## **Evaluating Haptic and Auditory Guidance to Assist Blind People** in Reading Printed Text Using Finger-Mounted Cameras

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Lee Stearns<sup>1</sup>, Ruofei Du<sup>1</sup>, Uran Oh<sup>1</sup>, Catherine Jou<sup>1</sup>, Leah Findlater<sup>2</sup>, David A. Ross<sup>3</sup>, Jon E. Froehlich<sup>1</sup> University of Maryland: Computer Science<sup>1</sup>, Information Studies<sup>2</sup>, Atlanta VA R&D Center for Visual & Neurocognitive Rehabilitation<sup>3</sup>











# What if **printed text** could be accessed **through touch** in the same way as braille?

\*Video Credit: YouTube—Ginny Owens—How I See It (Reading Braille)

distance until it is just a black dot against the sty. You distance until it is just a black dot against it. anotance untue to solve a black and assume of a final to a solve the solution of the solution What if **printed text** could be accessed **through touch** in the same way as braille? in considering how to su

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What if **printed text** could be accessed **through touch** in the same way as braille? **Reading printed materials** is still an important but challenging task for people with **visual impairments** 

## **POPULAR READING DEVICES**



## **POPULAR READING DEVICES** Scanner | OCR | Screen Reader

TOTOL

0-134

# POPULAR READING DEVICES

Dedicated devices (*e.g.*, video magnifiers)



## POPULAR READING DEVICES

Smartphone apps (*e.g.,* KNFB Reader iOS)



## **POPULAR READING DEVICES** Wearable Cameras (*e.g.*, OrCam)



Unfair edge over small investors

#### EUROPEAN TECHNINA FIND WAY TO U.S. MAR

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### **POPULAR READING DEVICES**



Scanner | OCR | Screen Reader



Smartphone Apps (*e.g.*, KNFB Reader iOS)

#### Dedicated Devices (*e.g.*, video magifiers)



#### Wearable Cameras (*e.g.*, OrCam)

# Open Questions (Existing Devices) 1. How to assist with aiming the camera to capture desired content?

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2. How to handle complex documents and convey layout information?

# HANDSIGHT A vision-augmented touch system

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Tiny CMOS cameras,



# HANDSIGHT A vision-augmented touch system

Tiny CMOS cameras, haptic actuators mounted on one or more fingers





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# HANDSIGHT

A vision-augmented touch system

#### \* Originally proposed in Stearns *et al.* 2014

Tiny CMOS cameras, haptic actuators mounted on one or more fingers

Smartwatch for power, processing, speech , and audio output





# **AUGMENTING THE USER'S FINGER** Survey: Digital Digits (Shilkrot *et al.* 2015)

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ns, and user interface. need to be sewn

# **AUGMENTING THE USER'S FINGER** Magic Finger (Yang *et al.* 2012)

**Camera & Optical Mouse Sensor** 

# AUGMENTING THE USER'S FINGER FingerReader (Shilkrot et al. 2014, 2015)

maked

no tello



# AUGMENTING THE USER'S FINGER HandSight (Stearns *et al.* 2014)

#### **Processing+Power**

Interface domain pape

ngelba omprehensive

**Vibration Motors** 

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

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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 vibration motors







# 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

# **Research Questions**

 To what extent are finger-based cameras a viable accessibility solution for reading printed text?
 What design choices can improve this viability?

# **Study Overview**

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

Study II: physical prototype study (4 participants)

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#### Goals:

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

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

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



Used an iPad to focus on user experience, gather finger trace data 19 participants

Median Age	48 ( <i>SD</i> =12, <i>Range</i> =26-67)
Gender	11 Male, 8 Female
Vision Level	10 Totally Blind, 9 Light Sensitive

Used an iPad to focus on user experience, gather finger trace data 19 participants

# Within-subjects, two guidance conditions: audio and haptic

Audio pitch

Haptic vibrations

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

19 participants

Within-subjects, two guidance conditions: audio and haptic Participants read two documents for each condition

> People have used coins as a means of exchange for thousands of years. Valued for their craftsmanship and purchasing power, coins have been collected in great numbers throughout 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 with these other pieces of information, coins can help historians reconstruct the details of lost eivilizations.

#### 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. 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, shricked, pounded the ground, and looked from one member of the family to the next. Still smilling 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.

A chimpanzee named Nim was raised by a





#### magazine

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

19 participants

Within-subject, two guidance conditions: audio and haptic

Participants read two documents for each condition

### Analysis: reading **speed** and **accuracy**, comprehension, subjective feedback

#### Animals also have emotions

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#### audio

The Ocean Floor

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In the 1800s, most geologists thought the

surprise, the ocean floor was found to be made up of long mountain ranges and deep valleys and troughs. Another surprise

In the mid-nineteenth century, ships depth-

sounding the ocean floor with sonar for a transatiantie elegraph cable made some

interesting discoveries. To geologists

sea floor was a lifeless expanse of mod. sediment, and the decaying remains of dead organisms. They thought that, with the exception of some volcanic islands. the bottom of the sea had no major geographic features, such as peaks or valleys.

finding in the Atlantia way 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 accidental in the beginning, were signals to geologists that their knowledge of the sea floor was very limited. Lorem ipsum dolor sit amet, consectetur

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### System Design: Exploration and Reading Modes

#### Animals also have emotions

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#### **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.

