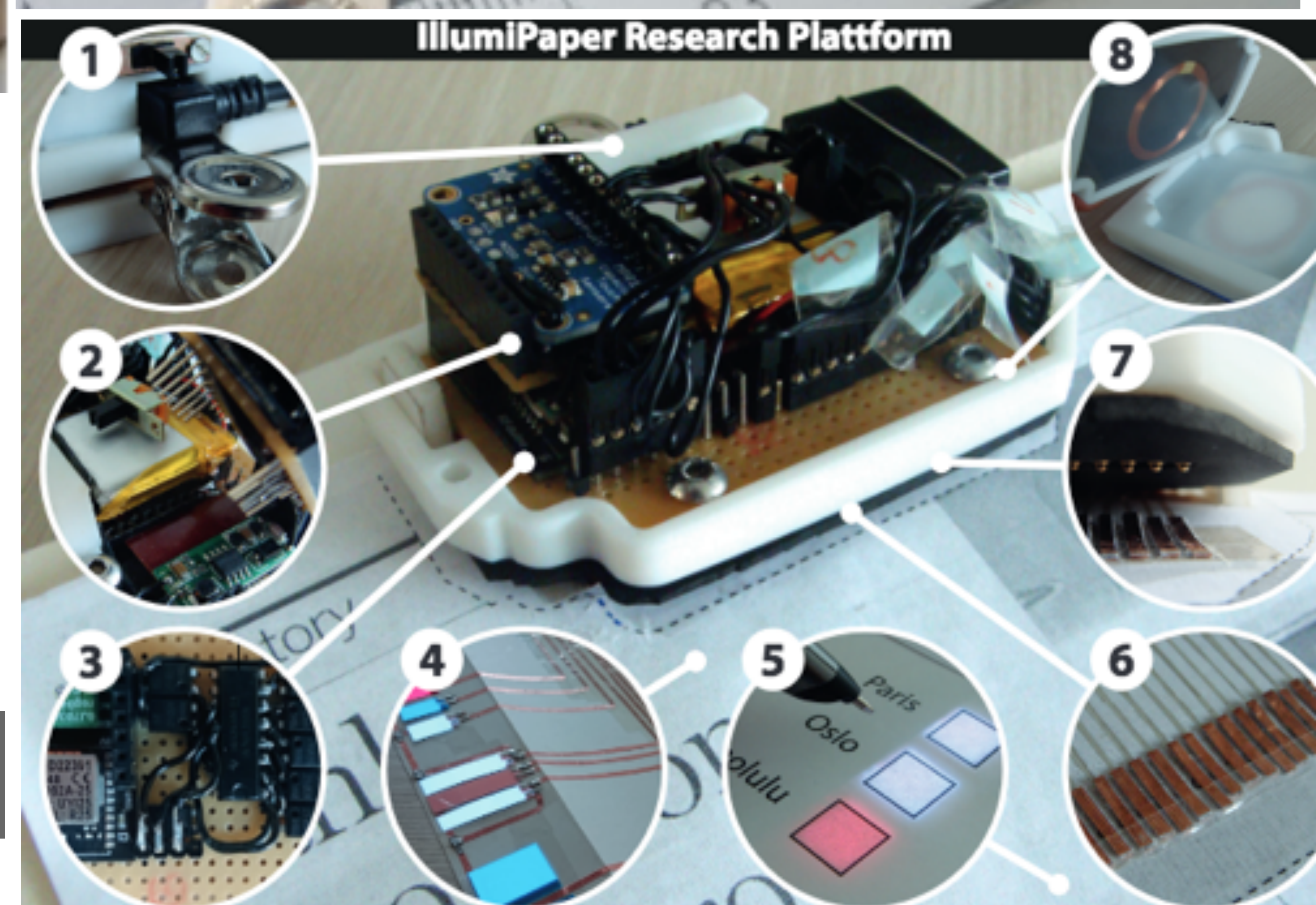
The human body has various types of landmarks which are distinct from their surroundings. It offers unique possibilities for interaction due to their tactile properties and visual appearance. For example, protruding skeletal landmarks, like the knuckles, provide physical affordances for touching and circling around them. Prior work in human-computer interaction has briefly explored the potential of such unique landmarks.



2017 interactive paper displays







2017 interactive paper displays

IllumiPaper: Illuminated Interactive Paper

Konstantin Klamka, Raimund Dachselt
Interactive Media Lab Dresden
Technische Universität Dresden, Germany
{klamka, dachselt}@acm.org

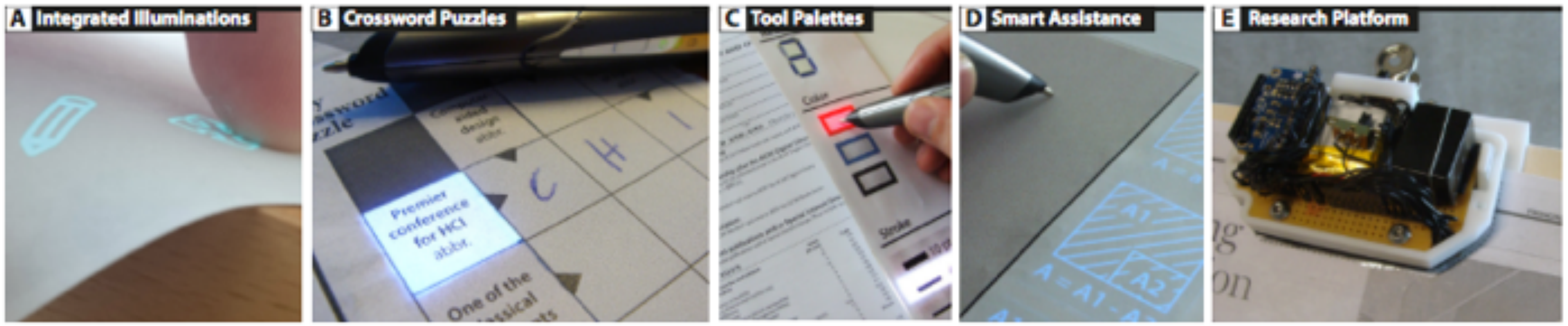


Figure 1. Our ILLUMIPAPER research platform (E) provides paper-integrated visual feedback without losing the sensory richness and flexibility of paper (A) and supports several applications including educational grid puzzles (B), interactive tool palettes (C) or even math exercise sheets (D).

ABSTRACT

Due to their simplicity and flexibility, digital pen-and-paper solutions have a promising potential to become a part of our daily work. Unfortunately, they lack dynamic visual feedback and thereby restrain advanced digital functionalities. In this paper, we investigate new forms of paper-integrated feedback, which build on emerging paper-based electronics and novel thin-film display technologies. Our approach focuses on illuminated elements, which are seamlessly integrated into standard paper. For that, we introduce an extended design space for paper-integrated illuminations. As a major contribution, we present a systematic feedback repertoire for real-world applications including feedback components for innovative paper interaction tasks in five categories. Furthermore, we contribute a fully-functional research platform including a paper-controller, digital pen and illuminated, digitally controlled papers that demonstrate the feasibility of our techniques. Finally, we report on six interviews, where experts rated our approach as intuitive and very usable for various applications, in particular educational ones.

