# HANDSIGHT: A TOUCH-BASED WEARABLE SYSTEM TO INCREASE **INFORMATION ACCESSIBILITY FOR PEOPLE WITH VISUAL IMPAIRMENTS** distance until it is just a still know that it is the red card

#### **Examining Committee:**

**Dr. Jon Froehlich** Chair / Advisor

Dr. Rama Chellappa

**Dr. Leah Findlater** Member

Dr. Ramani Duraiswami Member

Dr. Gregg Vanderheiden Dean's Representative

# Lee Stearns

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### **ACTIVITIES OF DAILY LIVING**

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very 15 Minutes (or Less)

Hollywood/Highland

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Preparing food

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### Previous research has used mobile cameras and computer vision for **at-a-distance tasks**

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**Five Points** 

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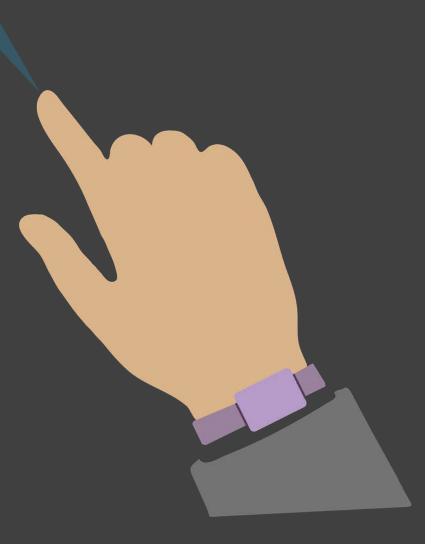
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# For people with visual impairments, touch is a **primary means** of obtaining information about the **physical world**

### **Research Goal**

Augment visually impaired users' sense of touch with interactive, real-time computer vision to improve the accessibility of information.



Category #1: access to visual information in the physical world

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Category #2: access to digital information by controlling computers or mobile devices

## **OPEN QUESTIONS**

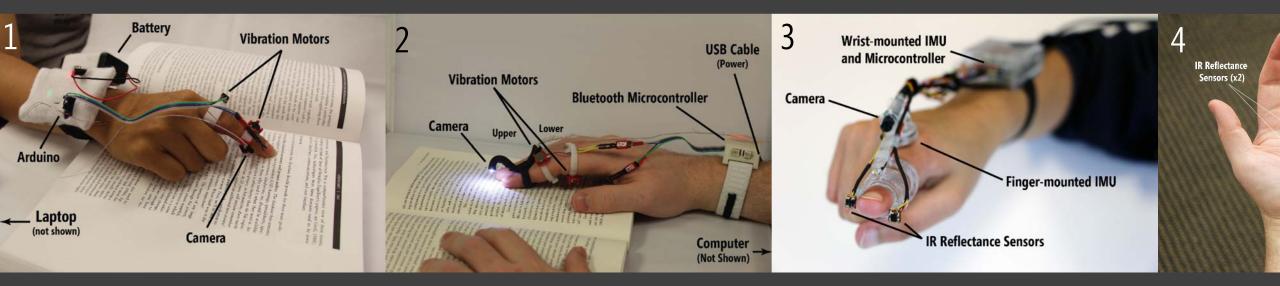
What is the best method to recognize the content that the user is touching, and how should information about that content be conveyed to the user?

## HANDSIGHT

Key aspects:

- 1. Physical hardware
- 2. Real-time algorithms
- 3. Interactive interface
- 4. Usability evaluations

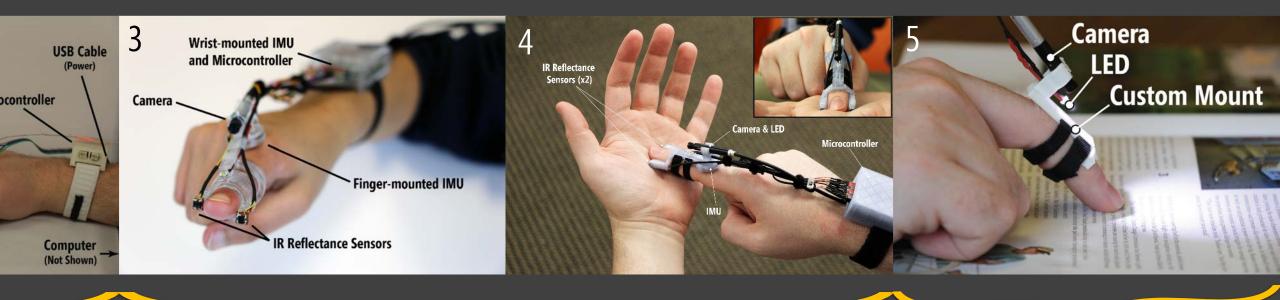
Development and iterative refinement of HandSight, a novel wearable system to assist visually impaired users.



Reading and exploring printed documents

Controlling mobile device through on-body input

Development and iterative refinement of HandSight, a novel wearable system to assist visually impaired users.



Controlling mobile devices through on-body input AR Magnification & Identifying Colors/Patterns

Development and iterative refinement of HandSight, a novel wearable system to assist visually impaired users.

Findings from **user evaluations** across a diverse set of tasks, which demonstrate advantages and disadvantages of our **finger-worn approach**.

Development and iterative refinement of HandSight, a novel wearable system to assist visually impaired users.

Findings from **user evaluations** across a diverse set of tasks, which demonstrate advantages and disadvantages of our **finger-worn approach**.

**Design Implications** for **future wearable assistive systems** and for the fields of accessibility, computer vision, AR and VR, and human-computer interaction.

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# RELATED WORK

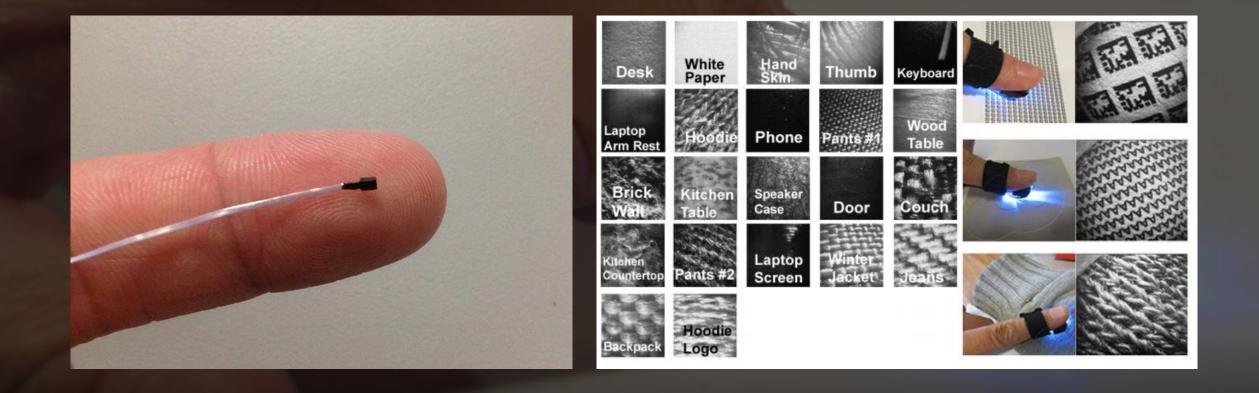
#### **Related Work**



**Tiny CMOS camera** 

Magic Finger: X.D. Yang, et al., "Magic finger: always-available input through finger instrumentation," in Proceedings of UIST 2012.

### **Related Work**



Magic Finger: X.D. Yang, et al., "Magic finger: always-available input through finger instrumentation," in Proceedings of UIST 2012.

Related Work	Control of the state of the sta	the set of the set
Finger-mounted camera	the alle	
Haptic vibration motors		
FingerReader: R. Shilkrot, <i>et al.</i> , "FingerReader: a W	earable Device to Explore Printed	Text on the Go," in Proceedings of CHI 2015.



FingerReader: R. Shilkrot, et al., "FingerReader: a Wearable Device to Explore Printed Text on the Go," in Proceedings of CHI 2015.

### **RELATED WORK**

#### Glasses-mounted camera

BUSINESS

Unfair edge over small investors EUROPEAN TECH STARI FIND WAY TO U.S. MARKE

EUTERS BREAKINGVIEWS

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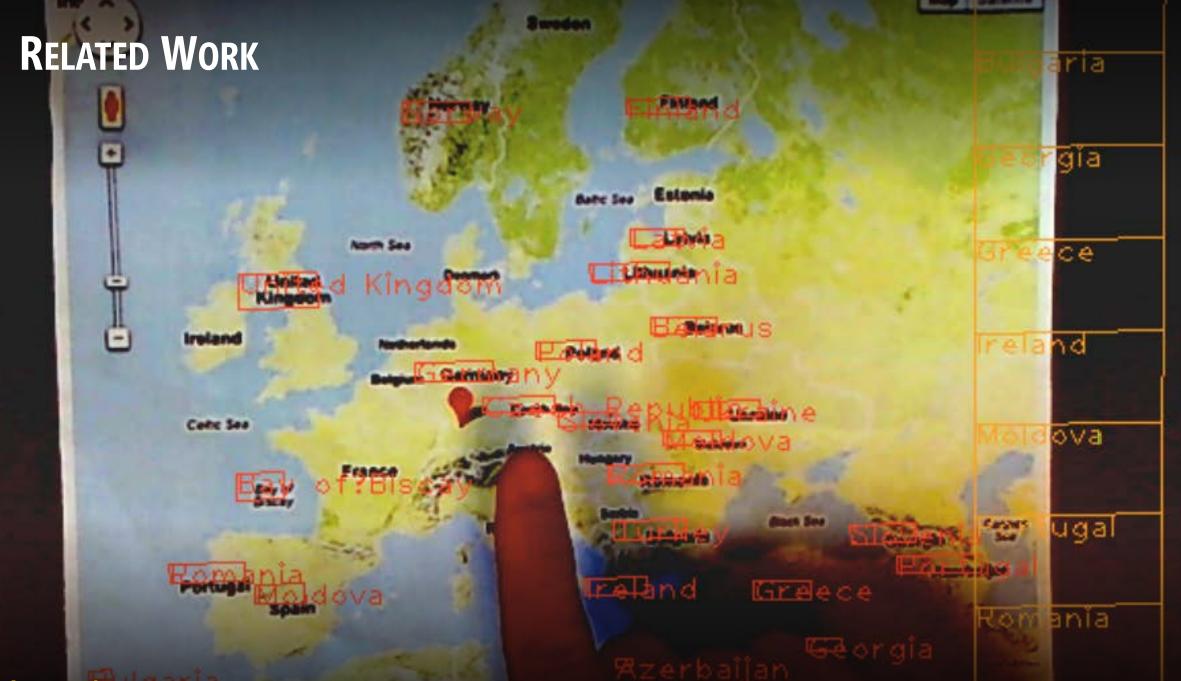
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OrCam MyEye: http://www.orcam.com

### **RELATED WORK**

Access Lens: S. Kane, et al., "Access lens: a gesture-based screen reader for real-world documents," in Proceedings of CHI 2013.



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### **Related Work**

**OmniTouch:** C. Harrison, *et al.*, "OmniTouch: Wearable Multitouch Interaction Everywhere," in Proceedings of UIST 2011.

### **RELATED WORK**

Table 3 - Touch Biases for X axis for a 30 degree monster angle (in cm) Negative bias means touch was to the left of the target. Mean Bias (cm) Y Position (cm) +0.54 1.24 +0.54 4.13 +0.49 +0.45 7.01 9.90 Table 4 - Touch Biases for Y axis for a 30 degree monitor angle (m cm) +0.41

Positive bias means touch was below target. subjects were touching. Y position represents how for from the screen subjects were touching.

Ranges represent the extreme misses on either side of

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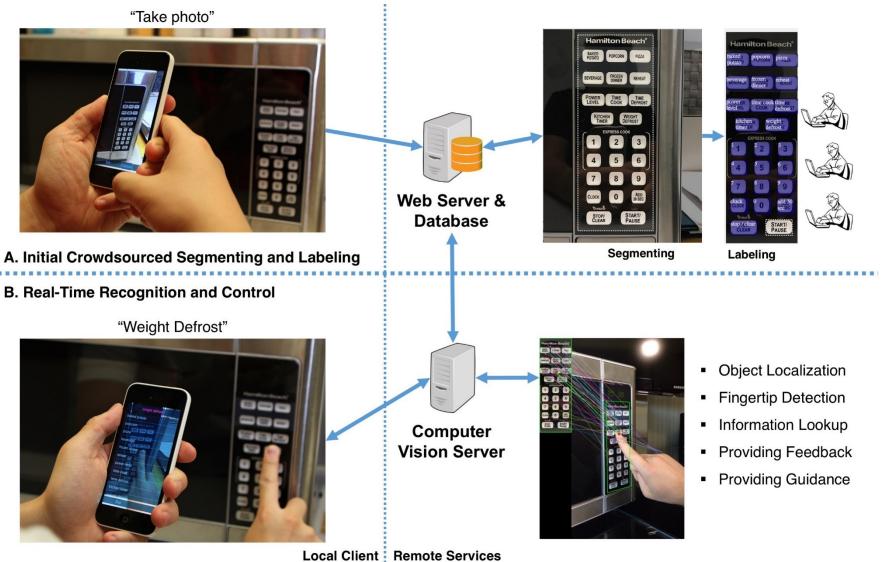
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**On-Body Input** 

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**Clothing Colors/Patterns** 

### Advantages of Touch-Based Reading 1. Does not require framing an overhead camera

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Advantages of Touch-Based Reading
1. Does not require framing an overhead camera
2. Allows direct access to spatial information
3. Provides better control over pace and rereading

