Navigation Assistance for People with Visual Impairment and Blindness

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My Recent Background

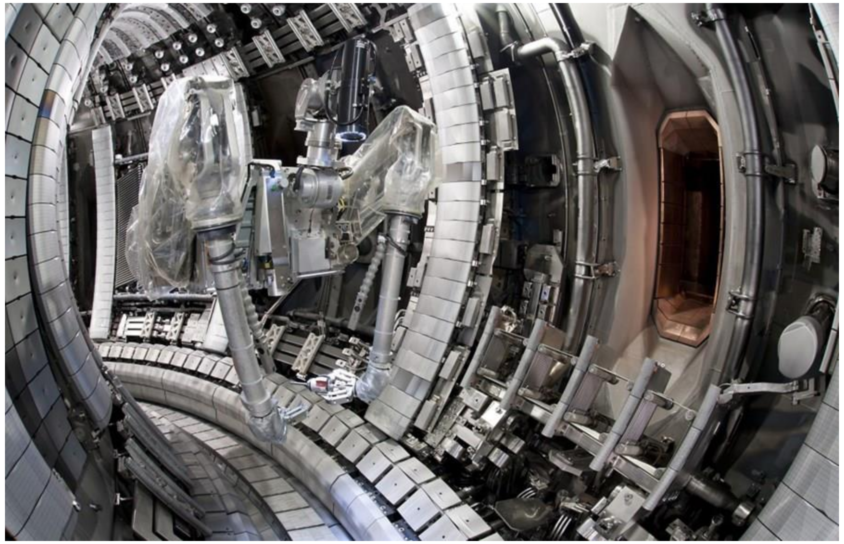
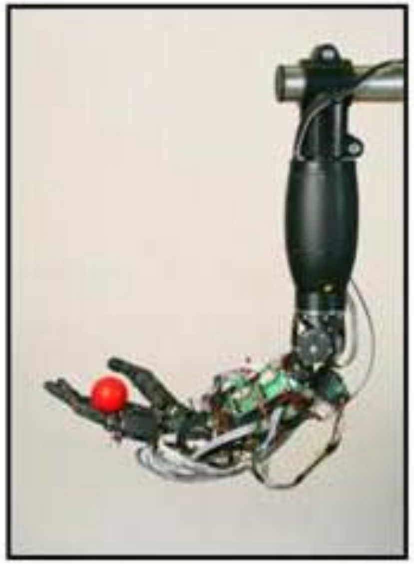
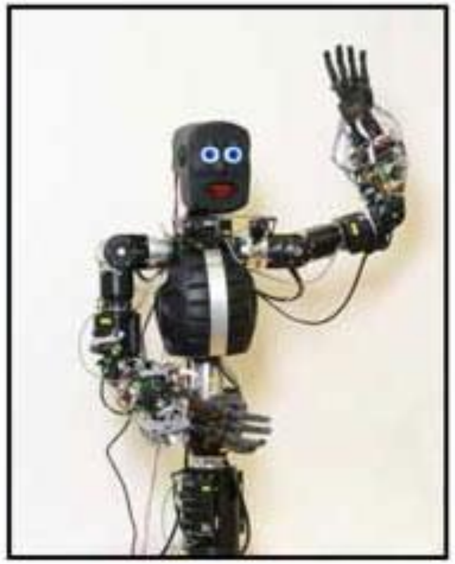
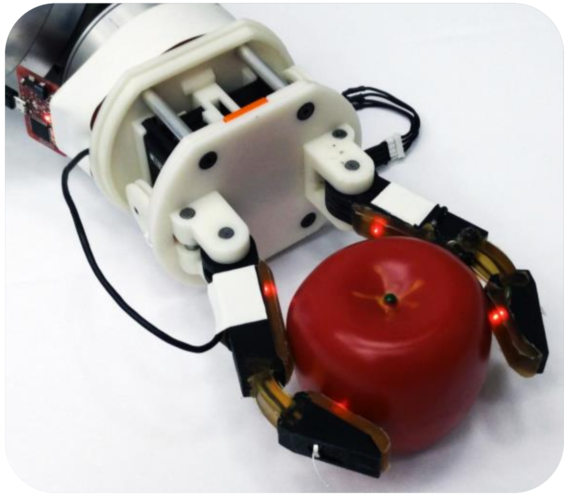
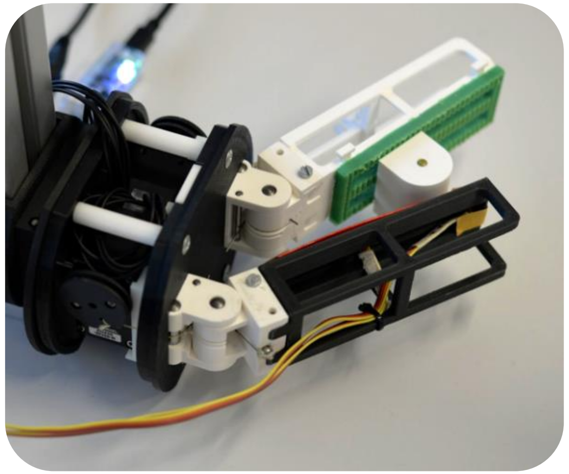
MPI-IS Department of Haptic Intelligence