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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 Same across both conditions



#### Animals also have emotions

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nam malesuada augue at venenatis vestibulum. Fusce non dapibus orci, in vestibulum nisi. Sed eu elit nec ex posuere dictum. Sed sed libero rutrum, dictum leo at, tempus elit. Integer porta egestas nibh, quis mollis erat dignissim non. Nulla nec luctus nisl. Sed ultrices. Sed ultrices libero a pellentesque sagittis. Sed ultrices libero a pellentesque sagittis. 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

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Flute sound: text Joy. People to demonstrate a capacity for 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.

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



# System Design: Reading Mode

Bimanual: right index finger to read, left to anchor start of line Directional guidance: audio or haptic depending on condition 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

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 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) on liture.

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Haptic vs. Audio: Quantitative Performance

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Line tracing / magazine documents: Audio significantly more accurate (p = 0.018)

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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 volcanie fock 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

Line tracing / magazine documents: Audio significantly more accurate (p = 0.018) Comprehension high, no significant differences between conditions

#### audio

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Preferences split (11 haptic, 7 audio, 1 equal preference)

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Preferred Haptic	
More intuitive	
Easier to use	
Faster	
Less distracting	

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Reflects contradictory findings in Stearns et al. 2014, Shilkrot et al. 2014, 2015

#### **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.



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

Study II: physical prototype study (4 participants)

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

Study II: physical prototype study (4 participants)

### **Goals:**

Evaluate HandSight prototype Gather subjective feedback Compare with KNFB Reader iOS

Study II: physical prototype study (4 participants)

### Study II: HandSight Prototype System



Finger-mounted camera to read physical documents

### HandSight:

Each participant used their preferred guidance from Study I to explore and read two documents



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Oce is seven Americana. He fulllion people, rely on food pantries and meal sorvice programs to feed themselves and their families, the study found.	

### **KNFB Reader iOS:**

### Photograph and read 3 physical documents



### HandSight: Overall Experience

Average reading speed: 45 wpm (*SD*=19, *Range*=18-60) Rated somewhat easy to use, but slow and required concentration

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Average reading speed: 45 wpm (*SD*=19, *Range*=18-60) Rated somewhat easy to use, but slow and required concentration

#### **Participant Quotes:**

"I'm very pleased and excited about the system. I think it could make a great difference in my life." (P19)

"It seems like a lot of effort for reading text." (P12)

### HandSight vs. KNFB Reader iOS

#### Participants unanimously preferred KNFB Reader iOS



HandSight



#### **KNFB** Reader iOS

### HandSight vs. KNFB Reader iOS

Participants unanimously preferred KNFB Reader iOS Faster, easier to concentrate on the content of the text



HandSight

**KNFB** Reader iOS



Pros	



Feasibility of a Finger-Based Reading Approach

Pros Spatial layout information



Feasibility of a Finger-Based Reading Approach

#### Pros

Spatial layout information

Direct control over reading

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Direct control over reading

Reduced camera framing issues

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#### Feasibility of a Finger-Based Reading Approach

#### Pros

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

Pros	Cons
Spatial layout information	Slower, requires increased concentration and physical dexterity
Direct control over reading	concentration and physical aexterity
Reduced camera framing issues	
Efficient text detection and recognition	
* We observed these in our studies	

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Efficient text detection and recognition	information is unclear
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Pros	Cons
Spatial layout information	Slower, requires increased concentration and physical dexterity
Direct control over reading	* Consistent with Shilkrot <i>et al.</i> 2014, 2015
Reduced camera framing issues	Importance of spatial layout
Efficient text detection and recognition	information is unclear * Has yet to be investigated in this context
* We observed these in our studies	

### Future Work

#### Study utility of spatial layout information in everyday use



#### (e.g., newspapers, menus, maps, graphs)

### Future Work

### Study utility of spatial layout information Explore possibilities for camera placement



# **HAND**SIGHT a vision augmented touch system

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distance until it is just a black dot at still know that it is the red cardine

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### **Evaluating Haptic and Auditory Guidance to Assist Blind People** in Reading Printed Text Using Finger-Mounted Cameras

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### ne would you had 'lear the strong of it say that learning will be wour yet on the property of the say that your yet of the say alone would not carry say that you had better to say that your Contact: lstearns@umd.edu

Lee Stearns<sup>1</sup>, Ruofei Du<sup>1</sup>, Uran Oh<sup>1</sup>, Catherine Jou<sup>1</sup>, Leah Findlater<sup>2</sup>, David A. Ross<sup>3</sup>, Jon E. Froehlich<sup>1</sup> University of Maryland: Computer Science<sup>1</sup>, Information Studies<sup>2</sup>, Atlanta VA R&D Center for Visual & Neurocognitive Rehabilitation<sup>3</sup> Thank you to our participants and the Maryland State Library for the Blind and Physically Handicapped. This research was funded by the Department of Defense.











Limitations of previous studies\*
1. Small sample size (3-4 participants)
2. No quantitative performance metrics
3. Contradictory participant preferences

\* Stearns *et al.* 2014, Shilkrot *et al.* 2014, 2015