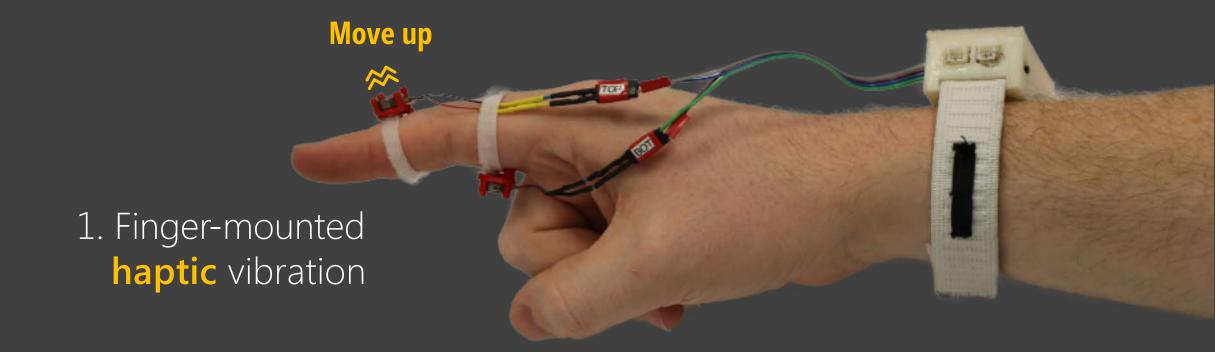
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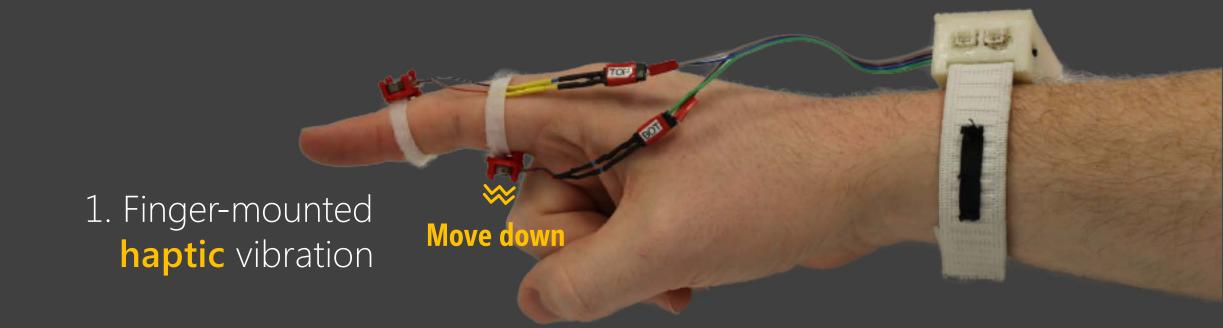
### **New Challenges**

How to precisely trace a line of text?
 How to support physical navigation?

2. Audio via built-in or external speakers

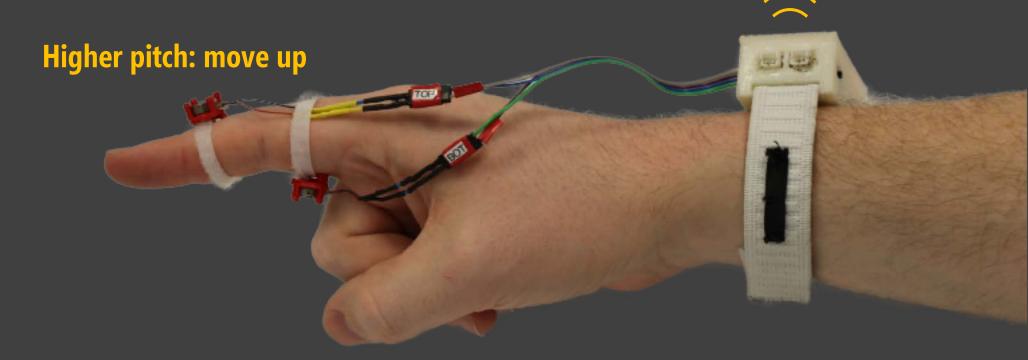
# 1. Finger-mounted haptic vibration





2. Audio via built-in or external speakers

2. Audio via built-in or external speakers



2. Audio via built-in or external speakers

Lower pitch: move down

## READING PILOT STUDY METHODS

#### **4** Participants

3 female, 1 male, ages 43-64 3 totally blind, 1 severe low vision



Lee Stearns, Ruofei Du, Uran Oh, Yumeng Wang, Leah Findlater, Rama Chellappa, and Jon E. Froehlich, "The Design and Preliminary Evaluation of a Finger Mounted Camera and Feedback System to Enable Reading of Printed Text For the Blind," in Proceedings of ECCV 2014 (ACVR Workshop).

# READING PILOT STUDY FINDINGS

### audio-only

Lunar rocks brought back by the Aporto astronauts more than 40 years ago contain ovidence of a Mars sized planet that scientists believe crashed into Earth and created the moon, new research shows.

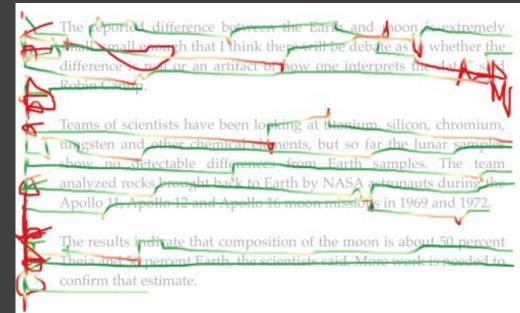
German scientists using a new technique said they detected a slight chemical difference between Earth rocks and moon rocks. Scientists said more study would be needed to confirm this long elusive piece of evidence that material from another body besides Earth contributed to the moon's formation some 4.5 billion years and.

Scientists believe the moon formed from a cloud of debris launched into space after a Mars sized body called Theia crashed into the young Earth.

### **4** Participants

3 female, 1 male, ages 43-643 totally blind, 1 severe low vision

## haptic-only



Example finger traces—Red lines mark drift off of the line

Audio was more accurate, about twice as fast, and preferred by 3 out of 4 participants

## **READING STUDIES | & ||**

Lee Stearns, Ruofei Du, Uran Oh, Catherine Jou, Leah Findlater, David Ross, and Jon E. Froehlich, "Evaluating Haptic and Auditory Directional Guidance to Assist Blind People in Reading Printed Text Using Finger-Mounted Cameras," in *ACM Transactions on Accessible Computing*, October 2016.

**Study I:** initial iPad study (19 participants)

Study II: physical prototype study (4 participants)

## **READING STUDIES I & II**

#### Goals:

Compare audio/haptic Explore & interpret spatial layouts Assess reading and comprehension

Study I: initial iPad study (19 participants)

**Participants:** 8 female, 11 male, ages 26-67) All totally blind or minimal light perception

## **READING STUDY**

Used an iPad to focus on user experience, gather finger trace data

# System Design EXPLORATION AND READING MODES

#### Animals also have emotions

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Despite the stubborn, widespread opinion that animals don't feel emotions in the same way that humans do, many animals have been observed to demonstrate a capacity for joy. People have often seen animals evincing behavior that can only be taken to mean they are pleased with what life has brought them in that particular moment. A chimpanzee named Nim was raised by a human family for the first year and a half of his life. After that time, Nim was separated from them for two and a half years. On the day that Nim was reunited with his human family, he smiled, shrieked, pounded the ground, and looked from one member of the family to the next. Still smiling and shrieking, Nim went around hugging each member of the family. He played with and groomed each member of the family for almost an hour before the family had to leave. People who were familiar with Nim's behavior said they had never seen him smile for such a long period of time.



Exploration Mode

history and buried for safekeeping. Because stores of coins gathered and hidden in this manner lie untouched for many years, they can reveal a great deal about a given culture.

Coins are useful in revealing many aspects of a culture. They can provide clues about when a given civilization was wealthy and when it was experiencing a depression. Wealthy nations tend to produce a greater number of coins made from richer materials. The distribution of coins can also reflect the boundaries of an empire and the trade relationships within it. Roman imperial gold coins found in India, indicate the Romans purchased goods from the East.

The way the coins themselves are decorated sometimes provides key information about a culture. Many coins are stamped with a wealth of useful historical evidence, including portraits of political leaders, important buildings and sculptures, mythological and religious figures, and useful dates. Some coins, such as many from ancient Greece, can be considered works of art themselves and reflect the artistic achievement of the civilization as a whole.

Information gathered from old coins by historians is most useful when placed alongside other historical documents, such as written accounts or data from archeological digs. Combined



# System Design EXPLORATION MODE

Continuous audio feedback to identify content beneath finger

- Flute sound: text **Cello sound**: picture
- Silence: empty space



#### Animals also have emotions

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**Silence:** empty space who were familiar with Nim's behavior said they had never seen him smile for such a long period of time.



System Design **READING MODE** Right index finger to read, left to anchor start of line Two directional guidance conditions: audio or haptic Used to stay on the line or find the start of the next line Audio: pitch of continuous audio Haptic: strength and position of vibration Additional audio cues (same for both conditions) Start/end of line or paragraph Synthesized speech

history and buried for safekeeping. Be Above the line: downward guidance this manner lie untouched for many years, the low pitch or lower vibration motor) a liture.

Coins are useful in revealing many aspects of a culture. They can provide clues about when a given civilization was wealthy and when it was experiencing a depression. Wealthy nations

tend coins (high pitch or upper vibration motor) he from richer (high pitch or upper vibration motor) hire and the tra imperial gold coins found in India, indicate the Romans purchased goods from the East.

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### Haptic vs. Audio: Quantitative Performance (n=19)

### audio

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### haptic

made up of long mountain ranges and deep valleys and troughs. Another surprise finding in the Atlantic was the existence of basalt, a volcanic rock thought only to exist in the Pacific Ocean. The presence of basalt in the Atlantic was a clue that volcanic activity occurs at the bottom of the sea. This and other discoveries, many of them

Example finger traces—Dashed red lines mark drift off of the line

### Haptic vs. Audio: Quantitative Performance (n=19)

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> 0.21cm Absolute error from line center

### haptic

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**Overall Reading Experience** 

#### Pros

Low learning curve

Flexible

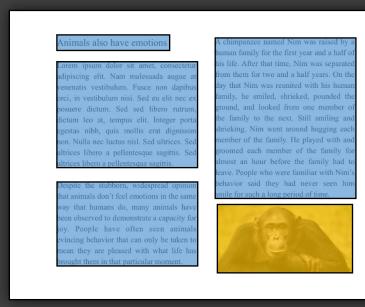
Direct control over speed

### **Overall Reading Experience**

Pros	Cons
Low learning curve	Hard to use for reading
Flexible	High cognitive load may affect comprehension
Direct control over speed	

### **Exploration Mode**

Participants appreciated direct access to spatial information, and nearly all able to locate images and count the number of columns.



## **READING STUDIES | & ||**

### **Study I:** initial iPad study (19 participants)

Study II: physical prototype study (4 participants)

## **READING STUDIES | & ||**

## **Goals:**

Evaluate HandSight prototype Gather subjective feedback Compare with KNFB Reader iOS

**Participants:** 1 female, 3 male, ages 39-64) All totally blind or minimal light perception

Study II: physical prototype study (4 participants)

## Study II Prototype

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# Study II METHOD: HANDSIGHT

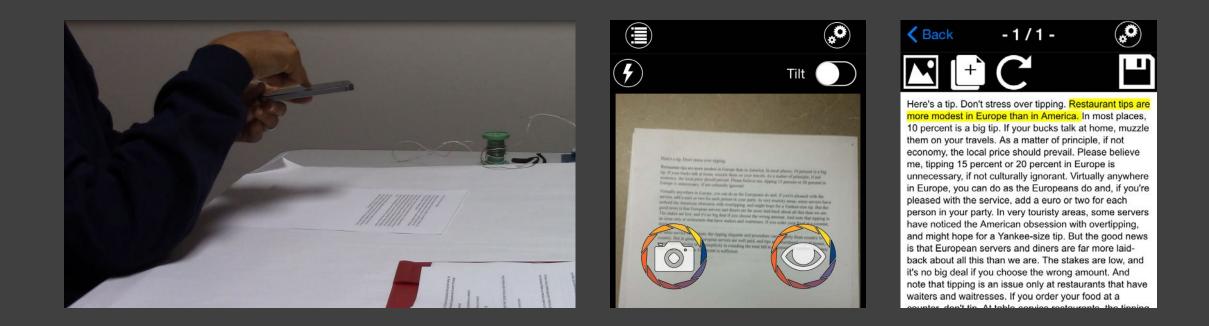
## Participants used **preferred guidance** from Study I to explore and read physical documents



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Ora: In seven Americana, 46 relillion people, roly on food pantrics and meak service program to feed themselves and their families, the study found.	

## Study II METHOD: KNFB READER IOS

## Photographed and read physical documents



Advantages and Disadvantages of a Finger-Based Reading Approach

Pros

Advantages and Disadvantages of a Finger-Based Reading Approach

#### Pros

Spatial layout information

Advantages and Disadvantages of a Finger-Based Reading Approach

#### Pros

Spatial layout information

Direct control over reading

Advantages and Disadvantages of a Finger-Based Reading Approach

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Reduced camera framing issues

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Spatial layout information Direct control over reading Reduced camera framing issues Efficient text detection and recognition \* We observed these in our studies

Advantages and Disadvantages of a Finger-Based Reading Approach

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Spatial layout information

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Efficient text detection and recognition

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#### Cons

Slower, requires increased concentration and physical dexterity

Advantages and Disadvantages of a Finger-Based Reading Approach

#### Pros

Spatial layout information

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Reduced camera framing issues

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Advantages and Disadvantages of a Finger-Based Reading Approach

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Spatial layout information
Direct control over reading
Reduced camera framing issues
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#### Cons

Slower, requires increased concentration and physical dexterity \* Consistent with Shilkrot *et al.* 2014, 2015

Importance of spatial layout information is unclear

# CONTRIBUTIONS

Implementation and systematic evaluation of haptic and auditory cues for directional finger guidance Identification of tradeoffs of both the finger guidance methods and touch-based reading in general in terms of speed, accuracy, and user preference Proof-of-concept **realtime system** for reading and exploring printed documents via touch

# EXTENSION FOR LOW VISION USERS's melting; warming seav The average elevation of the seaverage elevation elevatio The average elevation of the Deal Is

Lee Stearns, Victor De Souza, Jessica Yin, Leah Findlater, and Jon E. Froehlich, "Augmented Reality Magnification for Low Vision Users with the Microsoft HoloLens and a Finger-Worn Camera," in *Proceedings of ASSETS 2017*.