Author Keywords

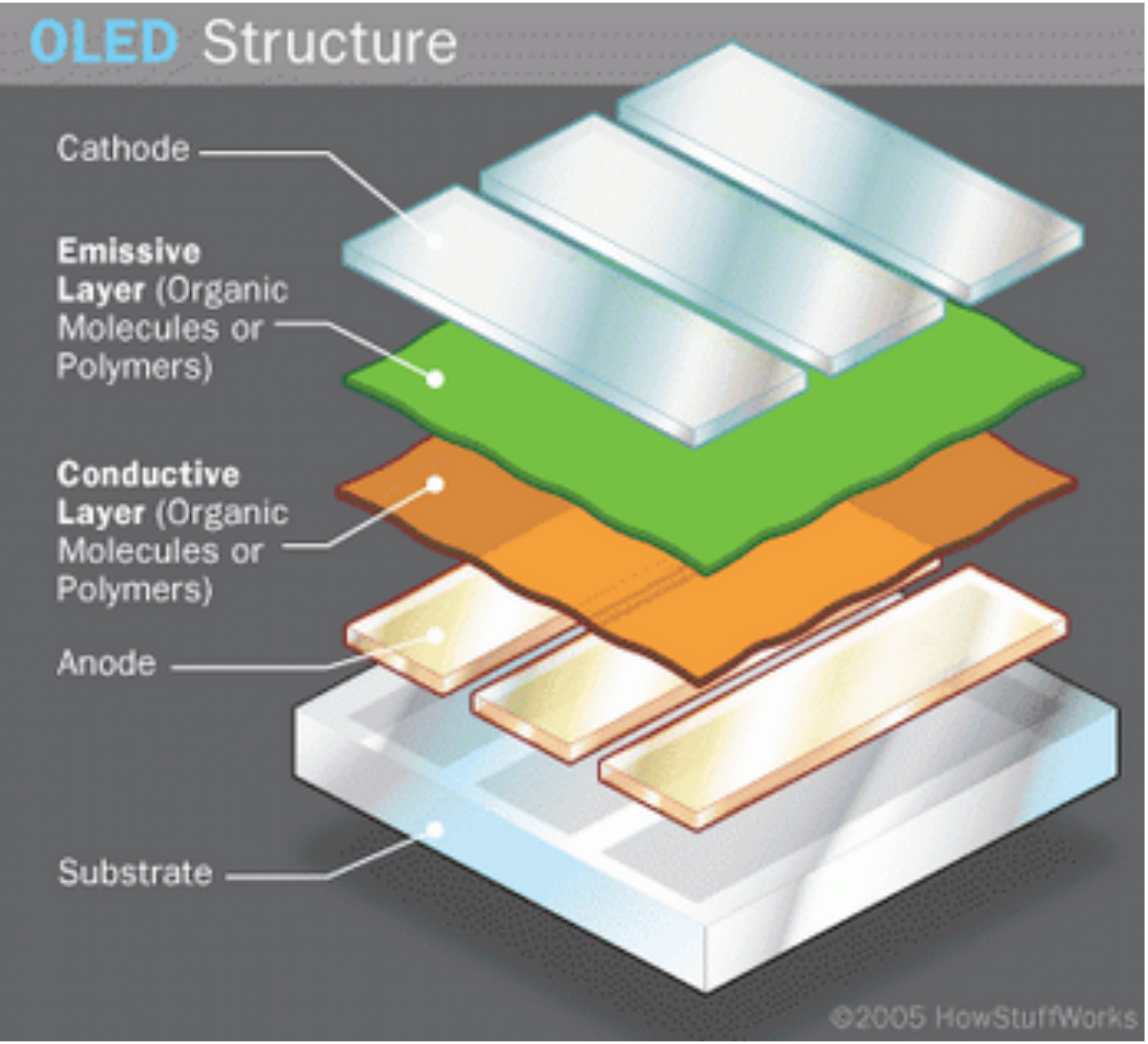
Digital pen and paper; electro-luminescence; pen interaction; visual feedback; Anoto; thin-film display; augmented paper.

INTRODUCTION

Over hundreds of years, the use of paper and writing has become a major cultural achievement and has maintained its importance until today's information age. The success of paper is based on its simplicity, sensory richness and versatility, which foster a widespread dissemination and ubiquitous availability. The affordances of paper for writing and sketching provide unique advantages over digital media [35, 34]. This becomes evident, for example, in active reading tasks when highlighting words, marking graphics or adding drawings. In addition, paper has been found to be the most direct, flexible and intuitive way to annotate documents [17]. Despite these advantages, the growing need of its digital integration into our daily life requires novel solutions. While maintaining the unique properties of paper, powerful software tools and computing functionality should be combined with real paper for added digital value.

The development of camera-based digital pens (e.g., with Anoto™ technology) or sensor-based versions laid the basis for recognizing and analyzing handwritten text on paper, but the provision of visual feedback, e.g., to communicate pen or system states, remains challenging. To address this problem, a wide range of modalities (cf. [55, 34, 59]), i.e., primarily vielectro-luminescense is also used in **OLEDs**

OLED (Samsung Youm CES 2013)



- same as EL displays
- organic instead of inorganic phosphors

2016 bend sensor + vibrotactile feedback

ReFlex: A Flexible Smartphone with Active Haptic Feedback for Bend Input

Paul Strohmeier[1,2], Jesse Burstyn[1], Juan Pablo Carrascal[1], Vincent Levesque[3], Roel Vertegaal[1]
[1]Human Media Lab, Queen's University, Kingston, ON, Canada
[2]Department of Computer Science, University of Copenhagen, Denmark
[3]Immersion Canada Corp., Montréal, QC, Canada
[1]{paul, jesse, jp, roel}@cs.queensu.ca, [3]vlevesque@immersion.com

ABSTRACT
ReFlex is a flexible smartphone with bend input and active haptic feedback. ReFlex's features allow the introduction of sensations such as friction or resistance. We report results from an experiment using ReFlex in a targeting task, as well as initial users' reactions to the prototype. We explore both absolute and relative tactile haptic feedback, paired with two types of bend input mappings: position-control and rate-control. We observed that position-controlled cursors paired well with relative bend feedback, while rate-controlled cursors paired well with absolute bend feedback to indicate targets. We also explored an eyes-free condition. Results suggest that while eyes-free, haptic feedback conditions were more error-prone than visual-only conditions, the size of the error was relatively small, and users were able to complete the task in all cases. We present two application scenarios that take advantage of the unique input and output modalities of ReFlex and discuss its potential for within document navigation.

Author Keywords
Flexible Displays; Bend Input; Haptic Feedback; Organic User Interfaces

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI):

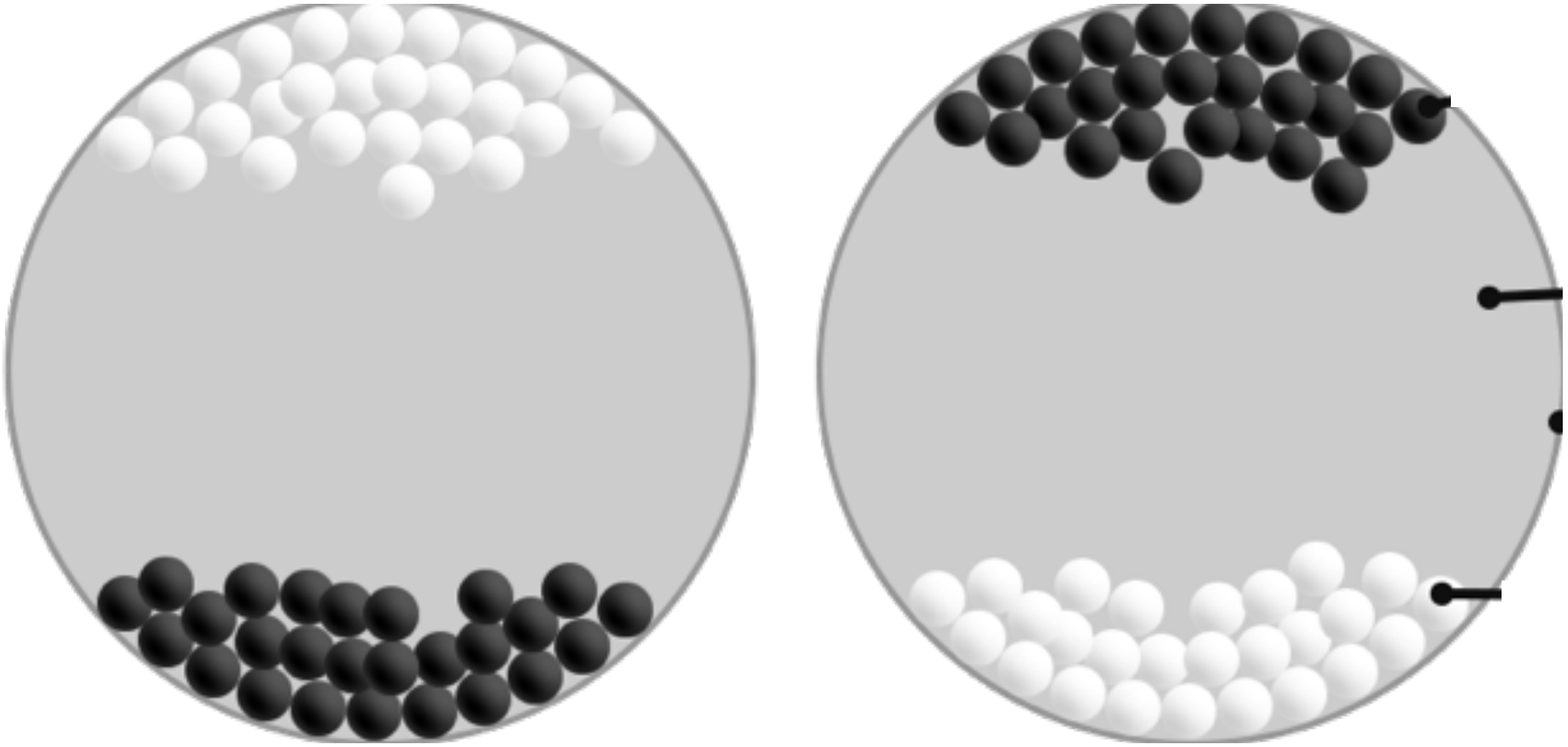
Figure 1. ReFlex, a flexible haptic smartphone.