Haptics

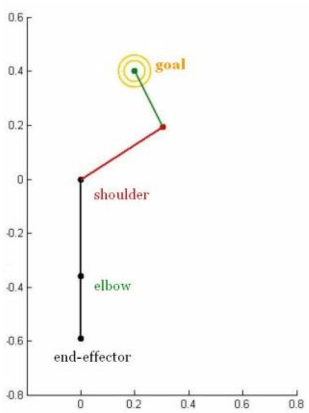
=

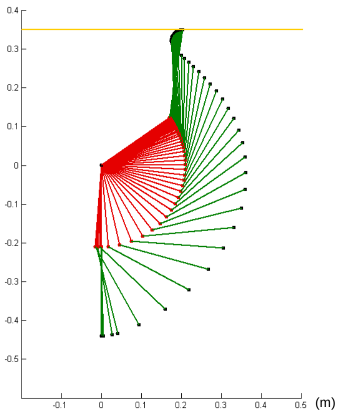
Touch

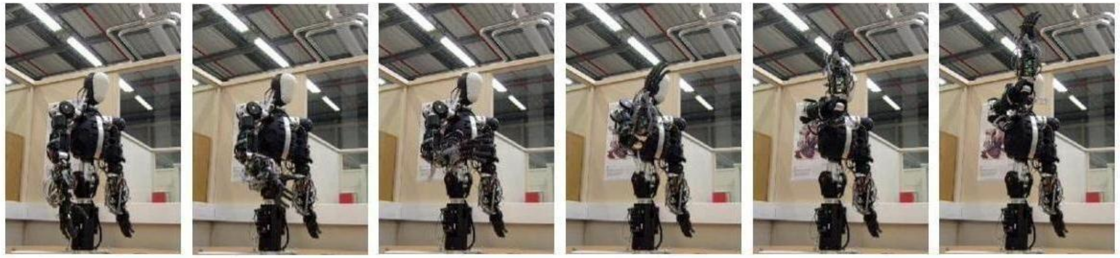
My Research – 1. Robotics

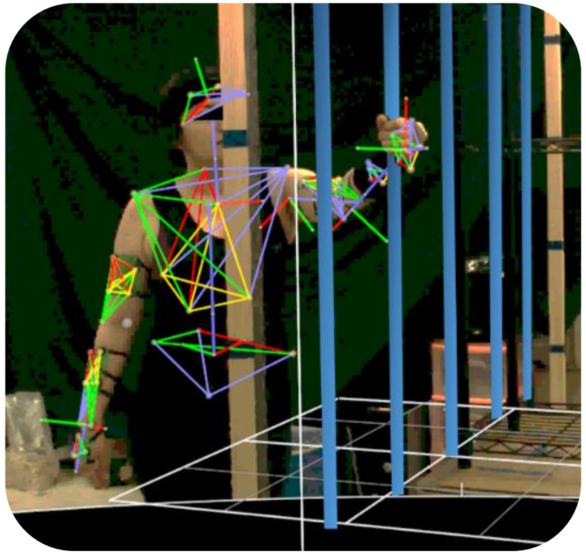






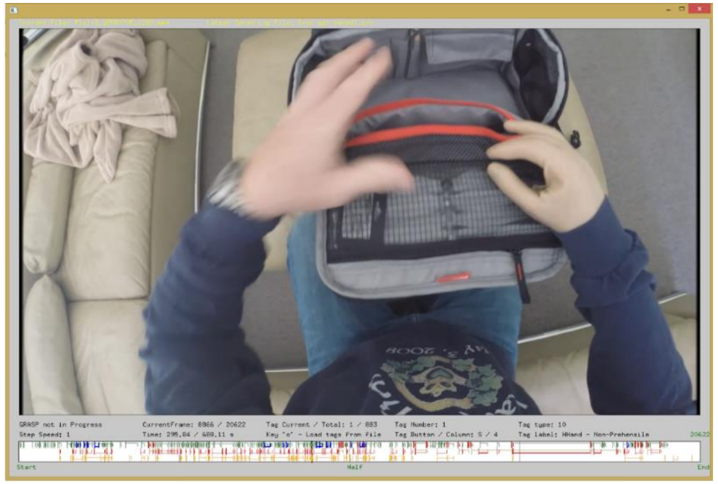
My Research – 2. Human Motion & Manipulation

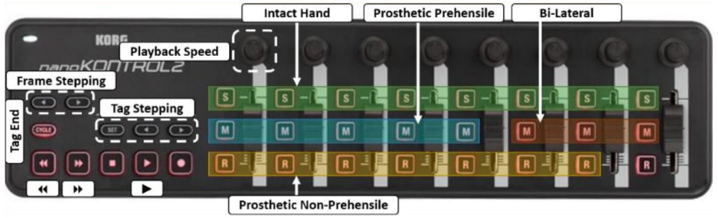












My Research – 3. Vision Impaired Navigation

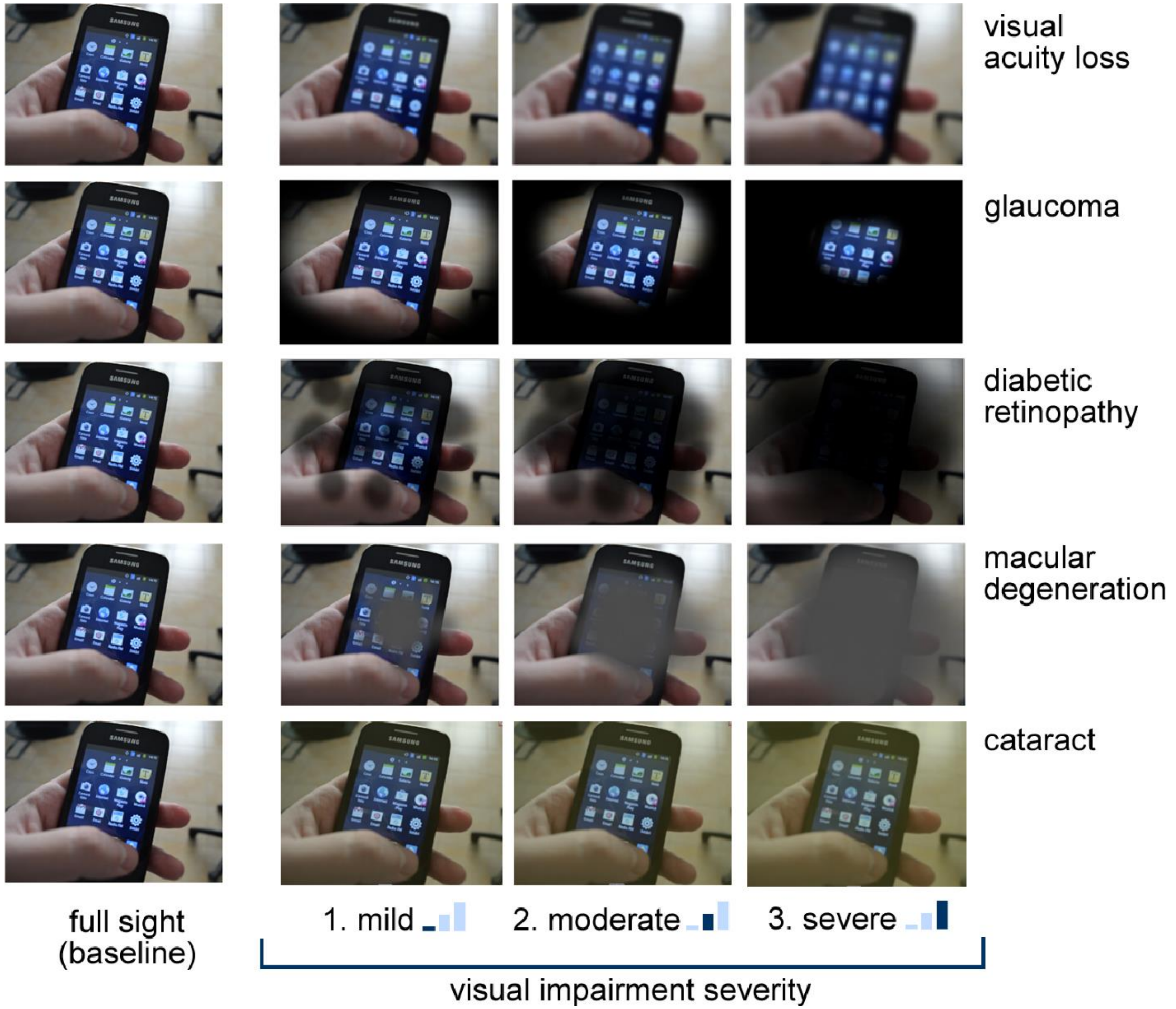
Flatland (2015) – Oshodi, Spiers et al.