Famine, drought, sickness and extin

thly life if carbon emissions aren't

ntually halted. But for Katherine

Lee Stearns, Leah Findlater, and Jon E. Froehlich, "Design of an Augmented Reality Magnification Aid for Low Vision Users," in Proceedings of ASSETS 2018 (To Appear).

## seeks more support for caregivers

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Common reading aids include closed circuit television (CCTV), handheld optical or digital magnifiers, and smartphone apps

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'Disability is an issue that affects every



Merica: Toward a National Agenda for Prevention began with these words. They

#### FORESEE Zhao *et al.*, ASSETS 2015

#### **GOOGLE GLASS**

**Edge Enhancement** 

Hwang and Peli, Optometry and Vision Science, Aug 2014

Smartphone Magnification Calculator

Pundlik et al., IEEE Trans. Neural Systems and Rehab. Engineering, Jan 2017

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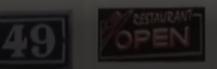
Photo from Wikimedia Commons

### **COMMERCIAL HEAD-WORN VISION ENHANCEMENT SYSTEMS**



NuEyes

IrisVision



## AR systems combine real and virtual objects, are interactive in real-time, and are registered in 3D

**Ronald T. Azuma (paraphrased)** A Survey of Augmented Reality, 1997



### **MICROSOFT HOLOLENS**

### **OUR APPROACH**

and factors are contributing: geolog d ice caps are melting; warming seav

weakening and carrying less water a:

The average elevation of the Deal Is

Famine, drought, sickness and extin

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ntually halted. But for Katherine

# DESIGN SPACE

#### Augment rather than replace existing vision capabilities

### DESIGN SPACE GOALS

#### **Augment** rather than **replace** existing vision capabilities

Leverage augmented reality and persistent 3D content

# Design Space

#### **Augment** rather than **replace** existing vision capabilities

Leverage augmented reality and persistent 3D content

Prioritize customization and flexibility

### **INITIAL INVESTIGATION: HOLOLENS** DESIGN



**Built-in camera** to capture images

**Two display modes:** Fixed 2D & Fixed 3D



Voice Commands to select mode



**Image Enhancements:** Binary threshold & Invert colors



# INITIAL INVESTIGATION: HOLOLENS **OBSERVATIONS**

Camera resolution too low

**Turning head** to look at desired content was uncomfortable

**Voice commands** cumbersome, imprecise, limited customization



# **AR PROTOTYPE 1** HoloLens and Finger-Camera

# HoloLens

### Camera

### **PHYSICAL DESIGN** AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA

## Camera LED Custom Mount

### **PHYSICAL DESIGN** AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA



### Virtual Display Design 1: Fixed 2D Acts as a heads-up display, stays in the user's view at all times

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rising seas.

### VIRTUAL DISPLAYS AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA

# Users customize the position and size of the display for each design using midair tap and drag gestures

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of marshland

### USER INTERACTIONS AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA

### AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA METHOD

3 Low Vision Participants (1 Female, 2 Male, Ages 28-54) Each participant used three virtual display designs to read documents and other text (e.g., mail, pill bottle, cereal box)

### AR PROTOTYPE 1: HOLOLENS AND FINGER-CAMERA METHOD

They provided **feedback and suggestions** on their likes, dislikes, design preferences, ideas for improvements or new features

#### Virtual Display Designs



#### **Fixed 3D (Vertical or Horizontal)**

Reading experience similar to using a CCTV or handheld magnifier.



#### **Finger Tracking**

Can help to quickly search a document.



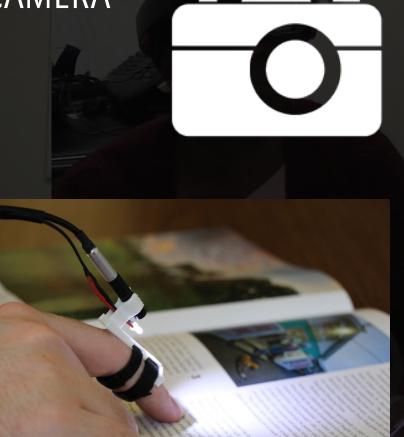
Aa Bb

#### Fixed 2D

Always visible, required least concentration.

**Finger-Worn Camera** 

[+] Flexible, allows hands-free use
[-] Requires moving finger to read
[-] Small field of view (~3-4 lines)

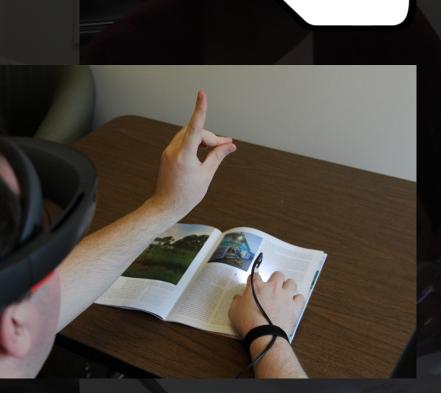


#### **HoloLens Display**

Low contrast due to transparency
 <u>Narrow view, center of vision</u>

#### **User Input**

[-] Midair gestures difficult to use[-] Unable to make quick adjustments



# **AR PROTOTYPE 2** HoloLens and Smartphone

# HoloLens

## iPhone

### **PHYSICAL DESIGN** AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE

### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE PHYSICAL DESIGN

3 Inch by inch, nature is a of marshland pines a bleached bones. These a bleached bones. These a the spiking salinity of ri The Maryland Clima future for the Chesapeake Bay, predicting Several factors are contributing: geologic and ice caps are melting; warming seawat is weakening and carrying less water awa the average elevation of the Deal Isla Famine, drought, sickness and extinc

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### Virtual Display Design 1: Attached to Headset Maintains fixed position relative to the user at all times

### **VIRTUAL DISPLAYS** AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE

And the other distance in the local distance of the local distance

Aa Bb

# Each design included several options for customization, including the position, size, and contrast/colors

### USER INTERACTIONS AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE

Several factors are contributing and ice caps are melting, warmin is weakening and carrying less w The average elevation of the 3 Famine, drought, sickness an earthly life if cathon eminimum a eventually habed. But for Kath 'Jo' Johnson Ph.D. '16, project do until cardier this year, caro had to its work in the present. Johnson grew up 20 miles away in Salis ages creating a network of true

such its institution

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### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE METHOD

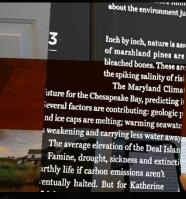
6 Low Vision Participants (3 Female, 3 Male, Ages 28-68) Each participant used three virtual display designs to read documents and other text (e.g., mail, pill bottle, cereal box)

### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE FINDINGS

Participants were more successful and positive about their experience using this version of our system.

They were better able to experience the **AR** aspects of our approach, which most participants found promising.

### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE FINDINGS Virtual Display Designs





everal factors are contributing: geologic p nd ice caps are melting; warming seawate weakening and carrying less water away The average elevation of the Deal Islan Famine, drought, sickness and extinct arthly life if carbon emissions aren' eventually halted. But for Katherine "Johnson Ph.D. '16, project director til earlier this year, oran had to start work in the present. Johnson, who

The Maryland Clim. are for the Chesapeake Bay, predicting



Attached to Headset

Easier to focus on the text

Potentially distracting

#### Attached to World

Natural reading experience

Easier to multitask

rise projections, he says, gi They have more imme about the environment im Aa Bb

3 Inch by inch, nature is as of marshland pines are bleached bones. These are the spiking salinity of ri-The Maryland Clim Future for the Chesapeake Bay, predicting Several factors are contributing: geologic and ice caps are melting; warming seawal is weakening and carrying less water aw. The average elevation of the Deal Isl. Famine, drought, sickness and extin

#### **Attached to Phone**

Versatile

Intuitive interactions

### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE FINDINGS

#### Smartphone

[+] Better camera
[+] More usable interactions
[-] No longer hands-free
[-] Too heavy for extended use



### AR PROTOTYPE 2: HOLOLENS AND SMARTPHONE FINDINGS

#### HoloLens

Issues with contrast, field of view, and physical size and weight still present.

Participants with central vision loss struggled to use the system.



# CONCLUSIONS

Strengths and Weaknesses of 3D AR for Magnification [+] Enables new interactions not possible with other approaches [+] Good for multitasking

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# CONCLUSIONS

Strengths and Weaknesses of 3D AR for Magnification [+] Enables new interactions not possible with other approaches [+] Good for multitasking

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CONTRACTORING DIRECT

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May require more effort to use than fixed 2D display

# CONTRIBUTIONS

Design space exploration: AR magnification & enhancement

Implementation and evaluation of proof-of-concept designs with low vision users

Cake Bay, r

nd carrying

April 1012

Proposed design recommendations for future AR vision enhancement aids

# HANDSIGHT APPLICATION AREAS

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On-Body Input

**Clothing Colors/Patterns** 

### HANDSIGHT APPLICATION AREAS

**Reading/Exploring Text** 

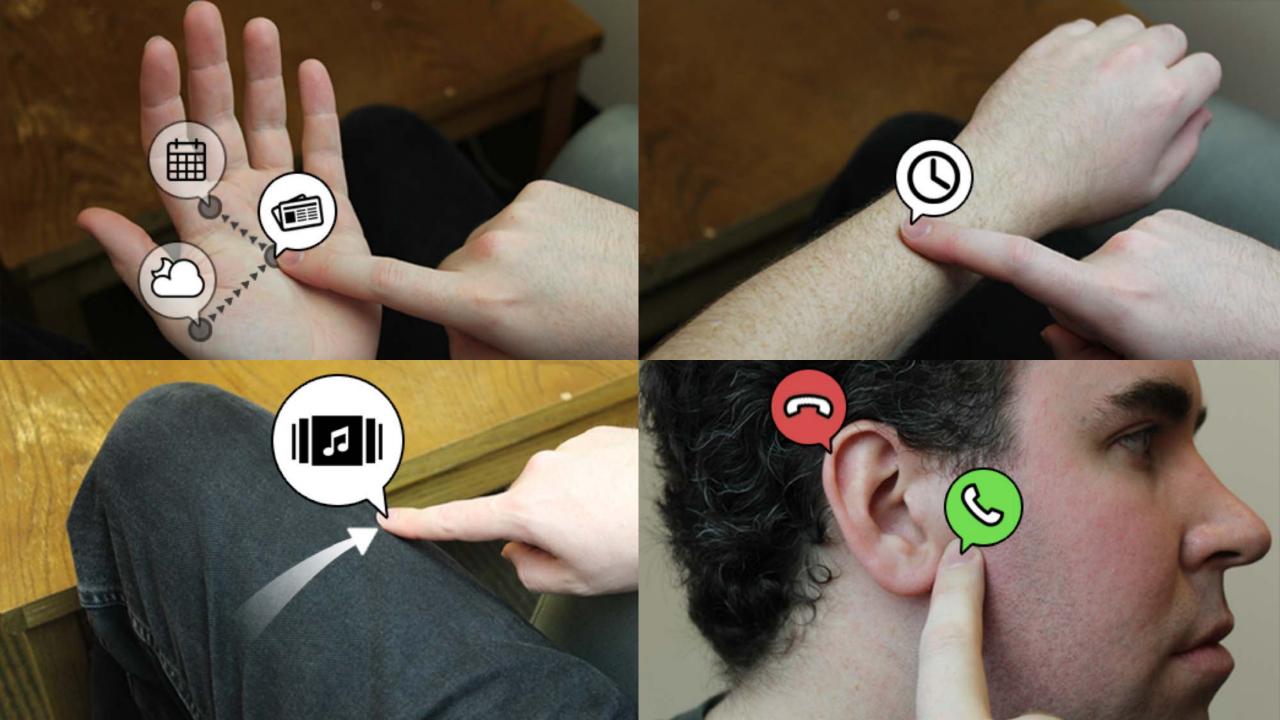
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**On-Body Input** 

**Clothing Colors/Patterns** 



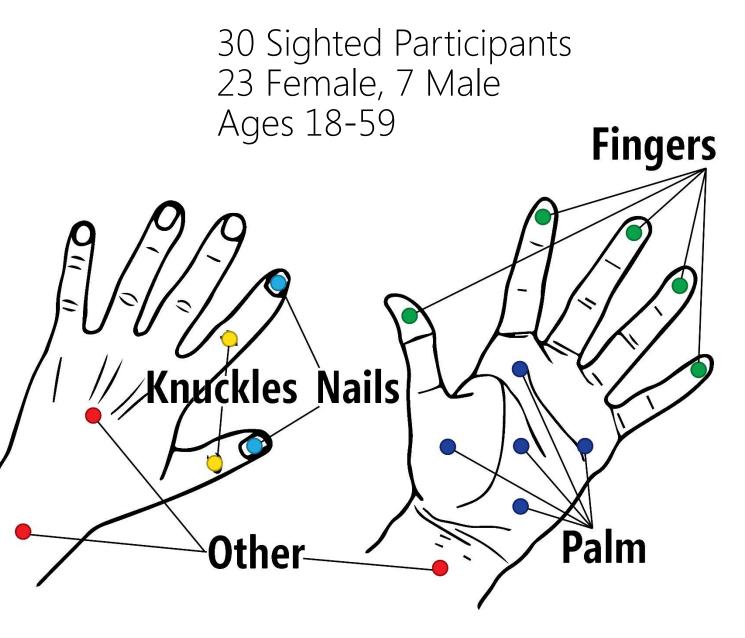
# **ON-BODY INPUT** Using Finger-Worn Sensors

### Advantages:

1. More easily scalable to other body locations and surfaces

- 2. Larger **input vocabulary**: touch position × relative gestures
- 3. Simplified sensing and processing due to sensor positioning