deformed, a rich set of sensations come into play to inform us about its internal structure. For example, when reading a paper document, the physical structure of pages can help guide users to particular locations in the document. A book can have physical tabs to indicate chapters and its pages might have dog ears to denote bookmarks or creases at frequently read passages. The distribution of pages between the hands provides some haptic representation of the current reading location. And pages sliding between a user's fingers provide feedback on the speed with which she is navigating. Many, if not all, of these haptic affordances are lost when navigating documents on rigid Tablet PCs. When designing

(2004)

e-ink

e-ink:

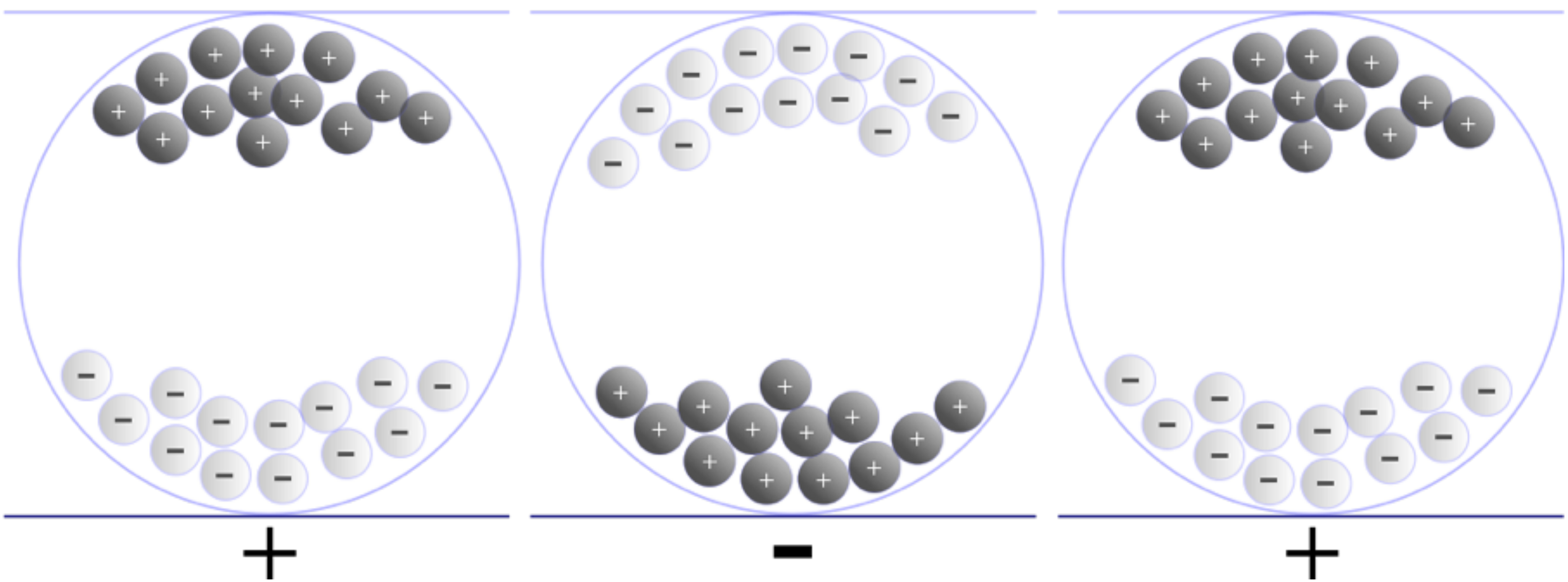


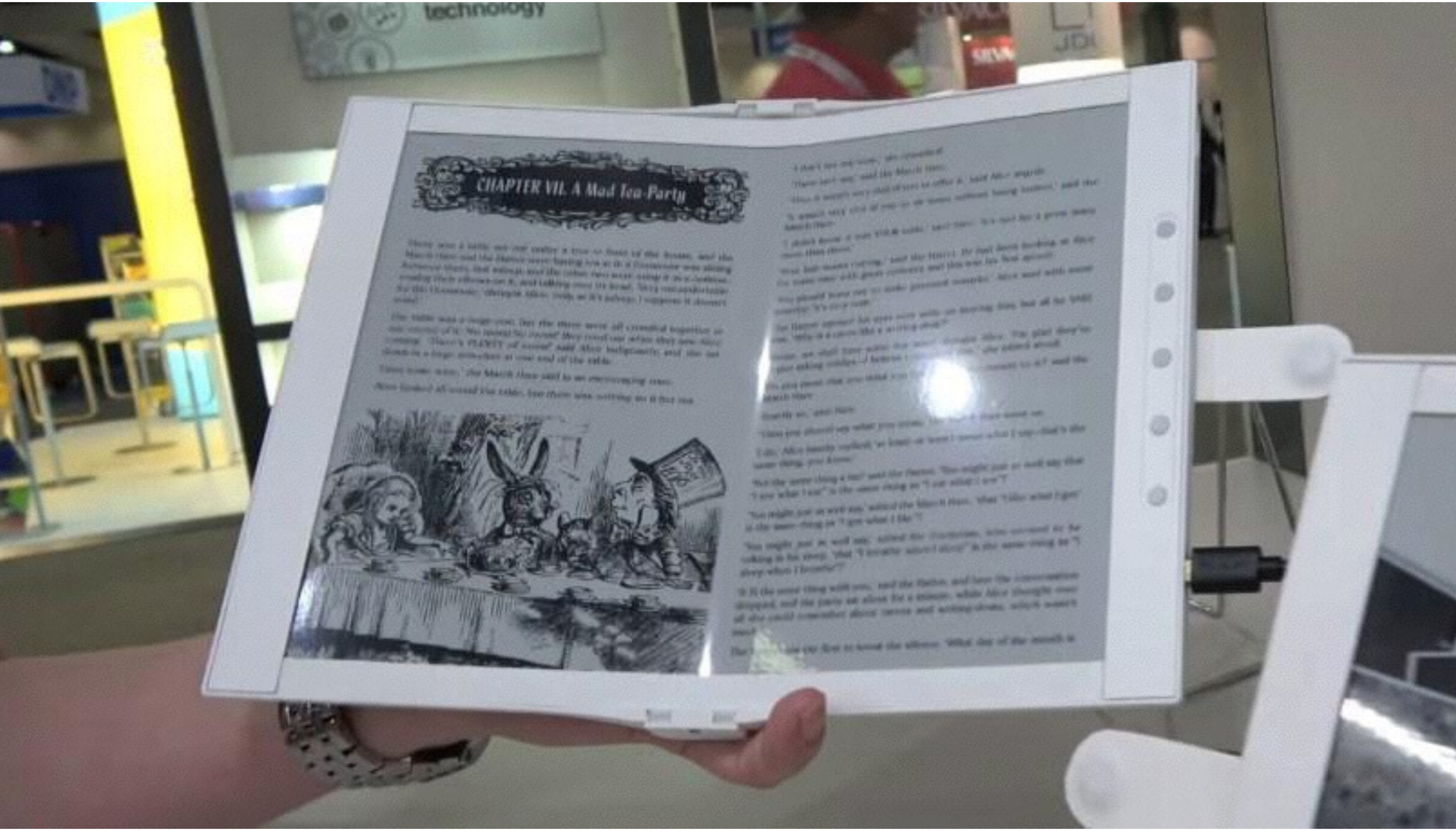
any idea how this works?