‘Vision Impairment’

- Blindness
  - Complete lack of vision
- Visual Impairment / Vision Impairment / Low Vision
  - Decreased ability to see
  - Not correctable by glasses
  - Also known as VI

- Visual Impairment (VI) includes blindness

Types of Vision Impairment



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Visual Impairments and Mobile Touchscreen Interaction: State-of-the-Art, Causes of Visual Impairment, and Design Guidelines

Radu-Daniel Vatavu

ABSTRACTThis article identifies, catalogues, and discusses factors that are responsible for causing visual impairment of either a pathological or situational nature for touch and gesture input on smart mobile devices. Because the vast majority of interactions with touchscreen devices are highly visual in nature, any factor that prevents a clear, direct view of the mobile device's screen can have potential negative implications on the effectiveness and efficiency of the interaction. This work... CONTINUE READING

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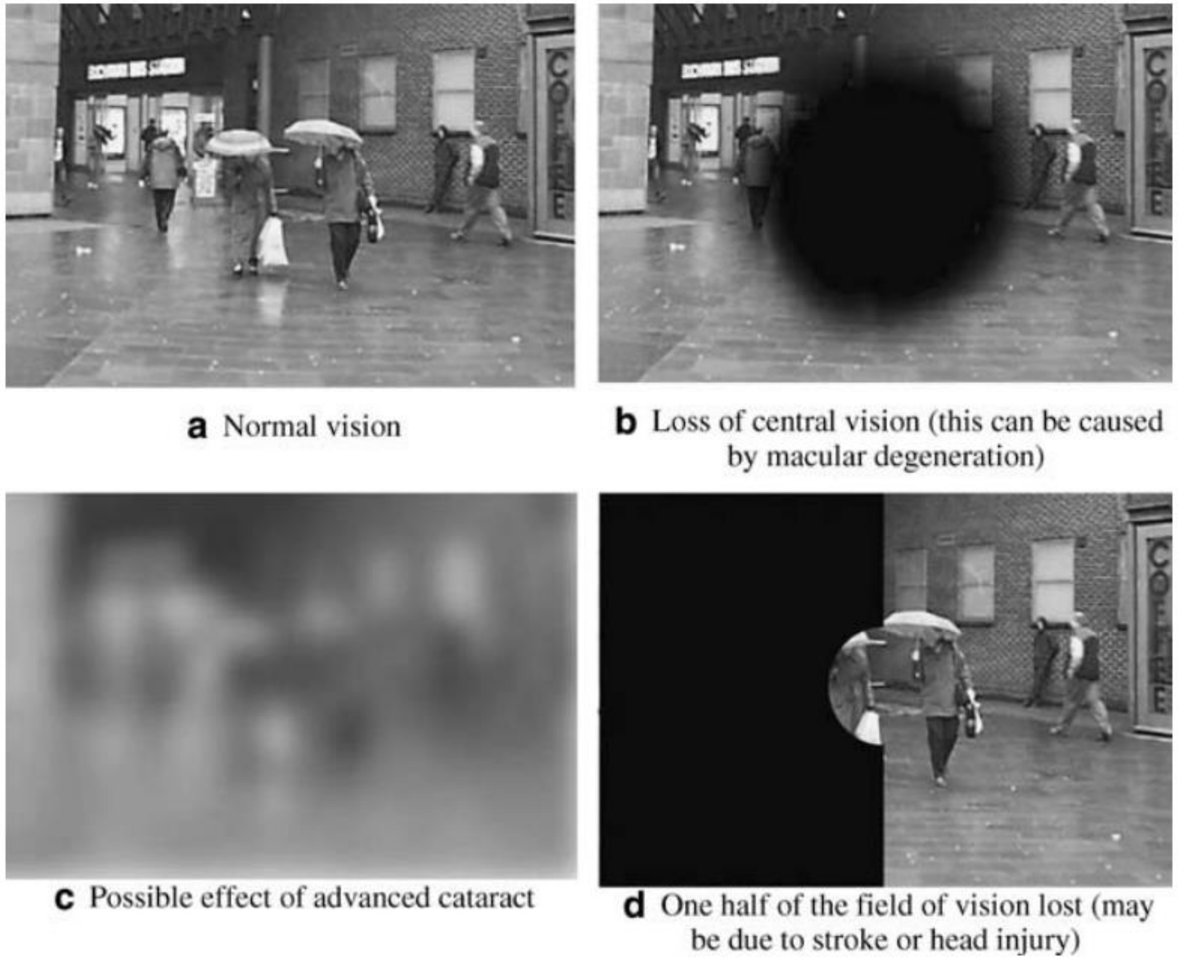
Vision Loss and Navigation



Bradley & Dunlop (2005)

Technical Interventions: Reading & Writing

On Paper

On A Computer

Technical Interventions: Navigation

Limited adoption of many other technologies

Medieval Solutions (~1300 AD)