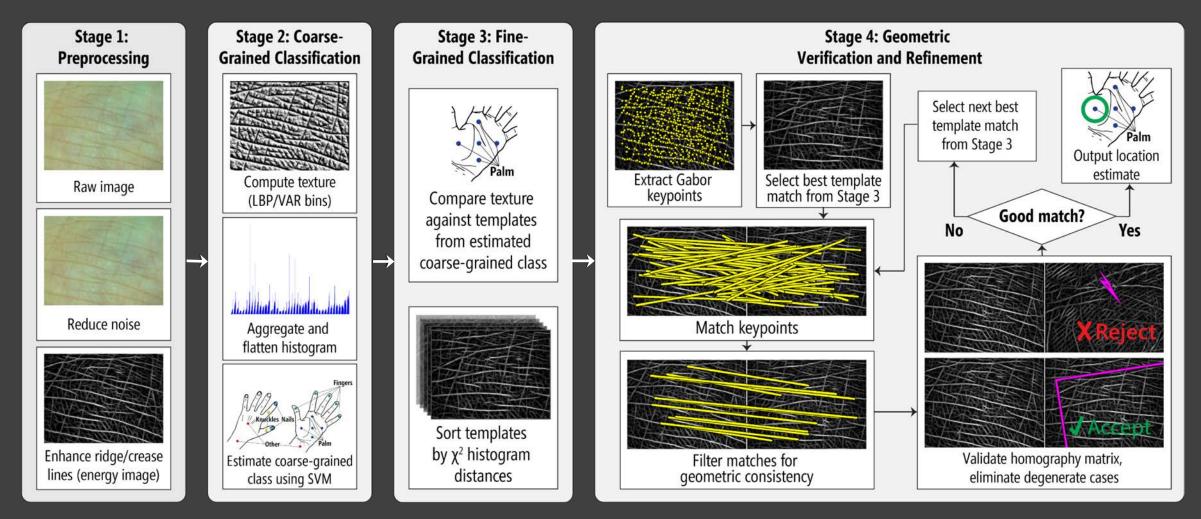
# ON-BODY STUDY I DATASET

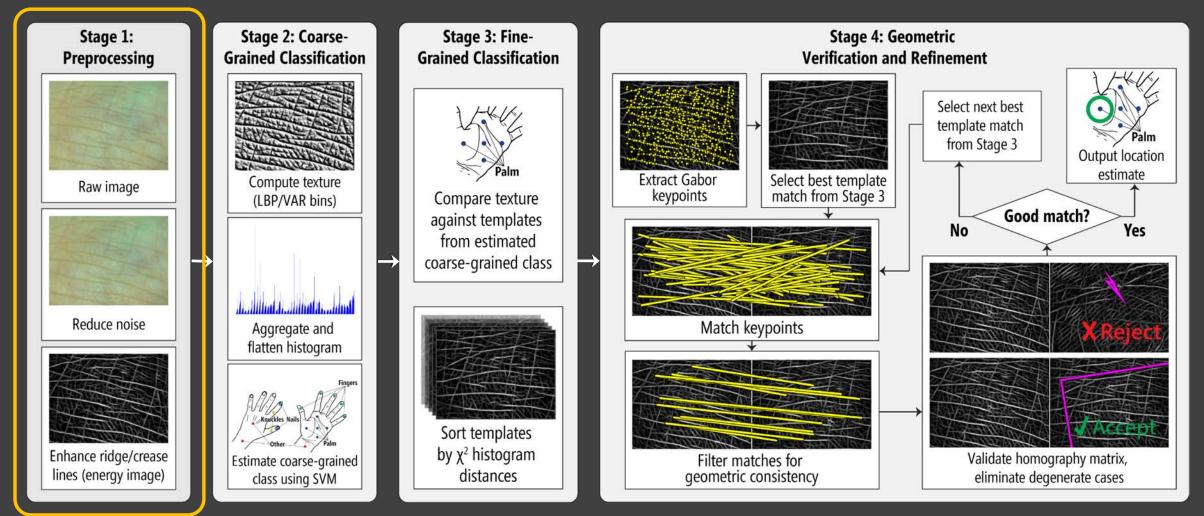


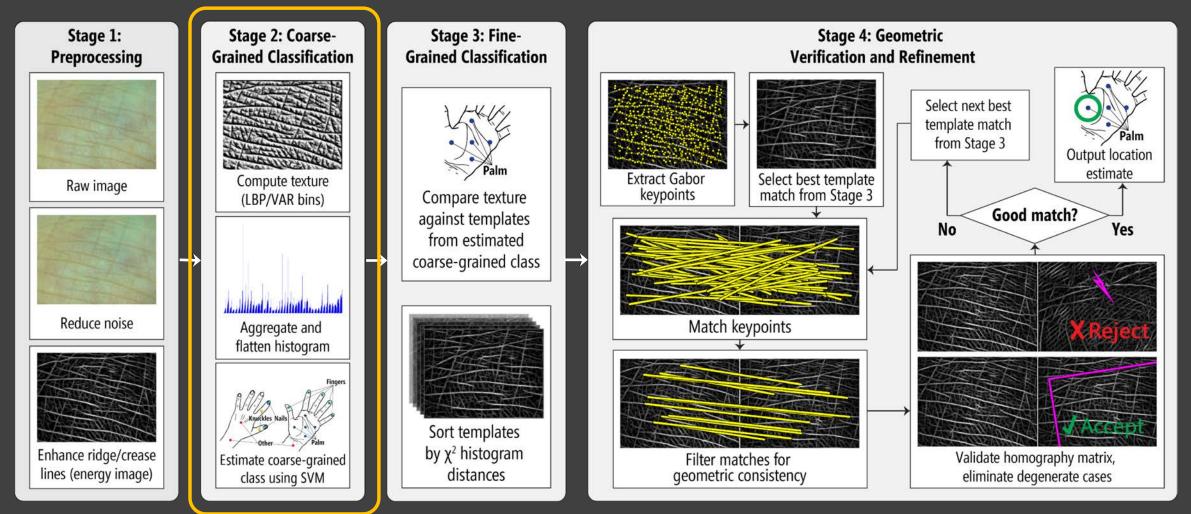
Lee Stearns, Uran Oh, Bridget J. Cheng, Leah Findlater, David Ross, Rama Chellappa, and Jon E. Froehlich, "Localization of Skin Features on the Hand and Wrist from Small Image Patches," in *Proceedings of ICPR 2016*.

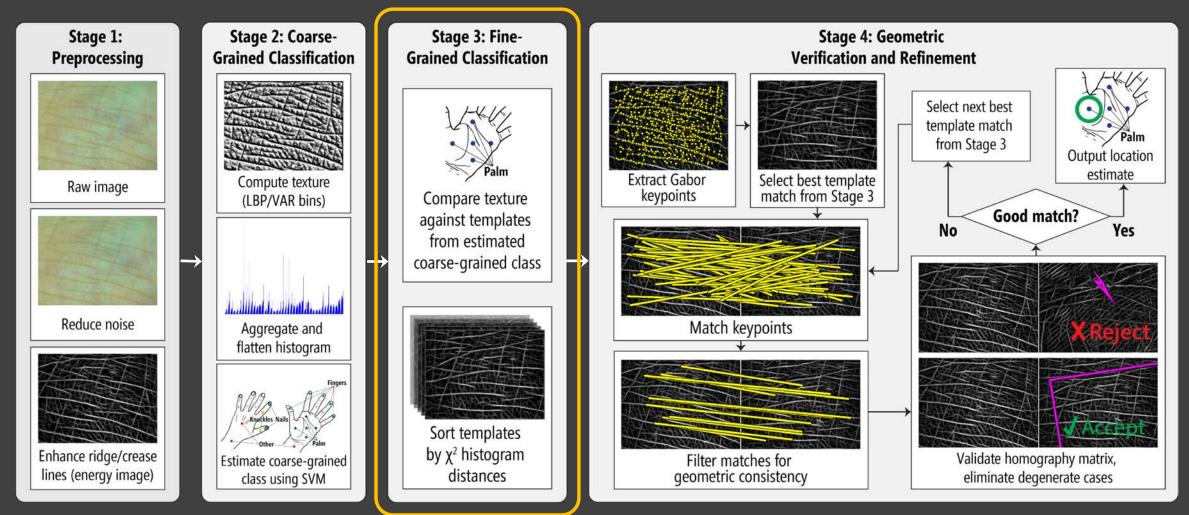
### 30 participants × 17 locations × 20 samples **Total dataset size: 10,198 images**

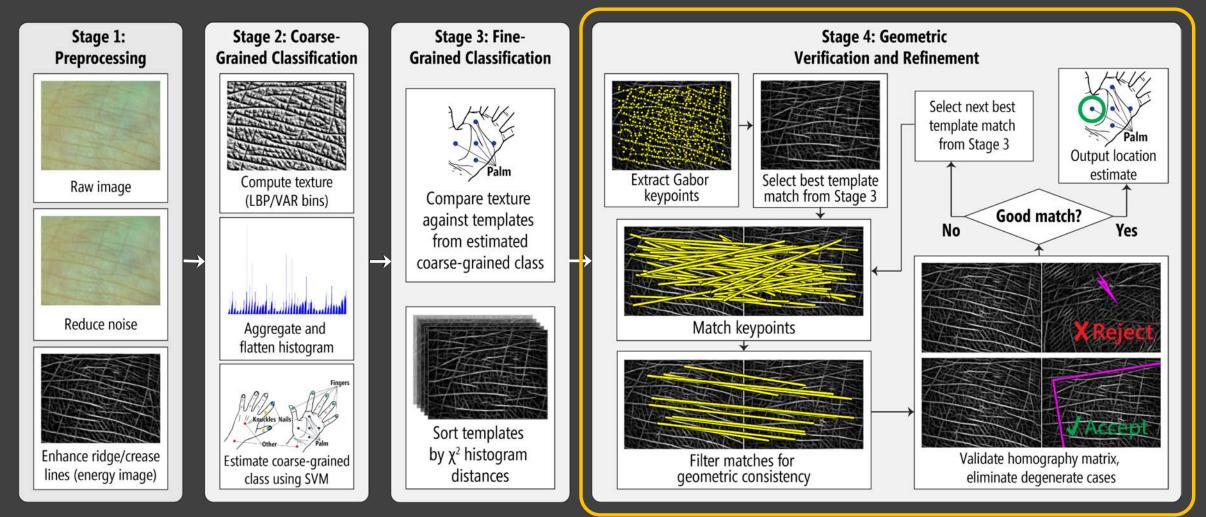
(one participant accidentally skipped two trials)









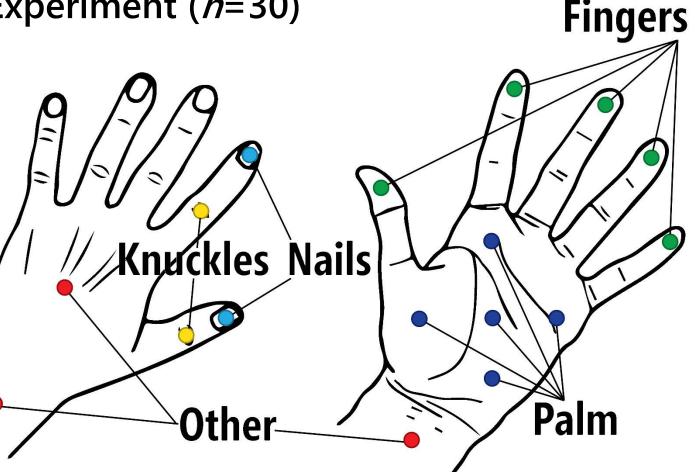


**Within-Person** Classification Experiment (*n*=30)

Coarse-Grained Localization (Stage 2)
(5 classes: ● finger, ● palm, ● knuckle, …)
accuracy: 99.1% (*SD*=0.9%)

Fine-Grained Localization (Stage 3)
(17 classes: ● palm up, ● palm down, …)
accuracy: 88.0% (*SD*=4.5%)