<30 sec brainstorming>

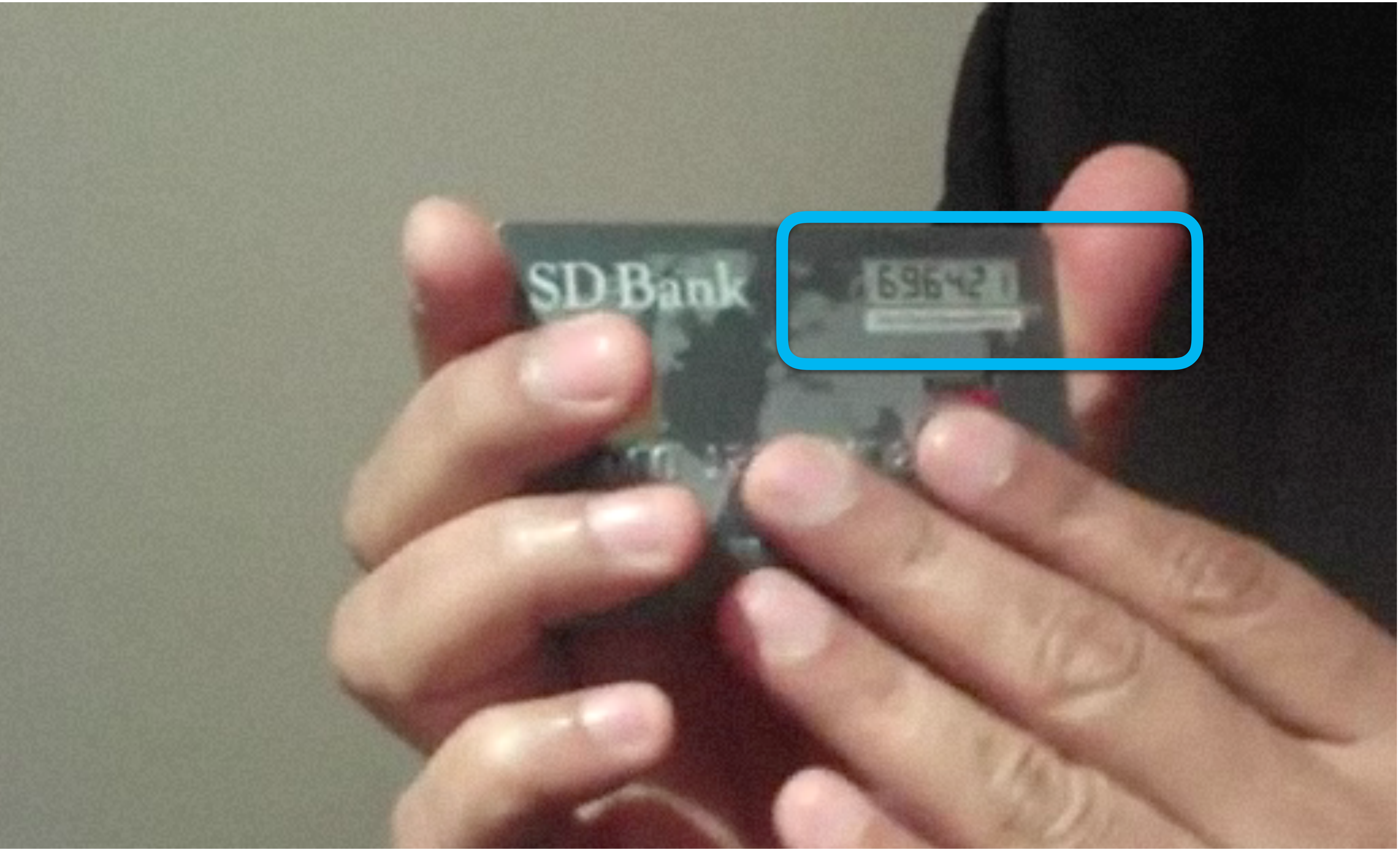
e-ink:

- tiny microcapsules filled with black/white particles
- black particles positively charged
- white particles negative charged
- move in the capsule as you applied + / -





e-ink readers:
no electricity required to maintain image (only for flipping pixels)