British Library, Stowe MS 17, fol. 135r

British Library, Royal MS 10 E IV, fol. 110r

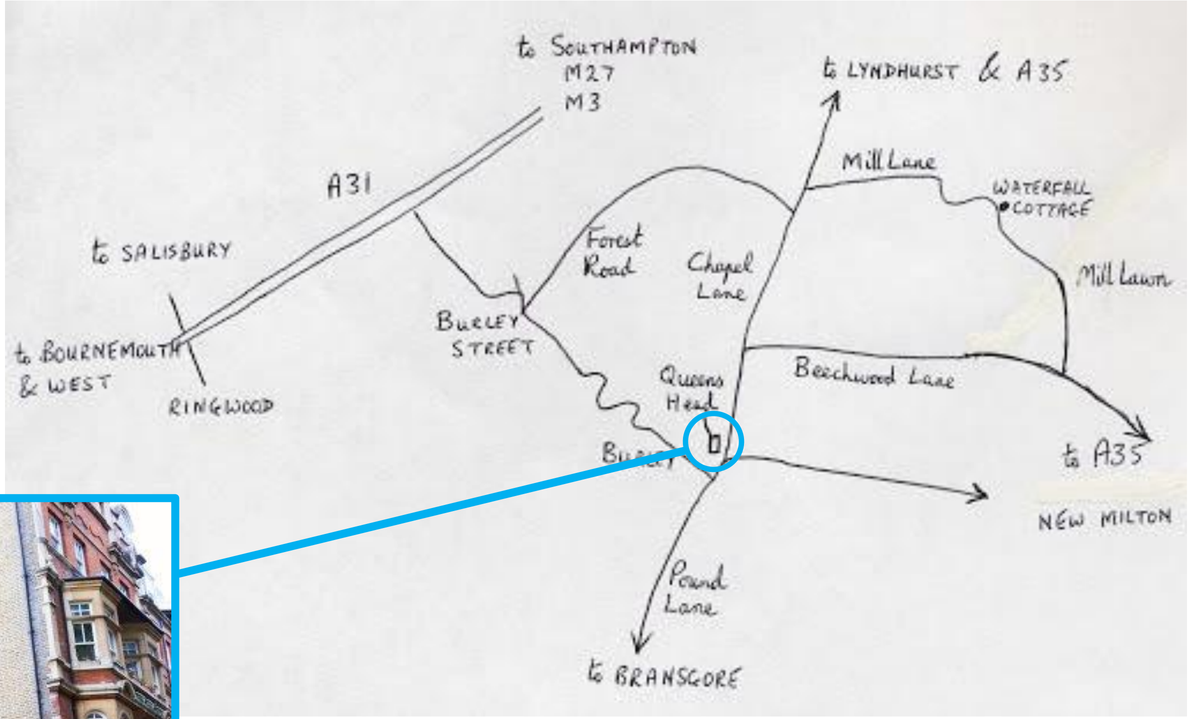
Two Types of Navigation

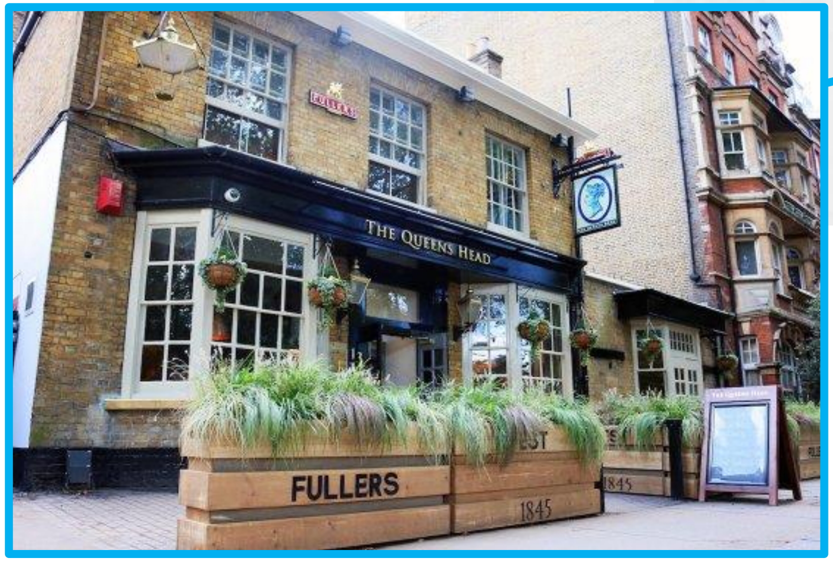
1. Obstacle Avoidance
   – Not bumping into things

Two Types of Navigation

2. Wayfinding

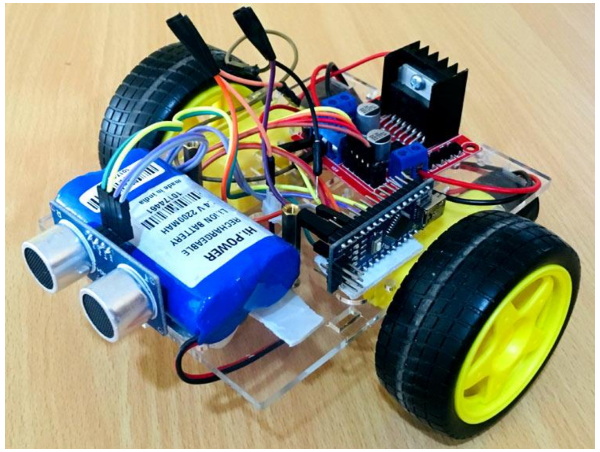
- Getting to a destination
- Also called 'Path Planning'

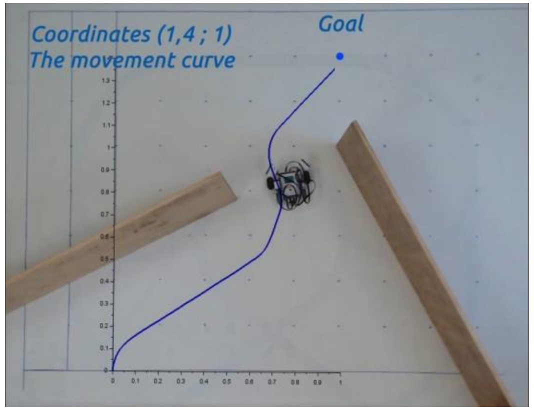




Obstacle Avoidance

- Considered a fundamental ability in biological systems
- Also taught as a fundamental ability in robotics classes
  - *“A [mobile] robot has to avoid obstacles before it can do anything useful”*
    - Prof. Kevin Warwick
      (my undergrad professor) ~2001