**Fine-Grained Localization (Stage 4)** accuracy: **96.4%** (*SD*=2.3%)



#### **Within-Person** Classification Experiment (*n*=30)



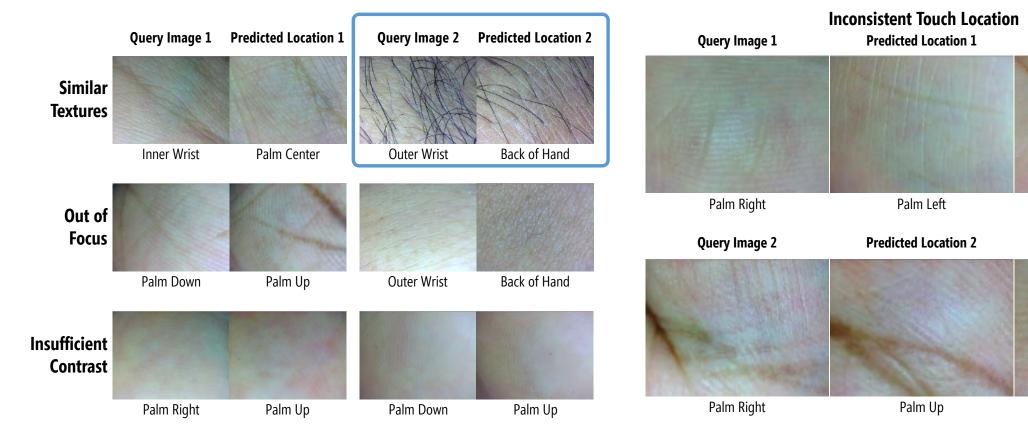
Correct Location 1

Palm Right

**Correct Location 2** 

Palm Right

#### **Within-Person** Classification Experiment (*n*=30)



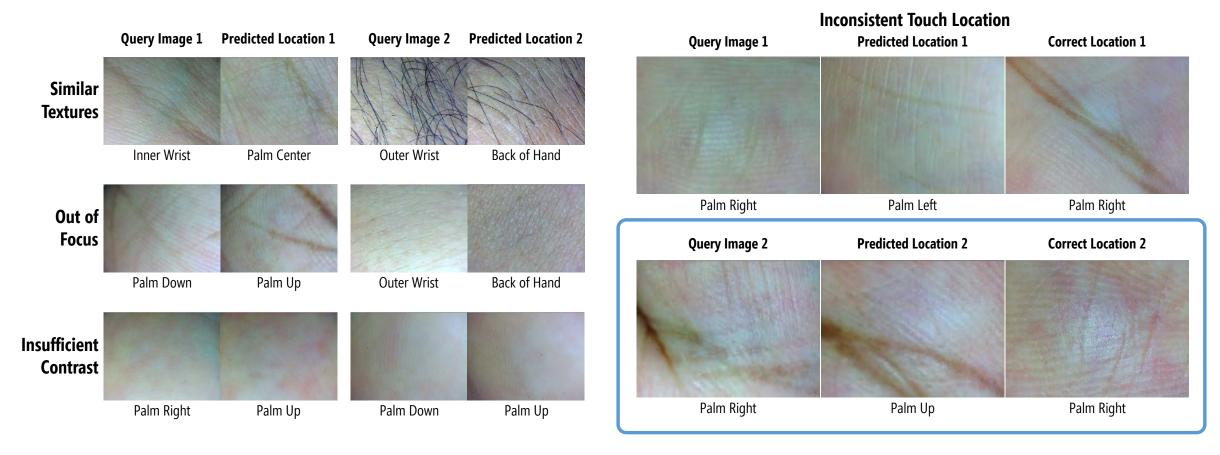
Correct Location 1

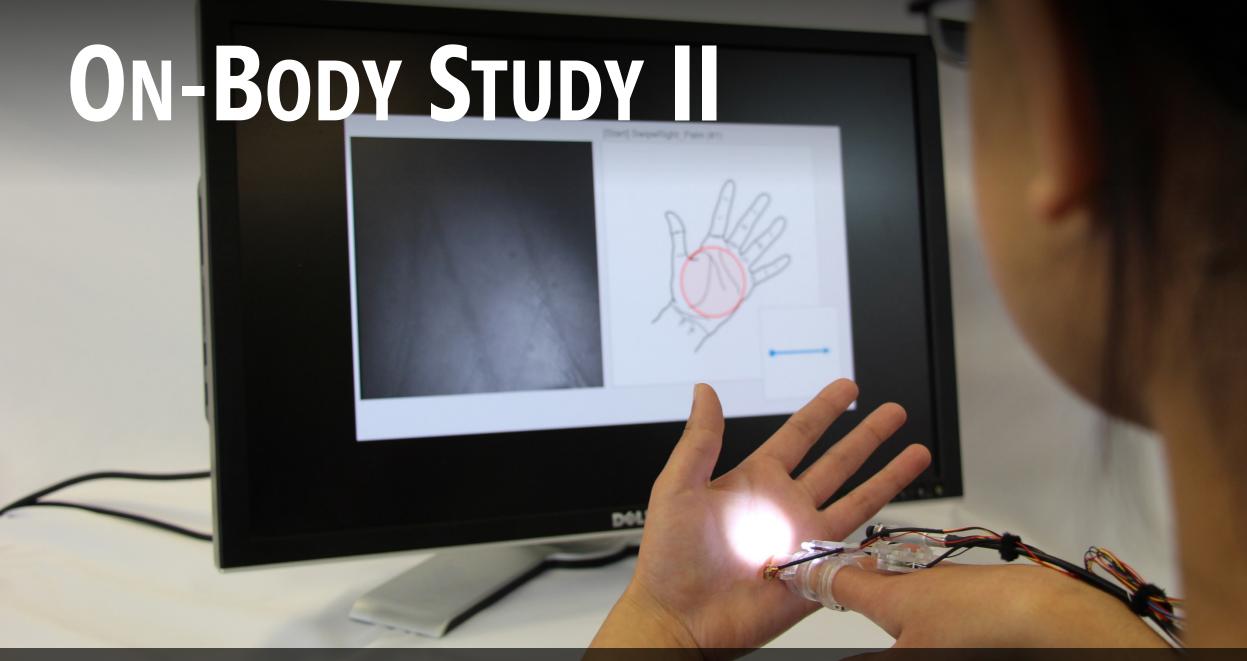
Palm Right

**Correct Location 2** 

Palm Right

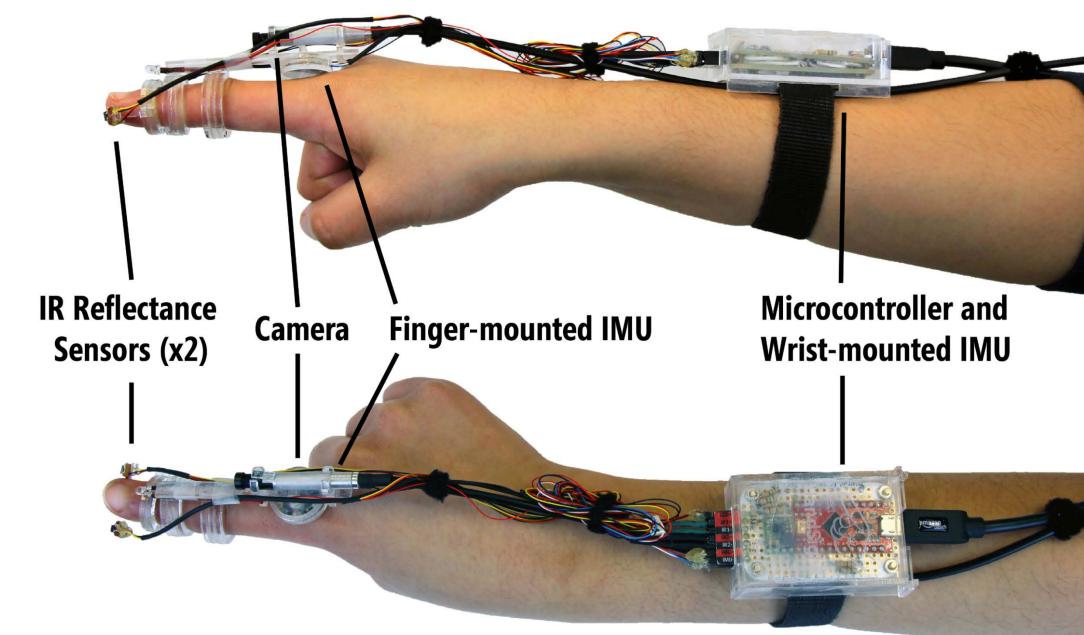
#### **Within-Person** Classification Experiment (*n*=30)

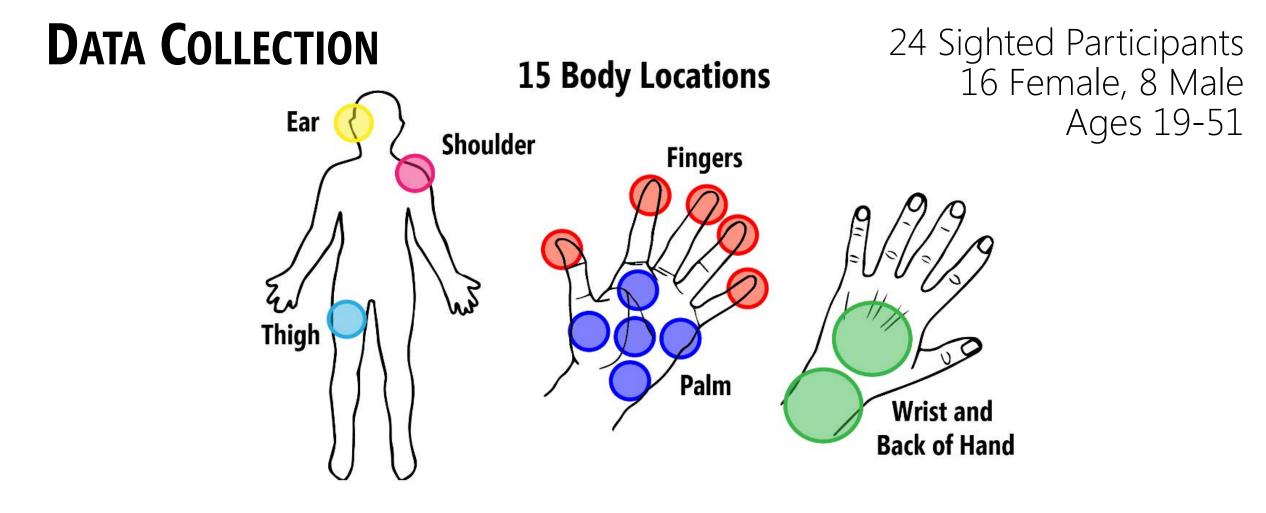


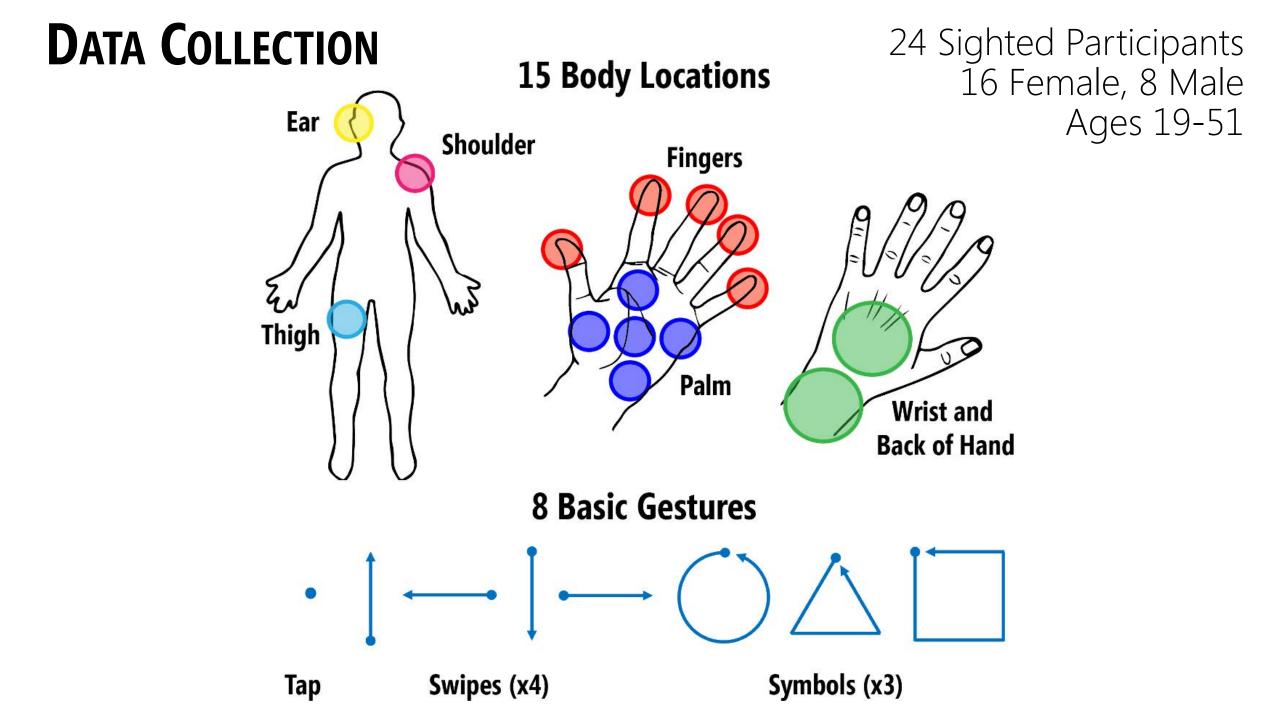


Lee Stearns, Uran Oh, Leah Findlater, Jon E. Froehlich, "TouchCam: Realtime Recognition of Location-Specific On-Body Gestures to Support Users with Visual Impairments," in Interactive, Wearable and Ubiquitous Technologies, December 2018.

### **OFFLINE PROTOTYPE**

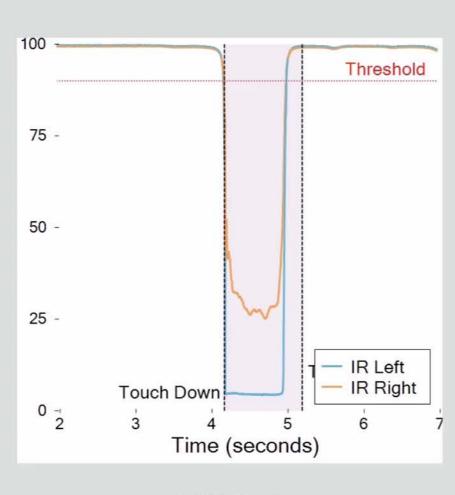








**Signals** 

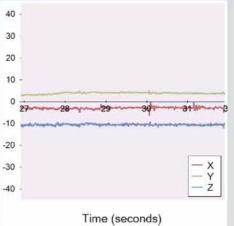


IR(% Max)



#### **Signals**





#### Camera

360

270 180

90

0 27

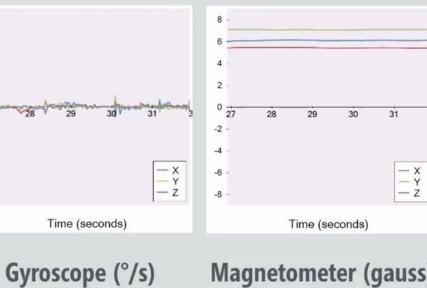
-90

180

.270

-360

#### Accelerometer (m/s<sup>2</sup>)



Magnetometer (gauss)



#### Signals

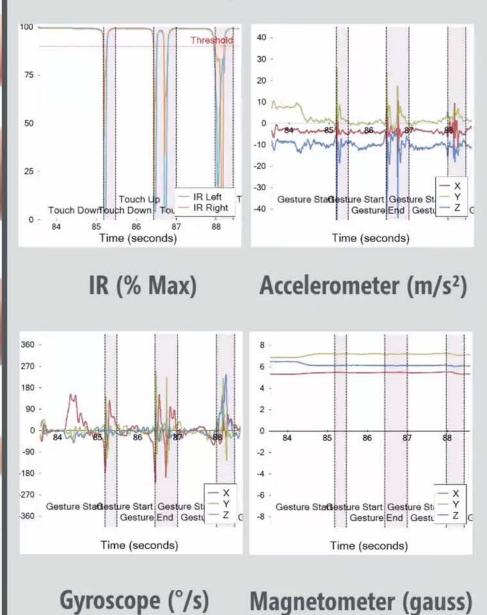


Camera



Swipe Right

#### **Signals**



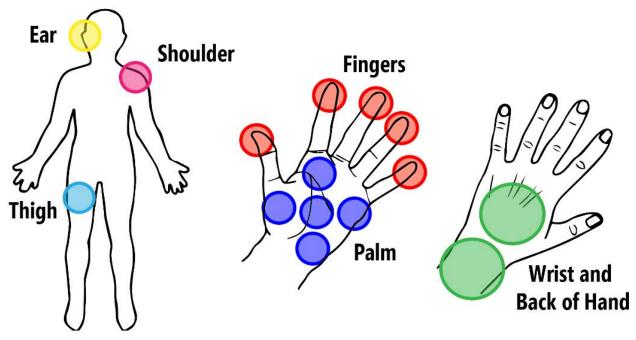
Within-Person Classification Experiment (n=24)