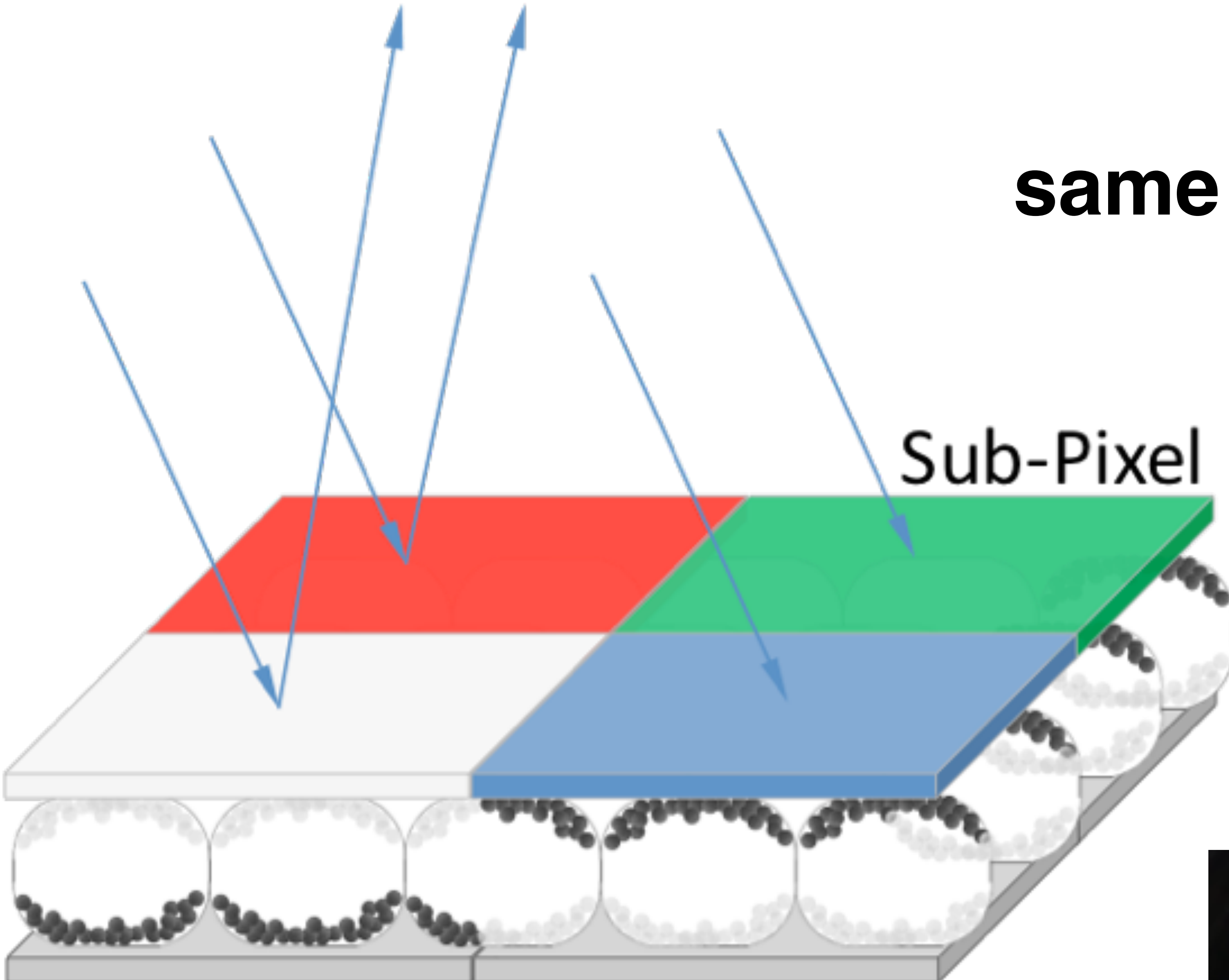


dynamic CVV on cards

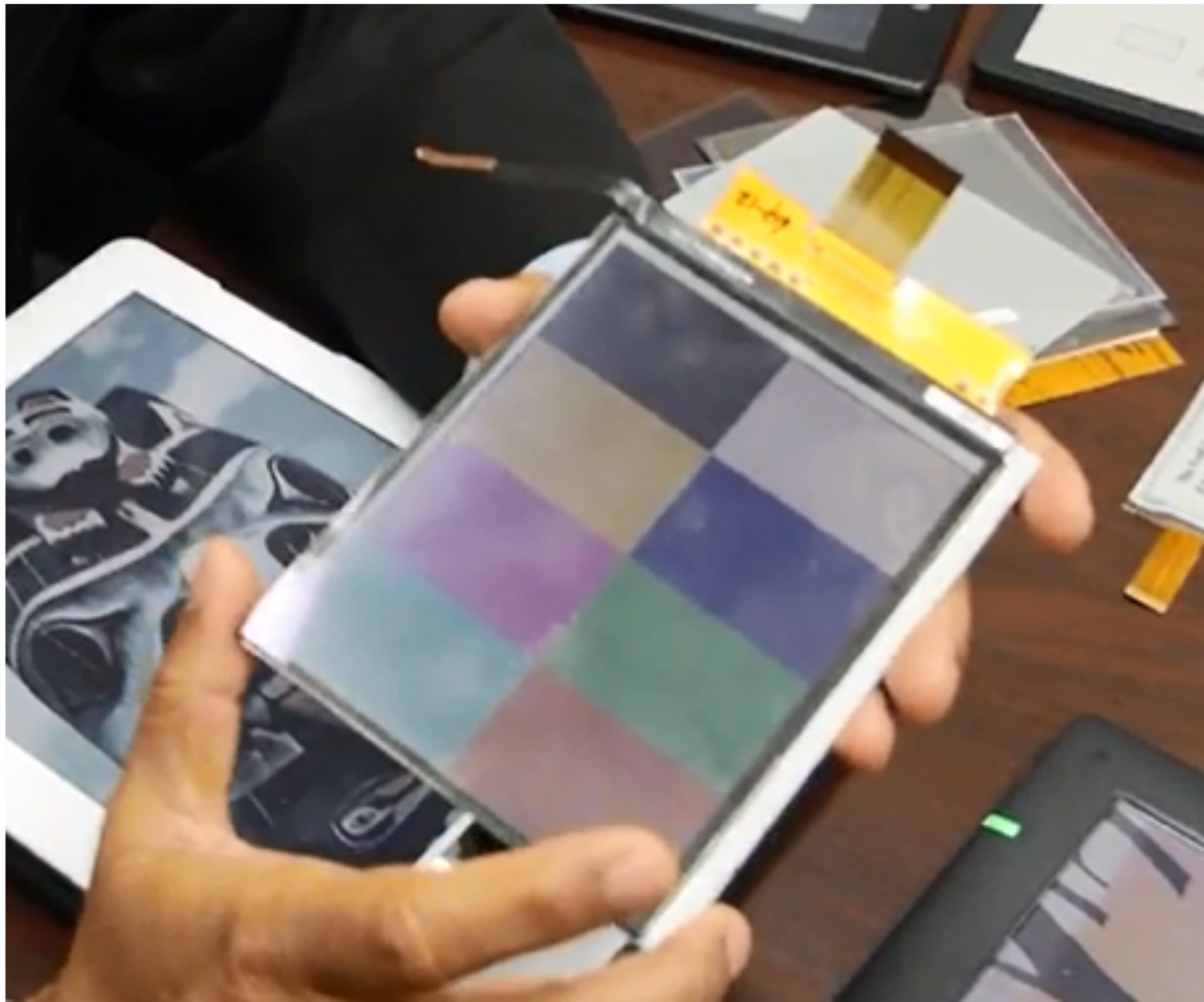
can we have e-ink **in color?**

<30 sec brainstorming>

same principle as with LCD



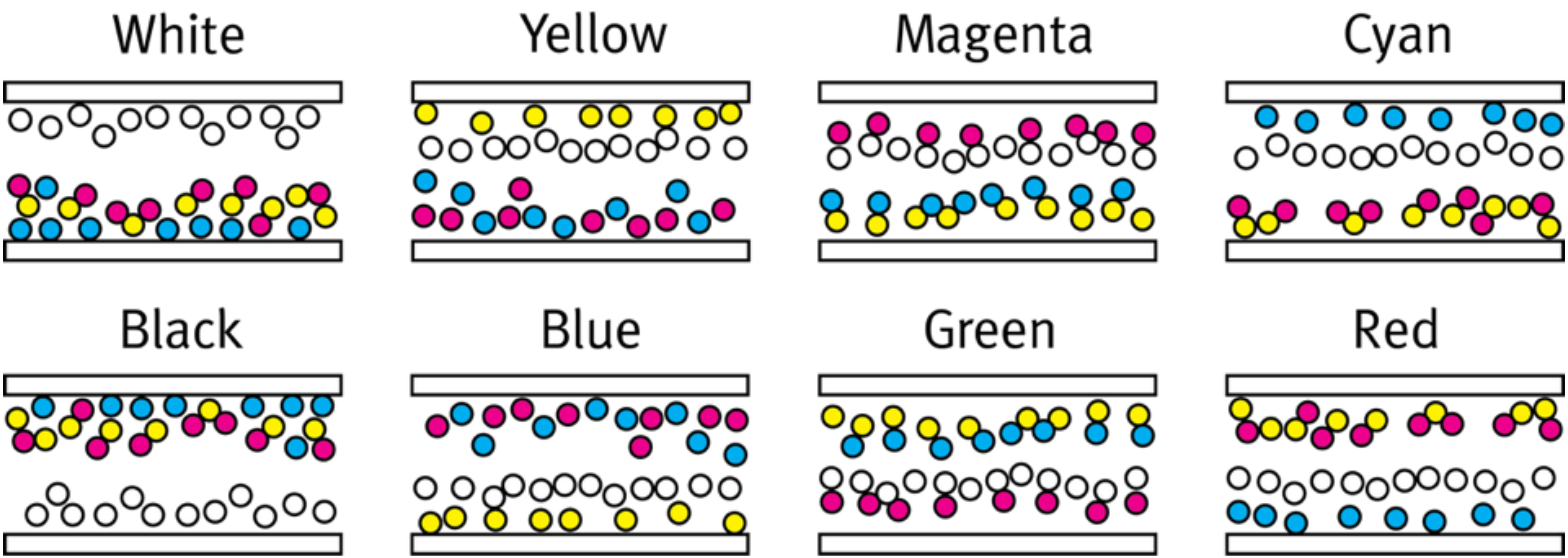
- black absorbs light (pixel off)
- white reflects light (pixel on)



[Triton Color e-ink]

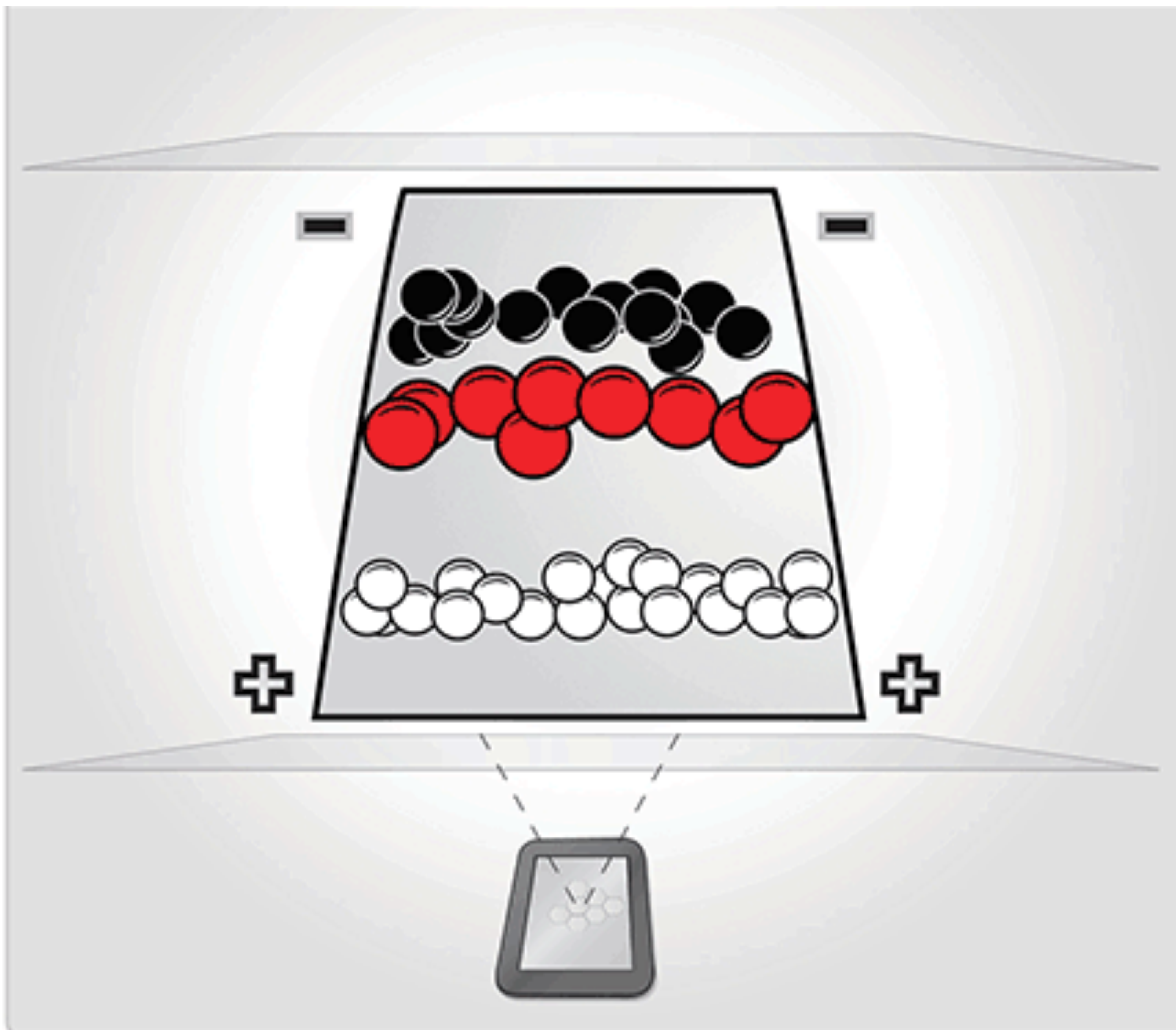
E-ink concept

- yellow, cyan, magenta and white in one capsule
- couldn't find out how they make it move…



E-ink concept

- ‘Spectra is utilizing a microcup ink structure.’
- mhhh…..



[eInk Spectra]

e-ink for multi-display environments
(cheap, no energy for maintaining image)

PaperFold: Evaluating Shape Changes for Viewport Transformations in Foldable Thin-Film Display Devices

Antonio Gomes
Human Media Lab
Queen's University
Kingston, ON, Canada, K7L3N6
gomes@cs.queensu.ca

Roel Vertegaal
Human Media Lab
Queen's University
Kingston, ON, Canada, K7L3N6
roel@cs.queensu.ca

ABSTRACT
In this paper, we investigate the use of shape changes in a multi-segmented mobile device for triggering viewport transformations in its graphical interface. We study PaperFold, a foldable device with reconfigurable thin-film electrophoretic display tiles. PaperFold enables users to attach, reorient and fold displays in a mobile form factor that is thin and lightweight even when fully collapsed. We discuss how our design was informed by a participatory study that resulted in 14 preferred shape changes. In a subsequent study, we asked users to rank the utility of shape changes for triggering common view operations in map and text editing applications. Results suggest participants were able to attribute specific view operations as automated responses to folding, attaching, reorienting or detaching displays. Collated or full screen views were preferred when users collocated two displays. When adding a third display, alternative views such as toolbars or a list of apps were suggested. Showing 3D views was strongly associated with folding PaperFold segments into a three dimensional structure.