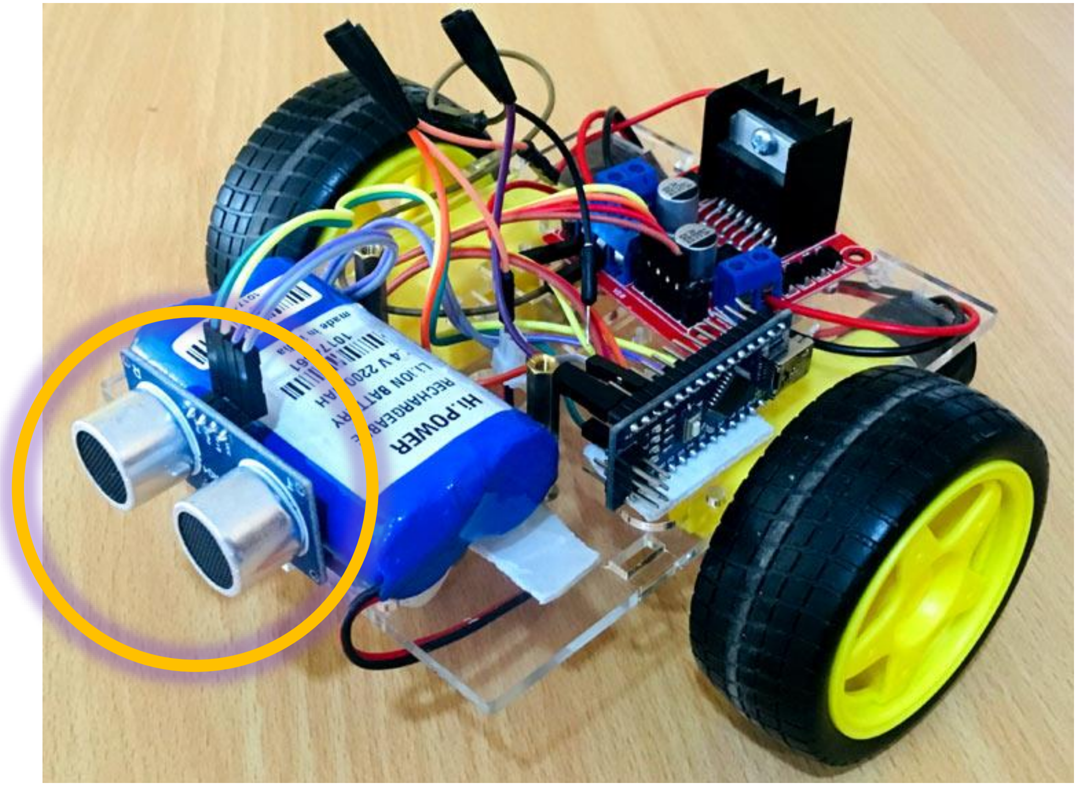


Visual Obstacle Detection (1966)

- Humans primarily detect obstacles via sight
- A source of inspiration in early **'top down'** (cognitive) robotics
- Shakey – 1966
  Stanford University, USA

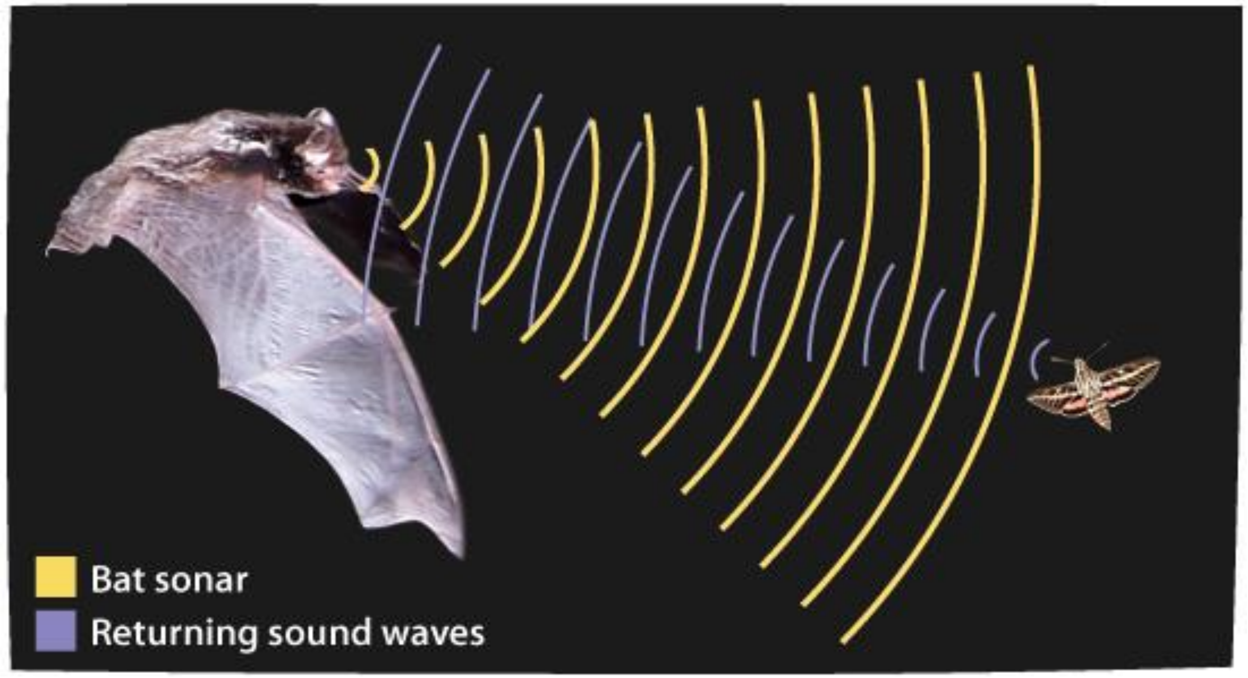
'Perceive → **Reason** → Act'