#### **Coarse-Grained Localization**

(6 classes: ● finger, ● palm, ● thigh, …) accuracy: **98.0%** (*SD*=2.3%)

#### **Fine-Grained Localization**

(15 classes: ●palm up, ●palm down, ...) accuracy: **88.7%** (*SD*=7.0%)



Within-Person Classification Experiment (n=24)

#### **Coarse-Grained Localization**

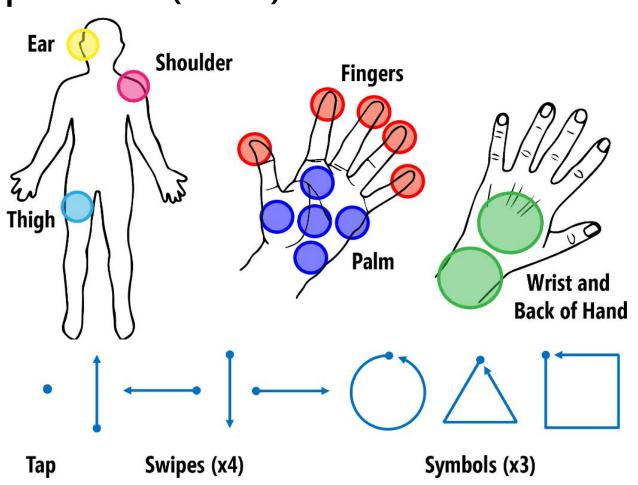
(6 classes: ● finger, ● palm, ● thigh, …) accuracy: **98.0%** (*SD*=2.3%)

#### **Fine-Grained Localization**

(15 classes: ●palm up, ●palm down, …) accuracy: **88.7%** (*SD*=7.0%)

#### **Location-Specific Gesture Recognition**

(24 classes: 3 locations × 8 gestures) accuracy: **95.7%** (*SD*=3.2%)



# ON-BODY STUDY III

**12 Participants:** 7 female, 5 male Ages 29-65 All blind or low vision

Uran Oh, Lee Stearns, Alisha Pradhan, Jon E. Froehlich, Leah Findlater, "Investigating Microinteractions for People with Visual Impairments and the Potential Role of On-Body Interaction," in *Proceedings of ASSETS 2017*.

Lee Stearns, Uran Oh, Leah Findlater, Jon E. Froehlich, "TouchCam: Realtime Recognition of Location-Specific On-Body Gestures to Support Users with Visual Impairments," in Interactive, Wearable and Ubiquitous Technologies, December 2018.

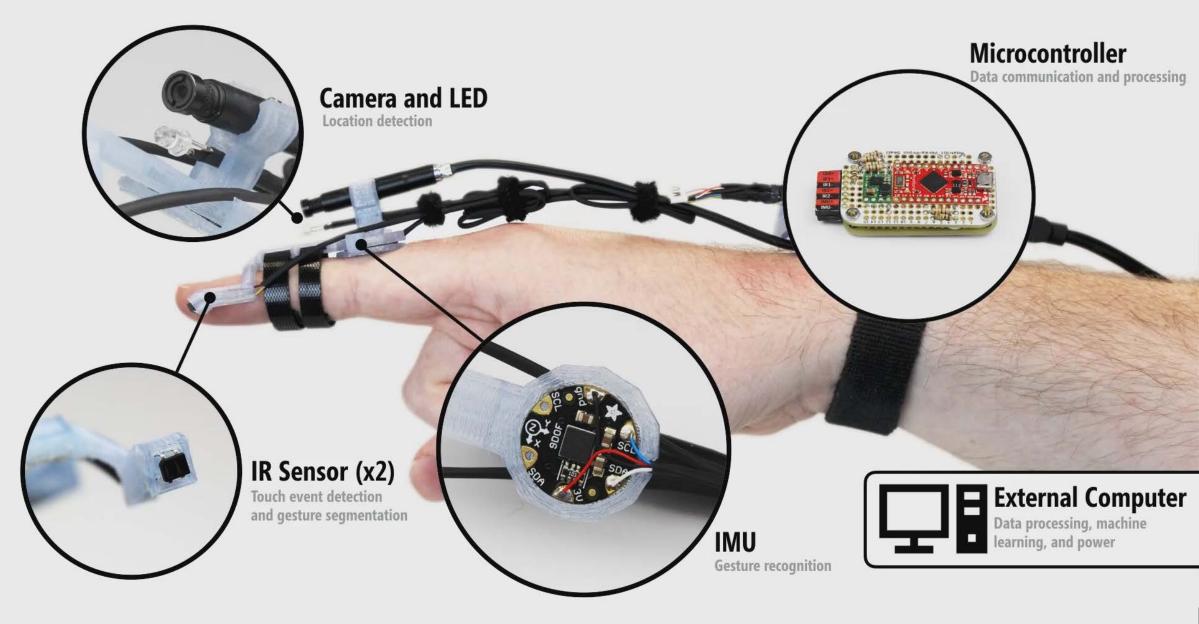
# ON-BODY STUDY III

#### Algorithms

Real-time processing (~60fps)

- Removed geometric verification stage (required 1-2s per image)
- Combine predictions across 20 video frames (~300ms)
- Increase number of texture features per image from **1792** to **15,552**
- Reduced number of fine-grained locations (removed 5 fingertip classes)

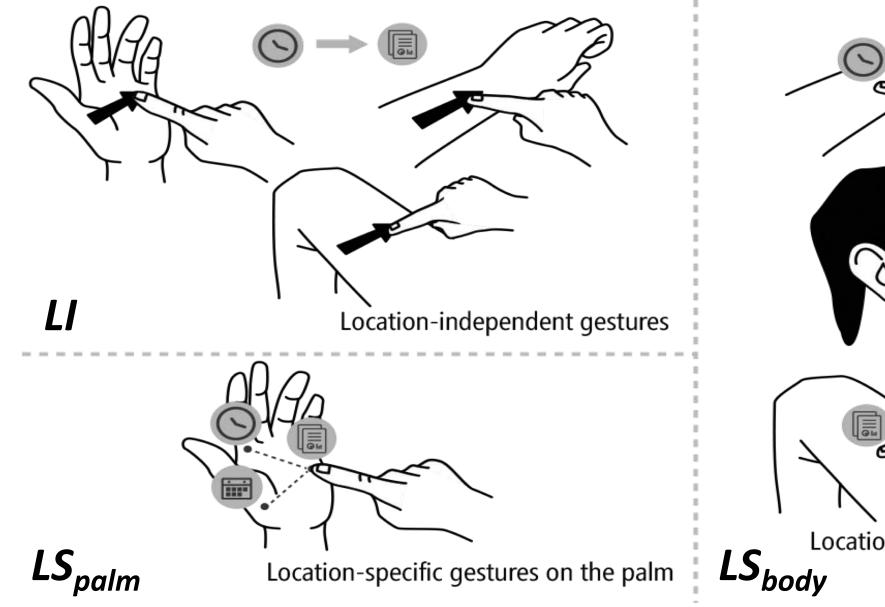
### **Realtime Prototype**



### **INTERFACE DESIGNS**

**Five applications:** 

Clock, Daily Summary, Notifications, Health and Fitness, Voice Input

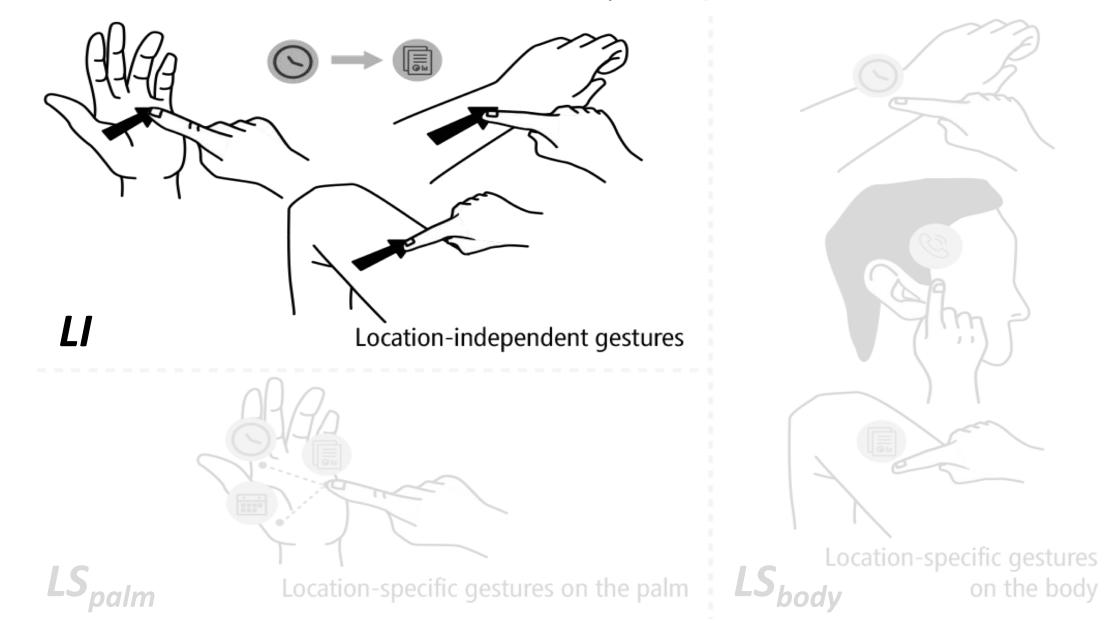


Location-specific gestures on the body

### **INTERFACE DESIGNS**

#### Five applications:

Clock, Daily Summary, Notifications, Health and Fitness, Voice Input





Health & Activities Notifications

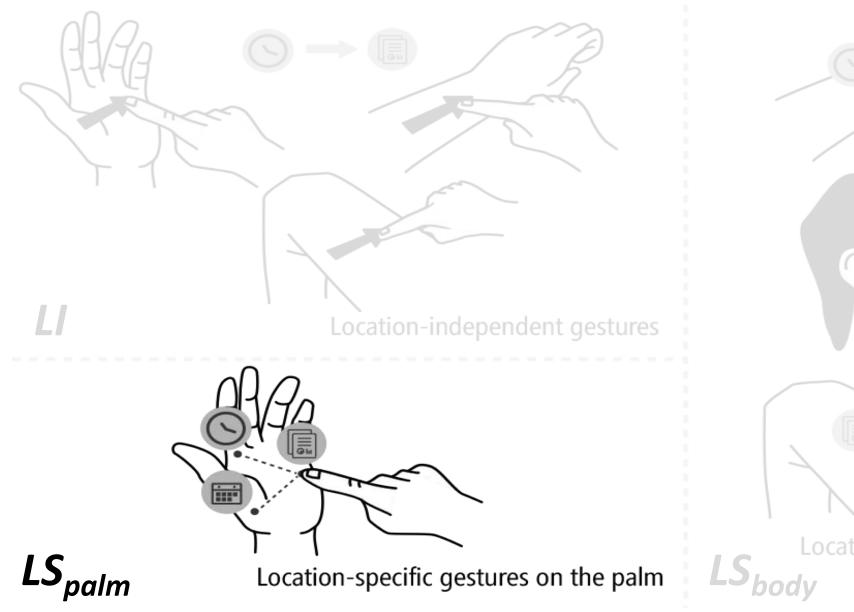
Daily Summary

### **Interaction Design 1: Location-Independent Gestures** Swipe left and right anywhere on the body to sequentially navigate a list of applications.

### **INTERFACE DESIGNS**

#### Five applications:

Clock, Daily Summary, Notifications, Health and Fitness, Voice Input



Location-specific gestures on the body



### Interaction Design 2: Location-Specific Gestures on the Palm Applications are mapped to five palm locations, select by directly touching a location. Supports "touch and explore".