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

Figure 1. PaperFold prototype folded into a 3D Hull.

through folding, tearing or combining multiple page elements. Such properties allow paper documents to be navigated and organized more efficiently, allowing concurrent access to multiple documents [19]. Paper is also very thin, durable and lightweight, perceived advantages in the mobile design space. As such, the development of electronic paper computers that adopt certain qualities or metaphors of interacting with paper documents has been an enduring research goal [9,19]. While initial research was

2013 e-ink can also be bent (here using shape memory alloy)

MorePhone: A Study of Actuated Shape Deformations for Flexible Thin-Film Smartphone Notifications

Antonio Gomes
Human Media Lab
Queen's University
Kingston, ON, Canada, K7L3N6
gomes@cs.queensu.ca

Andrea Nesbitt
Human Media Lab
Queen's University
Kingston, ON, Canada, K7L3N6
nesbitt@queensu.ca

Roel Vertegaal
Human Media Lab
Queen's University
Kingston, ON, Canada, K7L3N6
roel@cs.queensu.ca

ABSTRACT

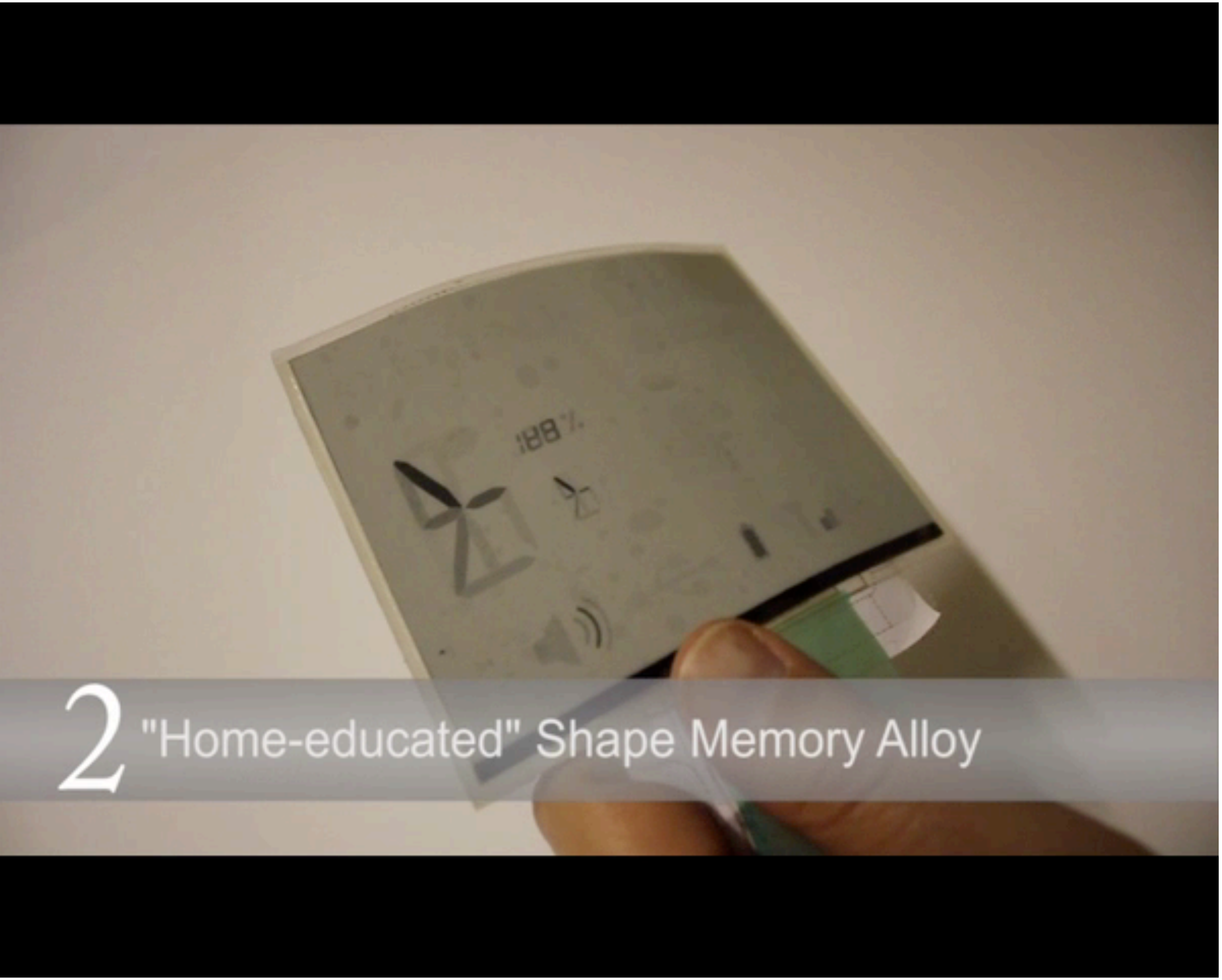
We present MorePhone, an actuated flexible smartphone with a thin-film E Ink display. MorePhone uses shape memory alloys to actuate the entire surface of the display as well as individual corners. We conducted a participatory study to determine how users associate urgency and notification type with full screen, 1 corner, 2 corner and 3 corner actuations of the smartphone. Results suggest that with the current prototype, actuated shape notifications are useful for visual feedback. Urgent notifications such as alarms and voice calls were best matched with actuation of the entire display surface, while less urgent notifications, such as software notifications were best matched to individual corner bends. While different corner actuations resulted in significantly different matches between notification types, medium urgency notification types were treated as similar, and best matched to a single corner bend. A follow-up study suggested that users prefer to dedicate each corner to a specific type of notification. Users would like to personalize the assignment of corners to notification type. Animation of shape actuation significantly increased the perceived urgency of any of the presented shapes.

Author Keywords

Flexible Displays; Shape Changing Interfaces; Actuation; Notification; Organic User Interfaces.

Figure 1. MorePhone actuated shape changing phone.

technologies and materials for computer input and display that can be used for designing flexible computers. Thin-film electrophoretic displays (Flexible E Ink) [18], flexible organic light emitting diodes (FOLEDs) [16], and surface mountable thin film bend, pressure and touch sensors have



2013 Morphees

Morphees: Toward High "Shape Resolution" in Self-Actuated Flexible Mobile Devices

Anne Roudaut[1], Abhijit Karnik[1], Markus Löchtefeld[2], Sriram Subramanian[1]

[1]Department of Computer Science,
University of Bristol, UK
{anne.roudaut, karnik, sriram}@cs.bris.ac.uk

[2]German Research Institute for Artificial Intelligence (DFKI), Saarbrücken, Germany
markus.loechtefeld@dfki.de

Figure 1. Morphees are self-actuated flexible mobile devices that adapt their shapes to offer better affordances. (a) E.g a mobile device can shift into a console-like shape by curling two opposite edges and be easily grasped with two hands. Among the six strategies we built to actuate Morphees, here are two high-fidelity prototypes using Shape Memory Alloys (SMA): (b) one using projection and tracking on wood tiles that are actuated with thin SMA wires; and (c) one directly bending a flexible touchscreen (E-Ink and Unmousepad) by using (d) SMA wires that we educated (forged) to remember the shape we needed.