Non-Visual Obstacle Detection



Bottom Up 'Reactive' Robotics

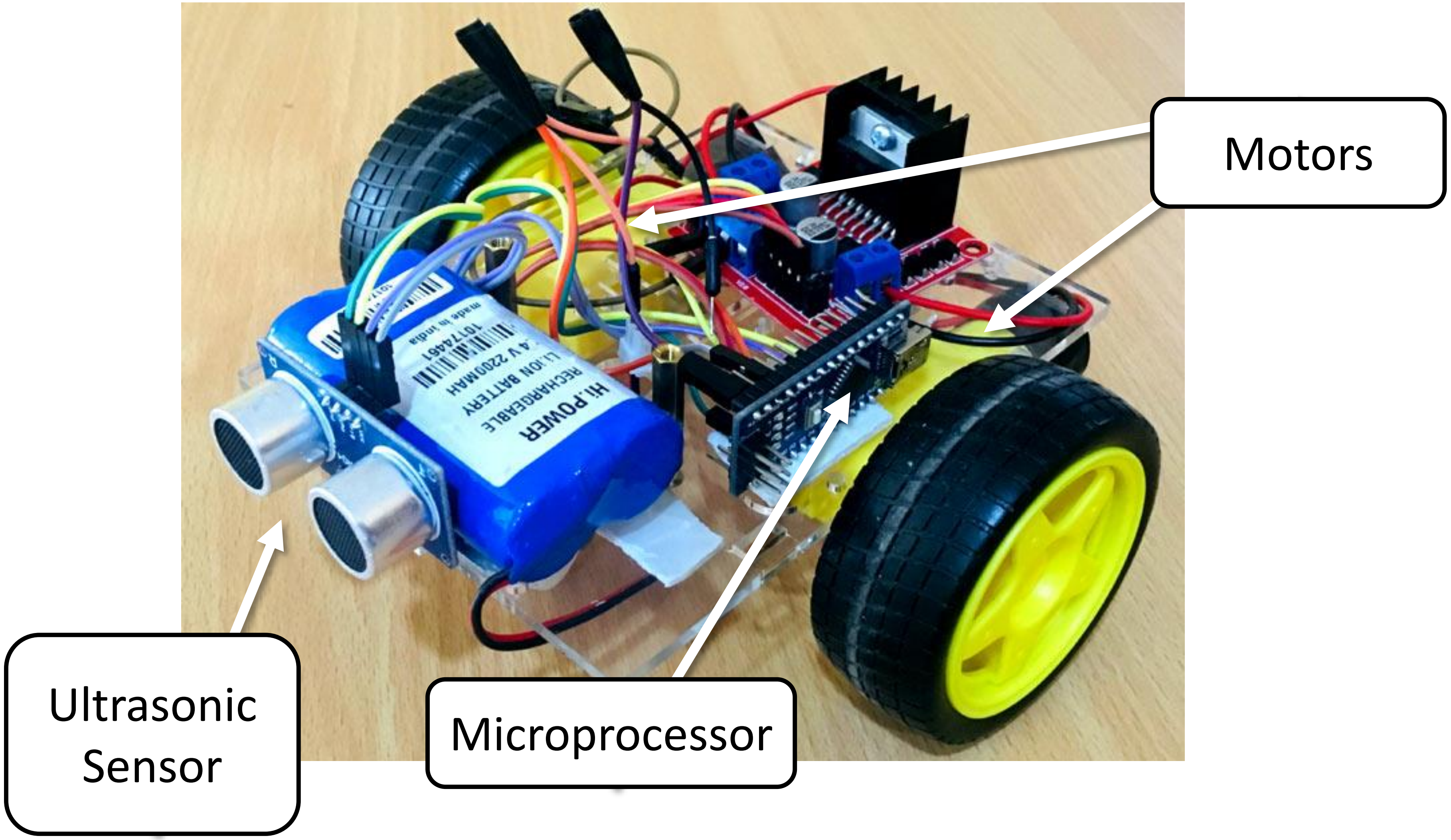
'Perceive → Act'



Visual Obstacle Detection (today)

- Visual obstacle detection / avoidance is now easily possible due to
  - Small cameras
  - Powerful processors
  - Algorithmic developments

DJI Spark Drone (with obstacle avoidance) - €429.00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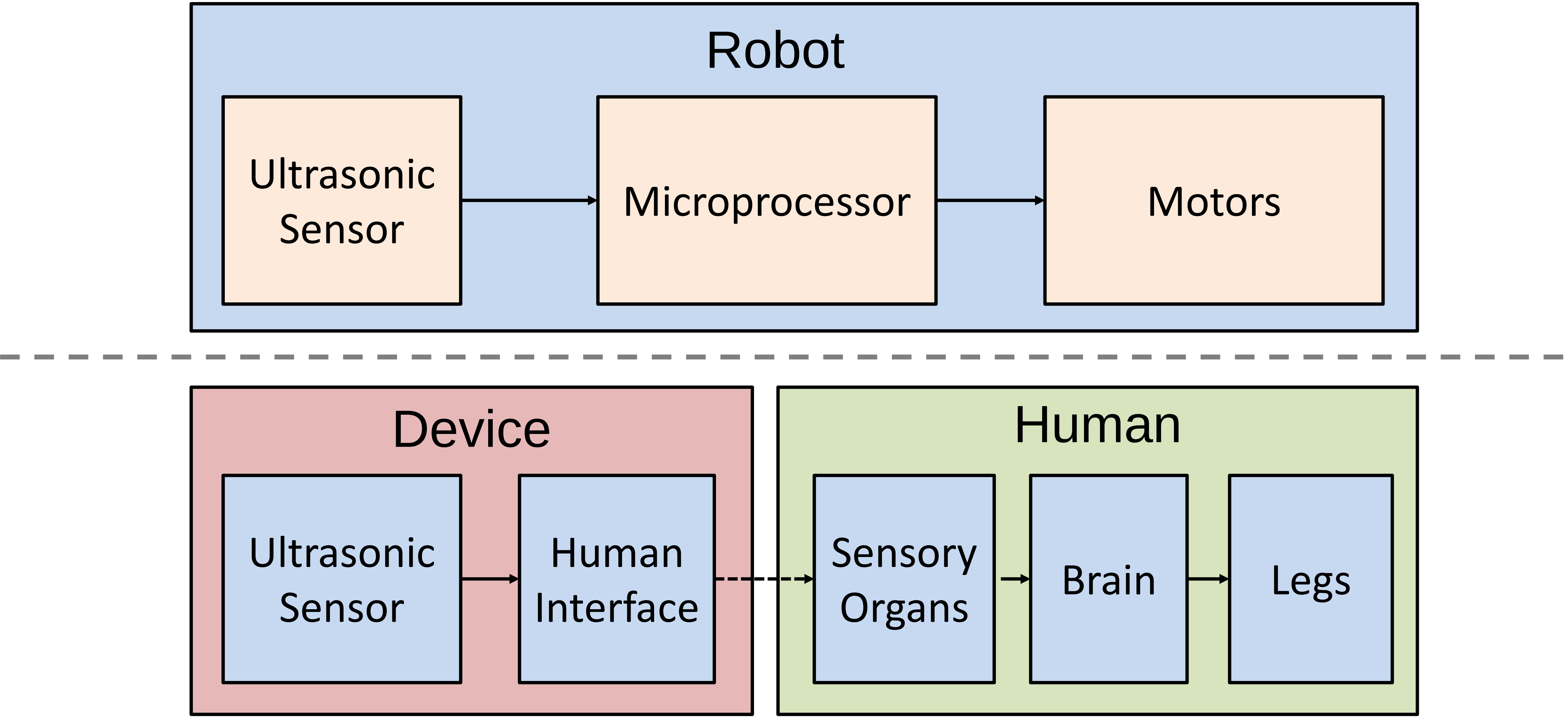
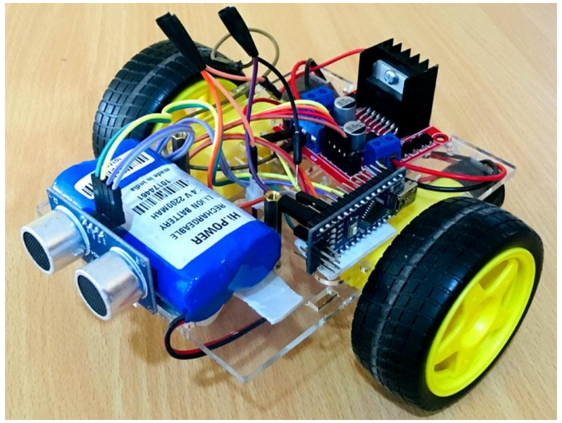
Ultrasonic Sensor
Microprocessor