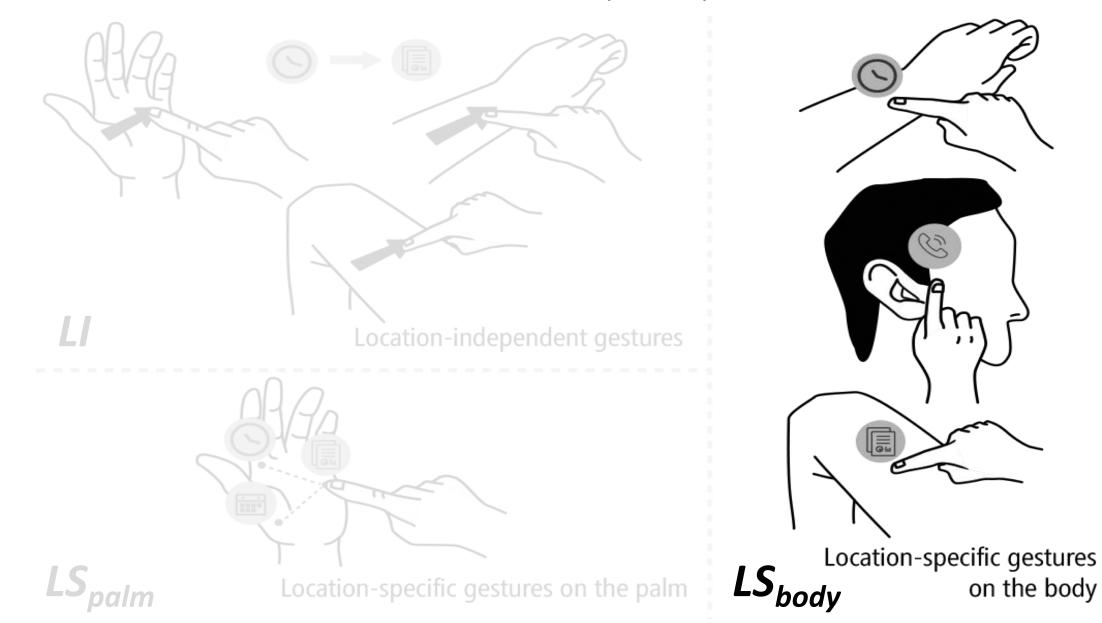
### **INTERFACE DESIGNS**

#### **Five applications:**

Clock, Daily Summary, Notifications, Health and Fitness, Voice Input

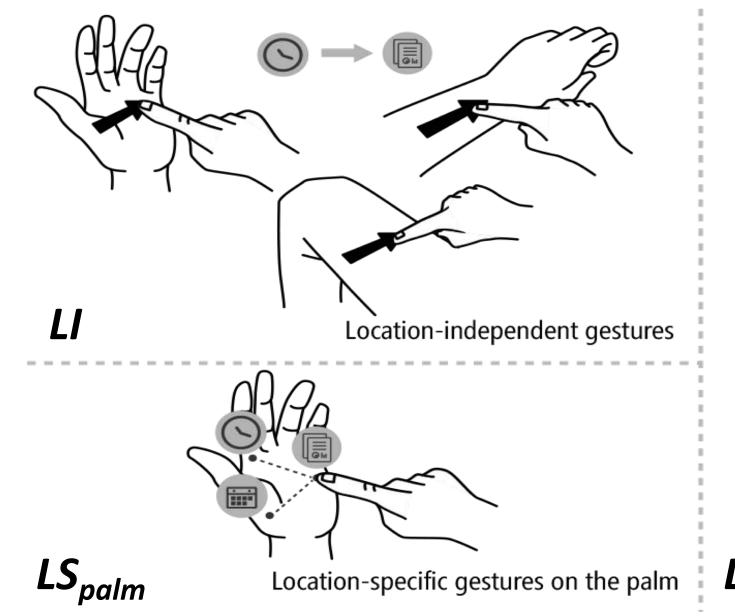
11

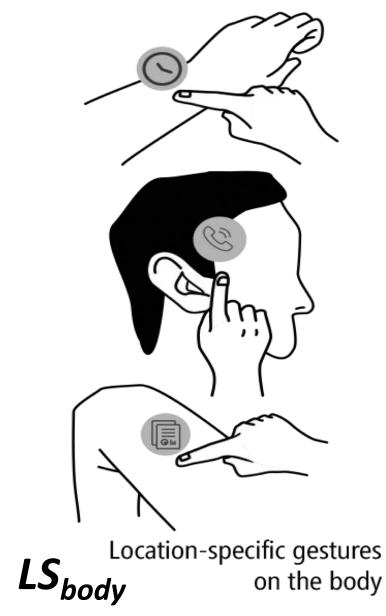
on the body

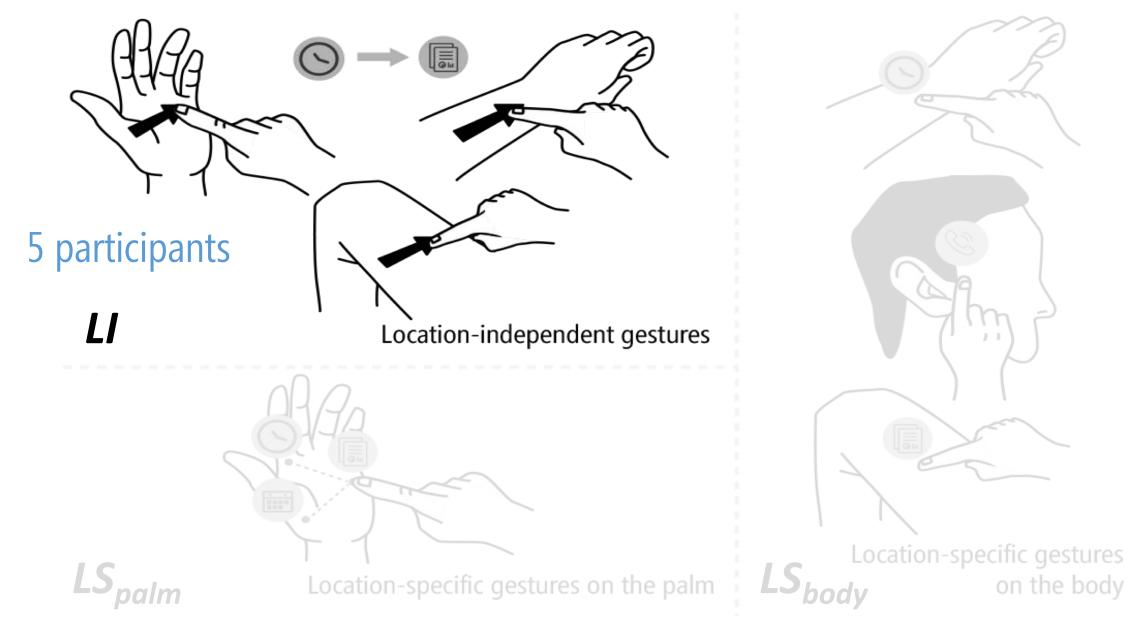


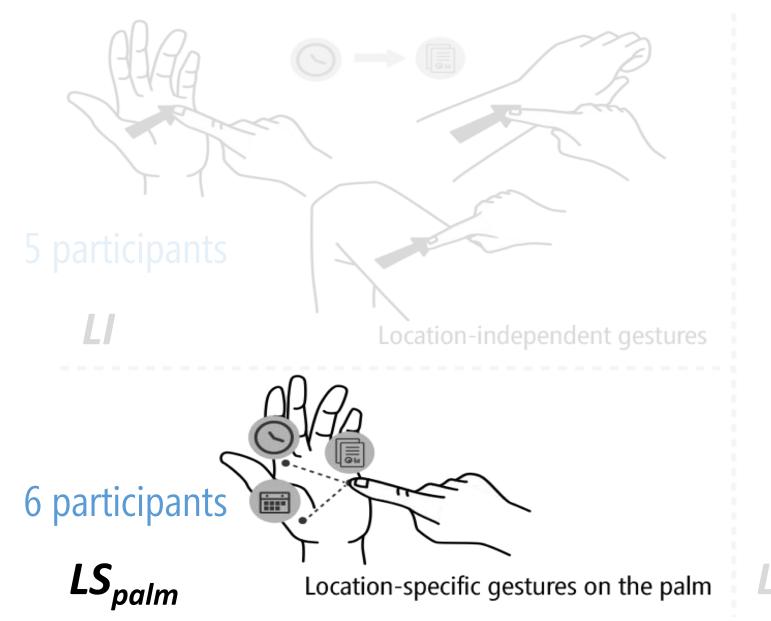


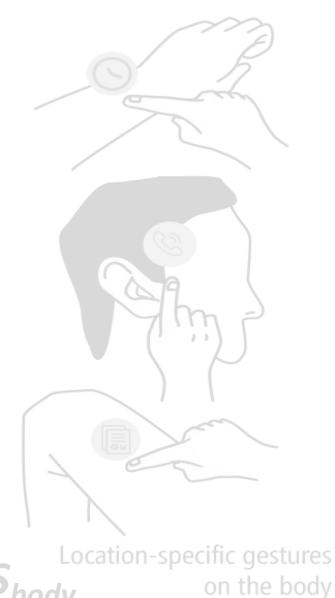
### Interaction Design 3: Location-Specific Gestures on the Body Applications are mapped to five body locations, semantically when possible. Touch to directly select application.

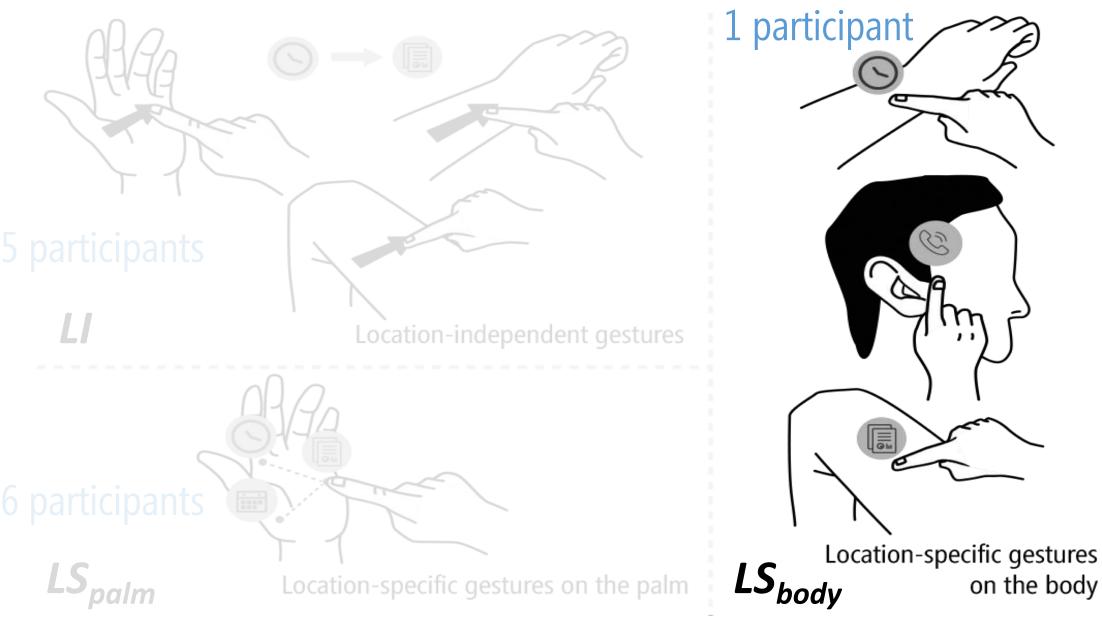












### CONTRIBUTIONS **On-body input method** using finger-worn sensors Mitigates camera framing issues New types of contextual, location-specific gestures Our findings demonstrate feasibility, with high accuracy and realtime performance We identified tradeoffs that will impact the design of future on-body interfaces (*e.g.*, accuracy, usability)

### HANDSIGHT APPLICATION AREAS

Reading/Exploring Text

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**On-Body Input** 

### HANDSIGHT APPLICATION AREAS

Reading/Exploring Text

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**On-Body Input** 

Clothing Colors/Patterns

# IDENTIFYING CLOTHING COLORS AND PATTERNS

Alexander Medeiros, Lee Stearns, Leah Findlater, Chuan Chen, Jon E. Froehlich, "Recognizing Clothing Colors and Textures using a Finger-Mounted Camera: An Initial Investigation," in ASSETS 2017 (Poster Track).

Lee Stearns, Leah Findlater, Jon E. Froehlich, "Applying Transfer Learning to Recognize Clothing Patterns Using a Finger-Mounted Camera," in ASSETS 2018 (Poster Track, To Appear).

### **COMMERCIAL COLOR RECOGNIZERS**

**Brytec Color Teller** 



LedScope Android App



Microsoft SeeingAl App

Colorino Color Identifier

### **COMMERCIAL COLOR RECOGNIZERS**

### **Limitations:**

Cannot recognize **patterns**, only **color** Do not allow users to quickly inspect **multiple locations** Accuracy affected by **lighting and distance** 

Orange-yel

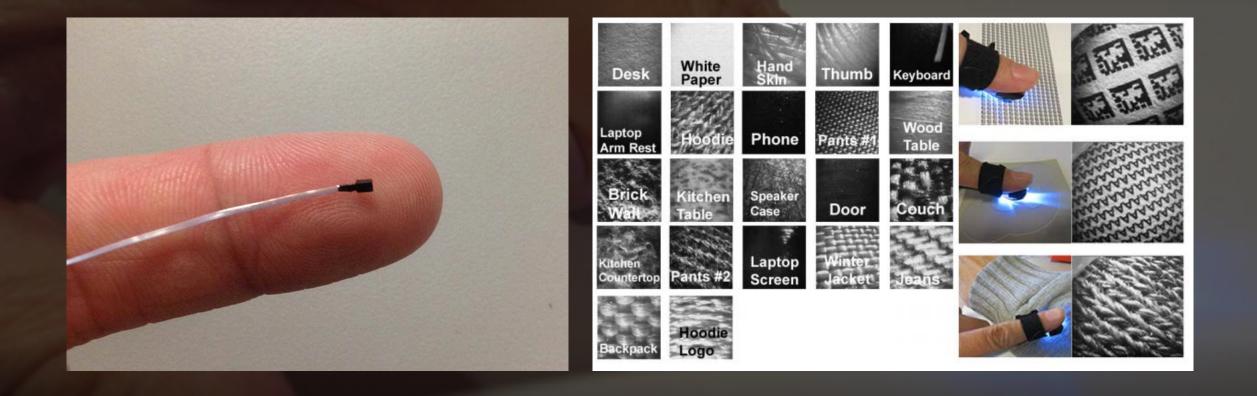
### **OTHER RELATED WORK**



ria

Access Lens: S. Kane, et al., "Access lens: a gesture-based screen reader for real-world documents," in Proceedings of CHI 2013.

### **OTHER RELATED WORK**



Magic Finger: X.D. Yang, et al., "Magic finger: always-available input through finger instrumentation," in Proceedings of UIST 2012.

### **OTHER RELATED WORK**





X. Yang, et al., "Assistive Clothing Pattern Recognition for Visually Impaired People," in IEEE Trans. on Human-Machine Systems, 2014.

# IDENTIFYING CLOTHING COLORS AND PATTERNS

### **Advantages of HandSight:**

Can recognize visual patterns as well as color Constrains distance and lighting for consistent results Allows for interactive exploration of colors and textures

## HANDSIGHT CLOTHING PATTERN DATASET

Collected **520 images** across **29 articles of clothing** and **9 categories of pattern** Controlled and varied the **distance** (5cm *vs.* 12cm), **rotation** (0° *vs.* 45°), **perspective** of the camera (90° *vs.* 45°), and the **tension** of the fabric (taut *vs.* hanging naturally)



## PATTERN CLASSIFICATION Initial Exploration

**Visual Texture Recognition Algorithms** 

\* Adapted from Cimpoi, *et al.*, 2012

 Deep convolutional activation features (DeCAF)
 Adapt a pretrained object classifier from the ImageNet Large Scale Visual Recognition Challenge, removing last two layers used for classification and using the outputs as a raw feature vector (4096 DeCAF features).