ABSTRACT

We introduce the term *shape resolution*, which adds to the existing definitions of screen and touch resolution. We propose a framework, based on a geometric model (Non-Uniform Rational B-splines), which defines a metric for *shape resolution* in ten features. We illustrate it by comparing the current related work of shape changing devices. We then propose the concept of *Morphees* that are self-actuated flexible mobile devices adapting their shapes on their own to the context of use in order to offer better affordances. For instance, when a game is launched, the mobile device morphs into a console-like shape by curling two opposite edges to be better grasped with two hands. We then create preliminary prototypes of *Morphees* in order to

INTRODUCTION

There are a growing number of shape-changing devices [20, 39, 42, 51]. However, most research has focused on demonstrating point-designs, i.e. illuminating a spot, in the space of possible shape-changing devices. We have reached a point in the evolution of these devices where it is necessary to be able to articulate how the devices compare and contrast with each other. If we take the analogy of a display device, we can express (and thereby compare and contrast) new display devices in terms of the number of pixels available, the pixel density, the screen size, screen refresh rate and number of bits per pixel. This tuple provides a rich space within which we can situate the different display devices built and identify gaps in the

light field displays

window or
t:blank
iidisplay.com
View against any light source, like a bright window or
a blank web page on your phone: about:blank
LUMII

Lumii: DIY Light Field Prints

Matthew Hirsch* Daniel Leithinger* Thomas Baran*
Lumii

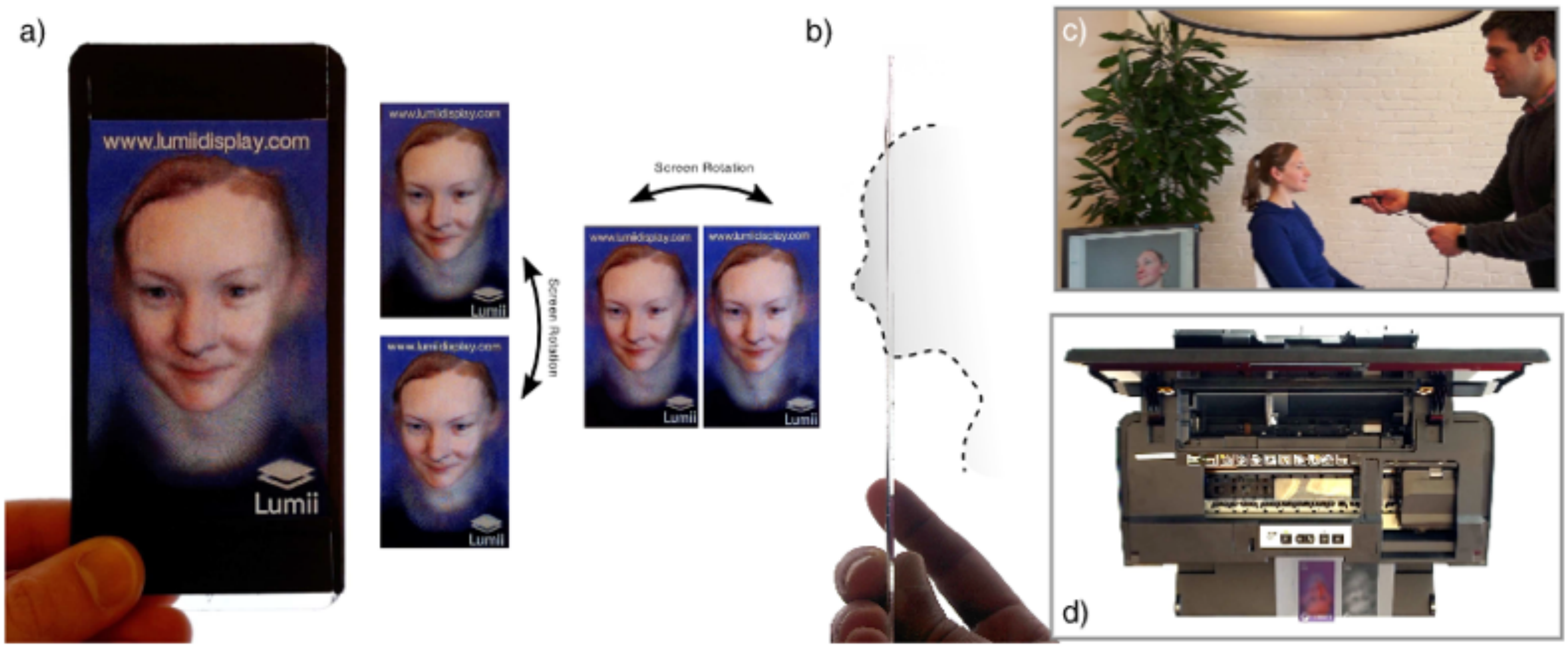


Figure 1: *Realistic, high-resolution light field displays (also known as glasses-free 3D or autostereo displays) (a) can now be created with tools readily available to graphics researchers and hobbyists, including depth cameras (c), photo printers (d), and commodity GPUs thanks to optimization-based techniques. Our technology enables unprecedented resolutions and pop-out-to-thickness ratio (b, side view of a).*

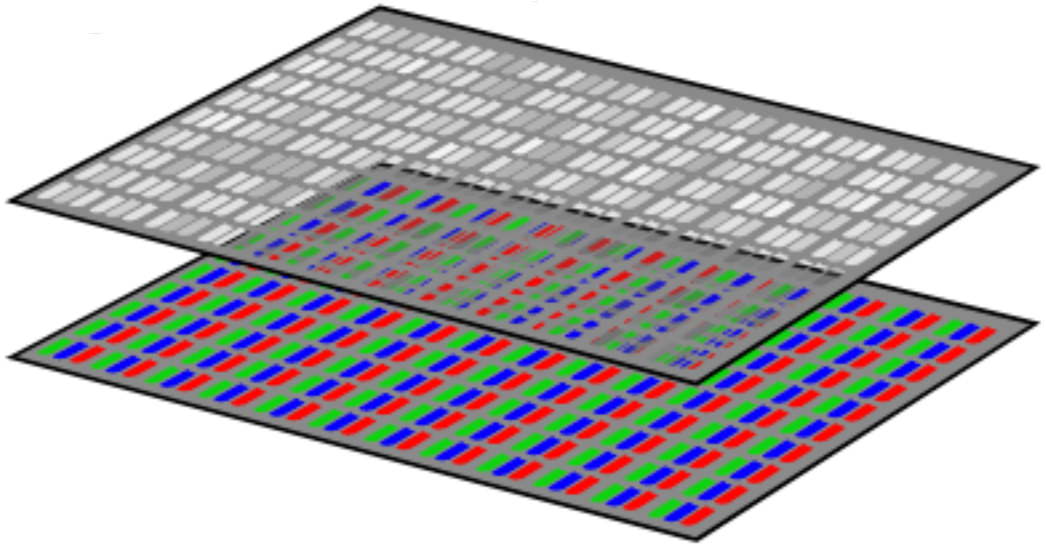
Abstract

In this emerging technology demonstration, we show that computational display methods can be used to create hologram-like 3D images on thin, printed surfaces using standard inkjet processes. Participants will receive a light field print of their own 3D-scanned face, created on-site using an inkjet printer. The computed patterns used in creating the print will also be made available to attendees, who will be able to create additional copies at home. The demonstration uses methods that represent a major step forward in the lineage of results presented previously at SIGGRAPH regarding the close integration of light field displays and optimization methods, which have previously been shown to outperform holograms as well as lens-based discretized light field displays in complexity and

1 Vision

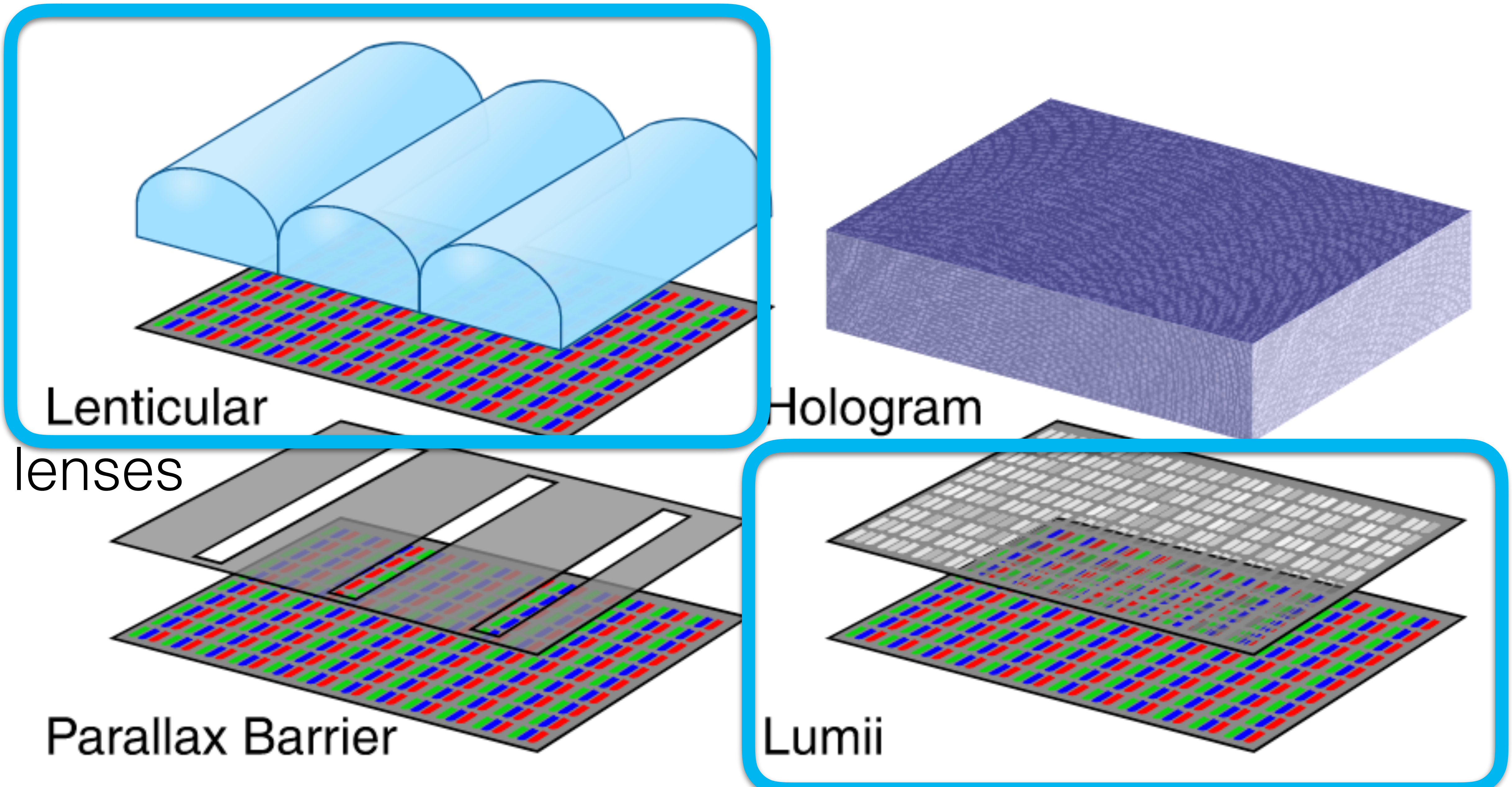
A long-standing vision of the display research community has been to create display surfaces with fidelity that is indistinguishable from reality. Our research is aimed at making progress toward this goal, in particular by creating high-resolution automultiscopic light field displays capable of full horizontal and vertical parallax. Emerging from this research is a user-facing light field engine, inspired by computational display research from the SIGGRAPH community, that can be used to generate thin, hologram-like light field prints using a standard inkjet printer.