Robot
Ultrasonic Sensor
Microprocessor
Motors
Device
Ultrasonic Sensor
Human Interface
Human
Sensory Organs
Brain
Legs

The Haptic Torch [Taschenlampe] (2004)

- Undergraduate research project
- Distance to obstacles measured via ultrasound
- Communication to a blind individual’s finger via a haptic interface
- The person can then walk around the obstacles

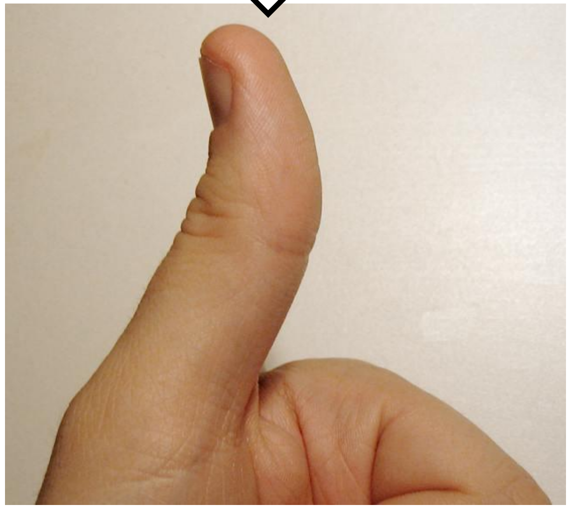


The Haptic Interface

- A rotating disc under the user's thumb
- A raised dome acts as an 'indenter' or 'tactor'
- Tactor position is related to distance

Sensory Substitution

- Normally, **vision** informs the brain about obstacles
- Here, **touch** informs the brain about obstacles
  - But with **much less information**
  - We do not know about the object's properties
    - Type
    - Color
    - Material
  - But these things are not important in this scenario



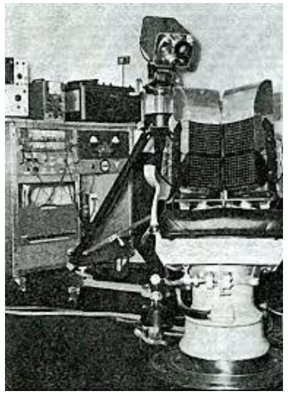
Other forms of Sensory Substitution for obstacle detection

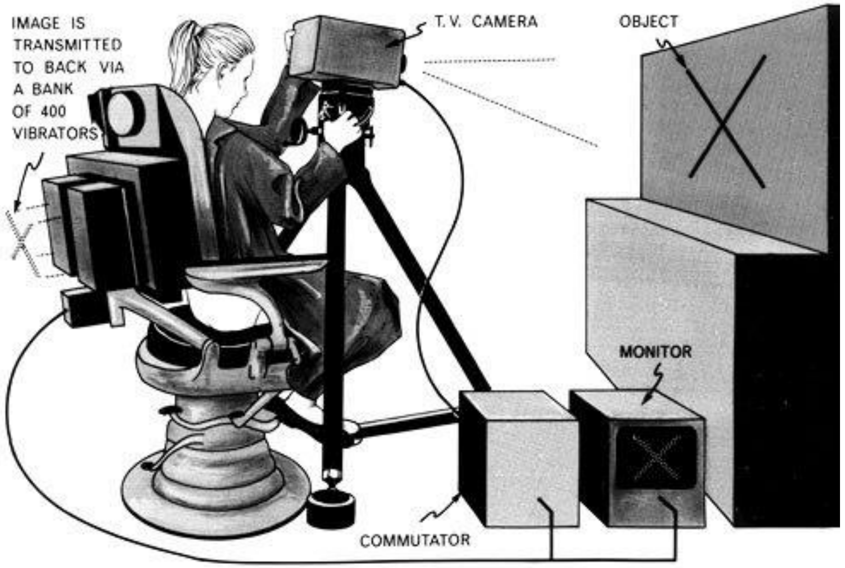
Ultracane:
Distance to Vibration Intensity
(Vibrotactile)

Distance to audio beep interval

Sensory Substitution & Cognitive Load

- TVSS (1969) - Tactile Visual Substitution System – Bach-y-Rita
- Camera input → Vibration intensity of vibrotactors in an array on the back or abdomen
- Blind people learned to interpret camera data
- Considered a landmark in Sensory Substitution research