## PATTERN CLASSIFICATION INITIAL EXPLORATION

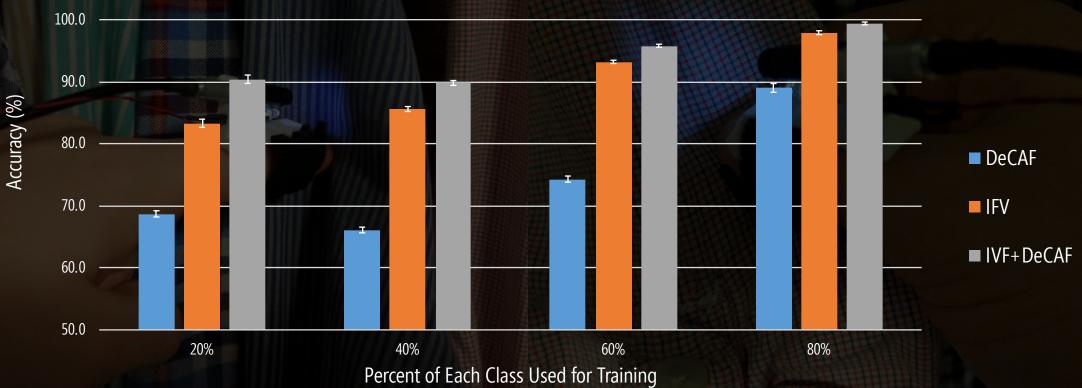
**Visual Texture Recognition Algorithms** 

\* Adapted from Cimpoi, *et al.*, 2012

 Deep convolutional activation features (DeCAF)
 Adapt a pretrained object classifier from the ImageNet Large Scale Visual Recognition Challenge, removing last two layers used for classification and using the outputs as a raw feature vector (4096 DeCAF features).

2. Dense SIFT features combined in an Improved Fisher Vector (IFV) Extract scale invariant features densely at multiple scales, then combine using the **Improved Fisher Vector** formulation. Results in a complementary set of features that captures important texture information (40,960 IFV features)

## PATTERN CLASSIFICATION Initial Exploration



**Average Classification Accuracies** 

## PATTERN CLASSIFICATION INITIAL EXPLORATION

Highly controlled dataset—risks overfitting, limits robustness Training process not easily scalable

## ONLINE CLOTHING PATTERN DATASET

Built a larger and more varied dataset of images downloaded from **Google Images** Focused only on **fabric patterns** that cannot easily be **distinguished by touch** 



Available online: https://github.com/lstearns86/clothing-pattern-dataset/

## ONLINE CLOTHING PATTERN DATASET

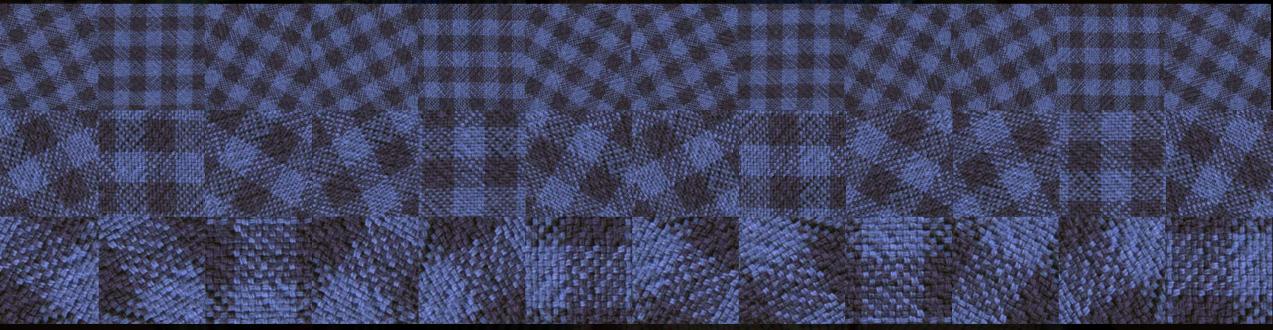
Built a larger and more varied dataset of images downloaded from Google Images
Focused only on fabric patterns that cannot easily be distinguished by touch
Downloaded top 1000 images for each category (*e.g.*, "striped fabric")
After removing erroneous results, duplicates, and cropping logos/backgrounds, contained 317–584 images per class (2764 total)



Available online: https://github.com/lstearns86/clothing-pattern-dataset/

## ONLINE CLOTHING PATTERN DATASET

Synthetic variations: rotation (30° increments), scales (1–4, depending on resolution) Final dataset: 8,232–17,304 samples per class, 77,052 total



Available online: https://github.com/lstearns86/clothing-pattern-dataset/

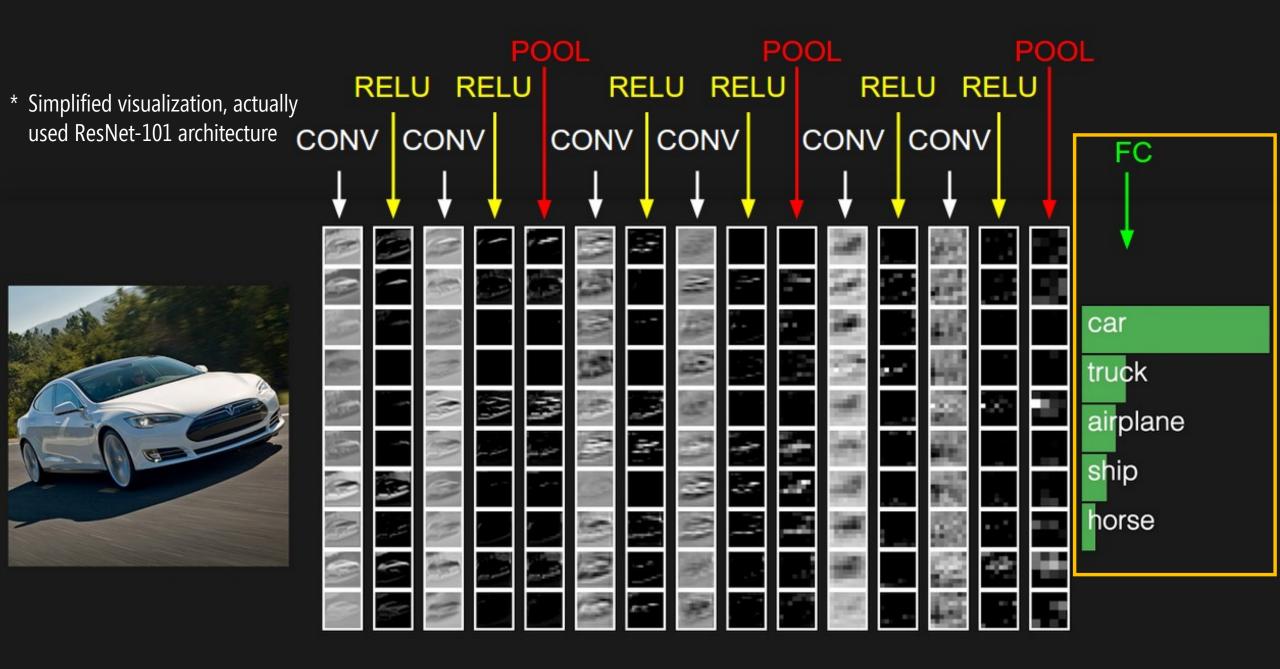


Image from Andrej Karpathy's "Convolutional Neural Networks for Visual Recognition" course, http://cs231n.github.io/convolutional-networks/

## PATTERN CLASSIFICATION An End-to-End Deep Learning Approach

Randomly sampled 6400 images per class for training, and 1600 for testing

Validation: classification accuracy on the test set was 91.7%

Accuracy on HandSight dataset (400 images) was **72.8%**.

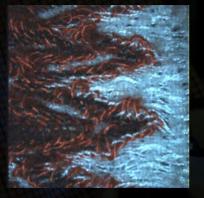
## PATTERN CLASSIFICATION An End-to-End Deep Learning Approach

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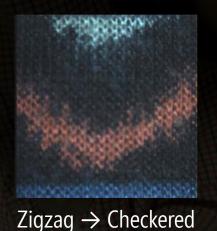
Fine-tuning the classifier with ~half of the HandSight images (N=36 per class) increases accuracy to **96.5%** 



 $Zigzag \rightarrow Floral$ 



Striped  $\rightarrow$  Checkered





Striped  $\rightarrow$  Solid

## **ONGOING WORK** Identifying Clothing Colors

Identify **multiple colors** in a single image

Two methods: K-means clustering and superpixel segmentation



## **ONGOING WORK** Identifying Clothing Colors

What is the best way to **convey** this information to **users**?

User-configurable level of detail: Color names Number of colors Frequency of feedback

purple	green	blue	pink	brown	red
(#7e1e9c)	(#15b01a)	(#0343df)	(#ff81c0)	(#653700)	(#e50000)
light blue	teal	orange	light green	magenta	yellow
(#95d0fc)	(#029386)	(#f97306)	(#96f97b)	(#c20078)	(#ffff14)
sky blue	grey	lime green	• 1 I	e violet	dark green
(#75bbfd)	(#929591)	(#89fe05)		(#9a0eea)	(#033500)
turquoise	lavender	dark blue	tan	cyan	aqua
(#06c2ac)	(#c79fef)	(#00035b)	(#d1b26f)	(#00ffff)	(#13eac9)
forest green (#06470c)	mauve (#ae7181)	dark purple (#35063e)	bright green (#01ff07)	maroon (#650021)	olive (#6e750e)
salmon	beige	royal blue	navy blue		black
(#ff796c)	(#e6daa6)	(#0504aa)	(#001146)		(#000000)
hot pink	light brown	pale green	peach	olive green	
(#ff028d)	(#ad8150)	(#c7fdb5)	(#ffb07c)	(#677a04)	
periwinkle	sea green	lime	indigo	mustard	light pink
(#8e82fe)	(#53fcal)	(#aaff32)	(#380282)	(#ceb301)	(#ffd1df)

## CONTRIBUTIONS

Two datasets of fabric pattern images
 529 images collected systematically using HandSight.
 77,052 images assembled from online sources and augmented synthetically (rotations, scaling, and cropping).
 Preliminary algorithmic results demonstrating the feasibility of recognizing clothing patterns with a finger-worn camera.

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**Reading/Exploring Text** 

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**On-Body Input** 

**Clothing Colors/Patterns** 

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### ALTERNATIVE OR SUPPLEMENTARY CAMERA LOCATIONS

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### Camera on the User's Finger or Wrist

Enables interactions anywhere the user can touch Reduced issues with occlusion Better resolution, more detail at the touch location Simplified processing of content beneath finger Easier to recognize relative gestures

### **Camera on the User's Upper Body**

Wider field of view, more contextual informationEasier to localize and track hand/finger positionCan use larger, higher-fidelity hardwareLess likely to interfere with motion or touch sensitivity

### ALTERNATIVE OR SUPPLEMENTARY CAMERA LOCATIONS

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SPATIAL EXPLORATION OF DOCUMENTS AND OTHER SURFACES

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#### 7.95 AND BUTURE RESEARCH DI k or pork with spicy-sour fish sauce 7.95 is, cilantro, ginger, and peanuts 1. SATAY MOOYAN emongrass

and onions with coconnection	5-45
COLDENTOFU	8.45
6. FRIED CALAMAN	9.45
7. KRA DOOM TONG	
	7.95
	8.45
	9.45
O. BKK CHICKEN WINGS CO	7.95
1. TOD MUN ried fish cakes (5)* or fried shrimp cakes (6) with	
ried fish cakes (5) of the auce	
weet & sour cucumber succe	7-95
eam pork dumplings with sweet soy sauce	-
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antro and fresh minus in spirit	7.95
NAM TOK** Il marinated beef or pork salad in spicy lime dressing	
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YUM PED YANG** sted duck salad in spicy lime dressing with tomatoes,	
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umber, ginger, onions and charter	10.45
YUM PLA GROB**	S
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ngrass, onions and cilantro	7.95
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CUM WOONSEN** cellophane noodle salad with ground chicken tossed with	ciri
cellophane noode and	
s and cilantro	7.95
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d beef salad with onions, cocomber, connect,	
ma dressing	9.45
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LL MARINATLO DO TO	7.95

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Large 10.25

fish with mushroom, scallions ngrass broth Large 10.25

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ENTREE	23.95
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brown sauce	12.95
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RA TIEM PRIK TAI* nelized garlic and pepper stir fried until frang	rant with choice of
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fried cellophane noocles with cgg and	
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s, scallions, onions and roasted chill st	
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p PED PAH** plants, peppercorns, onions, basils	peppers and the
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MAH KUER* oplants, basils, bell pepper, i	and onions stir fried in game i
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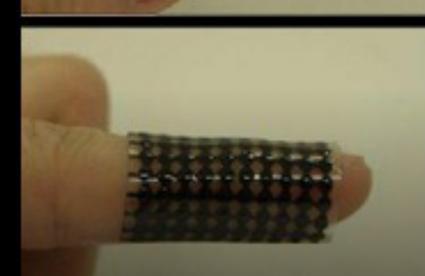
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SPATIAL EXPLORATION OF DOCUMENTS AND OTHER SURFACES

SPATIAL EXPLORATION OF DOCUMENTS AND OTHER SURFACES

### **ALTERNATIVE FEEDBACK METHODS**

TeslaTouch, Xu *et al.* 2011







Flexible Tactile Display, Choi et al. 2004



### ALTERNATIVE FEEDBACK METHODS

SMP Haptic Display, Besse et al. 2017

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6. FRIED COM TONG 7. KRA DOOM TONG Crunchy chicken popcorn with hot sauce	
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### ACKNOWLEDGEMENTS

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