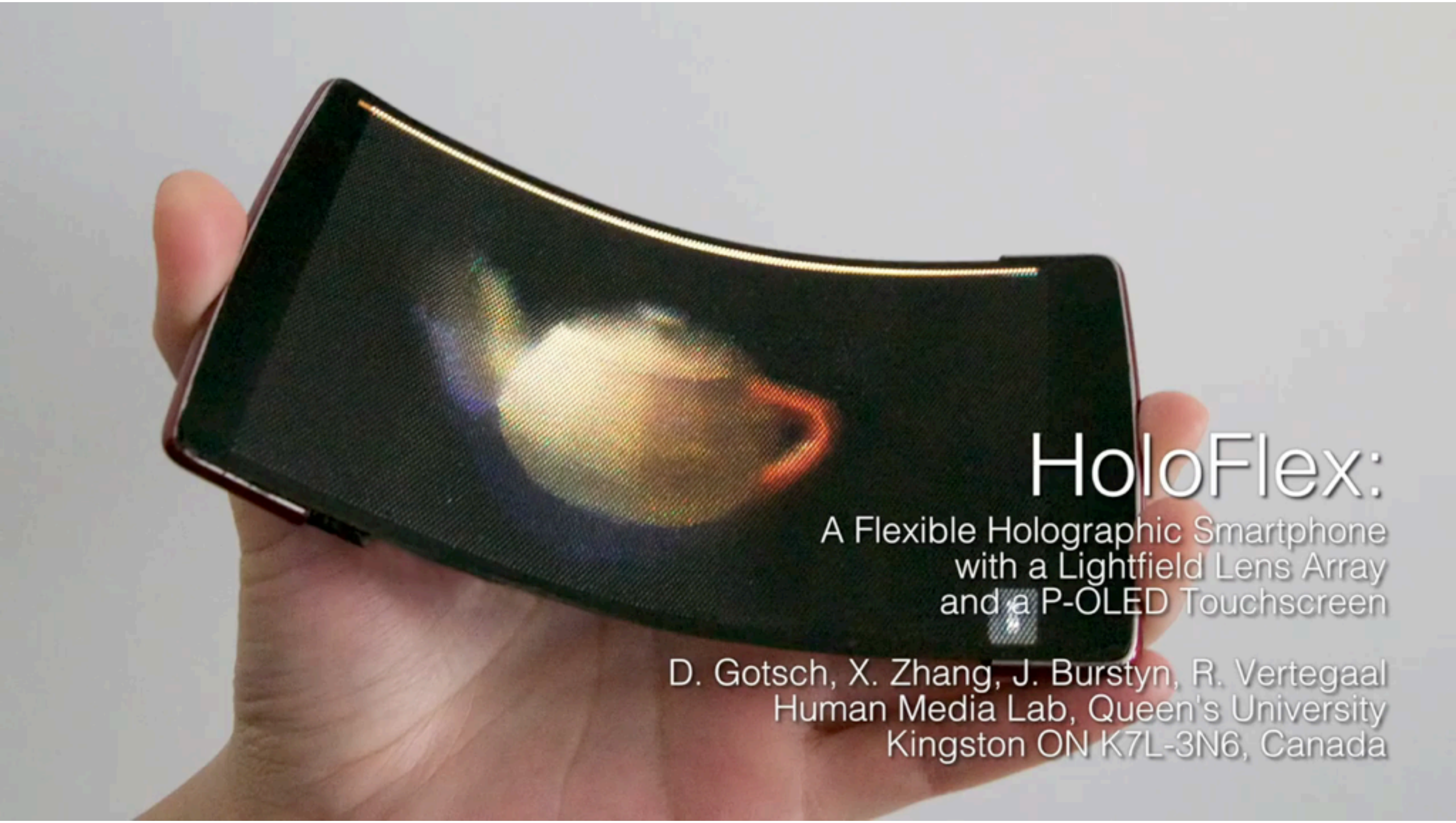
Along with the thriving 3D printing and 3D capture ecosystems, a nascent 3D display ecosystem is developing. Technologies to can-



- use regular photo printer
- layer both images

different light field display hardware:




HoloFlex:
A Flexible Holographic Smartphone
with a Lightfield Lens Array
and a P-OLED Touchscreen
D. Gotsch, X. Zhang, J. Burstyn, R. Vertegaal
Human Media Lab, Queen's University
Kingston ON K7L-3N6, Canada

HoloFlex: A Flexible Light-Field Smartphone with a Microlens Array and a P-OLED Touchscreen

Daniel Gotsch **Xujing Zhang** **Juan Pablo Carrascal** **Roel Vertegaal**
Human Media Lab, Queen's University
Kingston, ON, Canada, K7L 3N6
{goc, xzhang, jp, roel}@cs.queensu.ca

ABSTRACT

We present HoloFlex, a 3D flexible smartphone featuring a light-field display consisting of a high-resolution P-OLED display and an array of 16,640 microlenses. HoloFlex allows mobile users to interact with 3D images featuring natural visual cues such as motion parallax and stereoscopy without glasses or head tracking. Its flexibility allows the use of bend input for interacting with 3D objects along the *z* axis. Images are rendered into 12-pixel wide circular blocks—pinhole views of the 3D scene—which enable ~80 unique viewports at an effective resolution of 160 × 104. The microlens array distributes each pixel from the display in a direction that preserves the angular information of light rays in the 3D scene. We present a preliminary study evaluating the effect of bend input vs. a vertical touch screen slider on 3D docking performance. Results indicate that bend input significantly improves movement time in this task. We also present 3D applications including a 3D editor, a 3D *Angry Birds* game and a 3D teleconferencing system that utilize bend input.

Author Keywords

Organic User Interfaces; Light-field Displays; 3D Input.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

In the real world, humans rely heavily on a number of 3D depth cues to locate and manipulate objects and to navigate half-century, to date much of the 3D content remains rendered as a 2D image on flat panel displays that are unable to provide proper depth cues. One solution for rendering images in 3D is to use a lenticular display, which offers limited forms of glasses-free stereoscopy and limited one-dimensional motion parallax [40]. Other, more immersive solutions, such as the Oculus Rift [41] and the Microsoft HoloLens [38], offer full stereoscopy and motion parallax but require headsets or motion tracking. Recently, there has been a renewed interest in 3D displays that do not require glasses, head tracking or headsets. Such *light-field* displays render a 3D scene while preserving all angular information of the light rays in that scene. With some notable exceptions [28], the size of light-field displays makes them unsuitable for mobile use. Current smartphones are also limited in terms of 3D input. Z-Input—control along the *z* axis, i.e., perpendicular to the screen—is frequently mapped to *x,y* touch input [33,50], sacrificing the relation between input and control task structures [19].

In this paper, we present HoloFlex, a glasses-free 3D smartphone featuring a flexible thin-film light-field display with thousands of microscopic lenses. 3D images are rendered on a high resolution Polymer Organic Light Emitting Diode (P-OLED) display by a ray-tracing algorithm that simulates a hexagonal array of 160×104 pinhole cameras distributed on a 2D plane. Each camera independently renders a wide-angle 2D image from a given position onto a circular 12-pixel wide block (see Figure 1). An array of 16,640 half-dome microlenses distributes the 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

prototype future interaction with projection

until we get the tech right..

end.