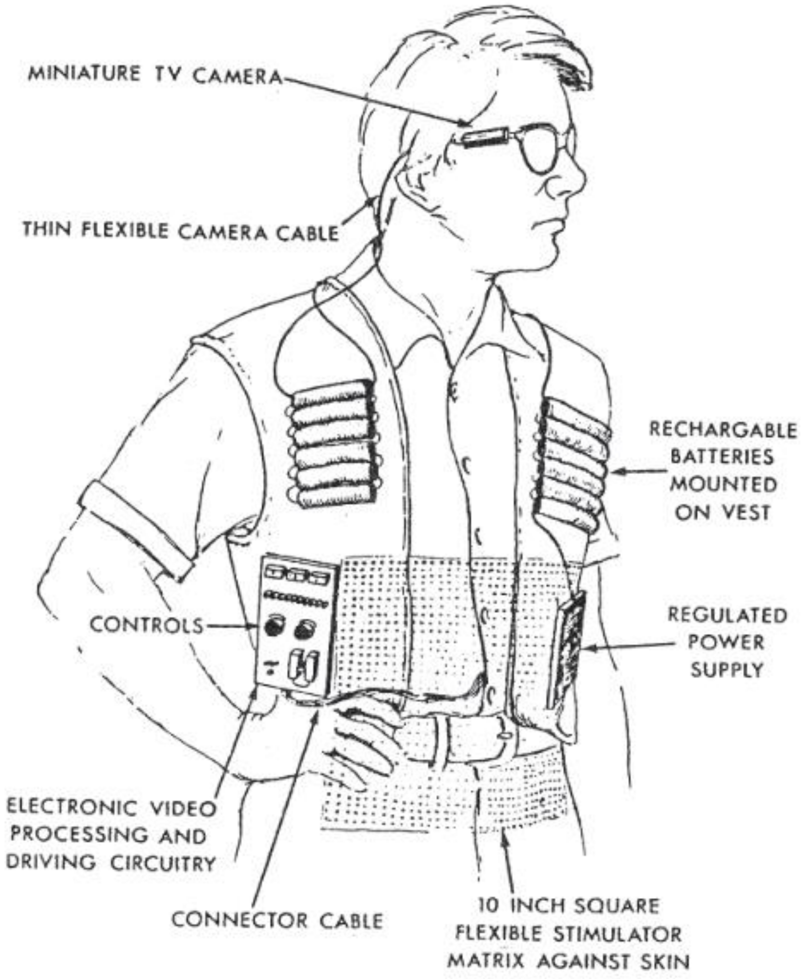




Bach-y-Rita P, Collins C, Saunders F, White B, Scadden L. Vision substitution by tactile image projection. *Nature* 1969, 221:963–964.

Sensory Substitution and Cognitive Load

- Over 100 hours of participant training
- Attempts at mobile use for navigation
- Required ‘unsustainable levels of concentration’ [when used outdoors or egocentrically]
  - – C. C. Collins (1985)



Visual Sensory Substitution with Sound

- *'Sonification'*
  - Converting data to Sound
- Brock & Kristensson (2013)
- Many previous examples

Figure 2: The raw RGB VGA image from the camera.

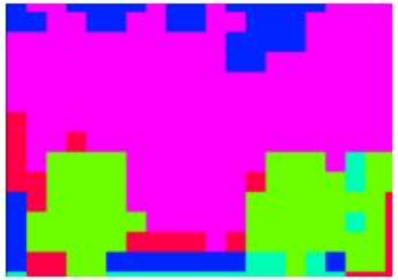
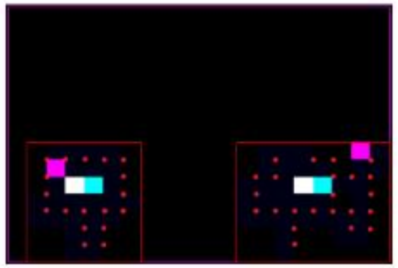


Figure 3: The depth map after down-sampling.



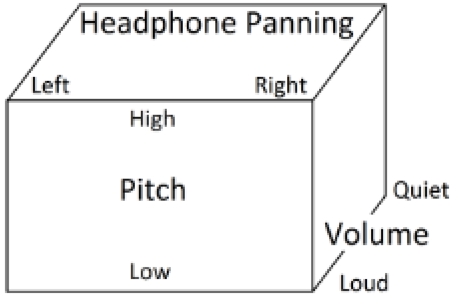


Figure 5: The conversion from 3D location to sound within a given sonification volume. The

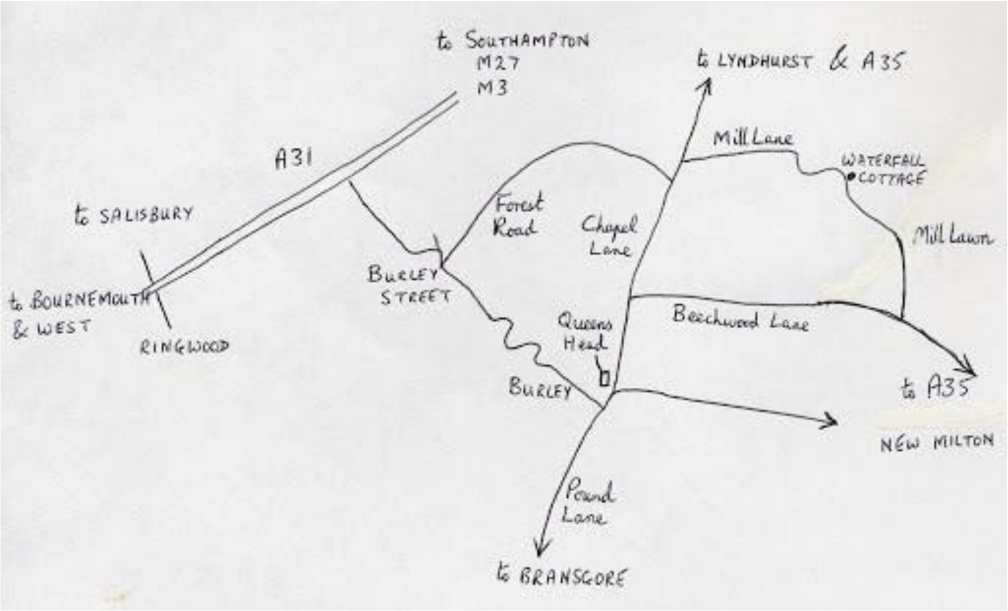
Sound & Distraction

Imagine constantly listening to beeping whenever you walked somewhere…

Design Choices

1. What information should we deliver?
    - Distance / visual scenes?
2. What sense should we target?
    - Sound, Touch (vibration, moving tactors, etc.)

Wayfinding / Path Planning



Wayfinding - How Do People Navigate?

A research topic in:

- Neuroscience
  - Structure and function of the nervous system
- Experimental Psychology
  - Empirical approach to studying the mind
- Cognitive Science
  - Thought, learning and mental organisation

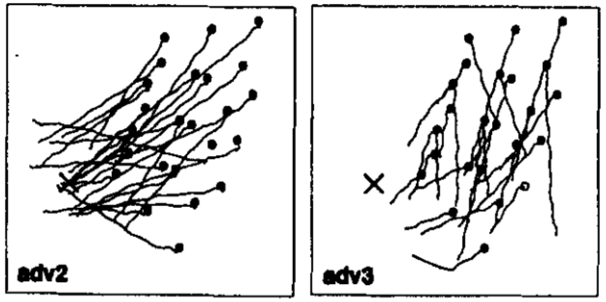
BARRY, C. AND BURGESS, N. 2014. Neural mechanisms of self-location. *Current Biology*

ULANOVSKY, N. 2011. Neuroscience: How is three-dimensional space encoded in the brain? *Current Biology*

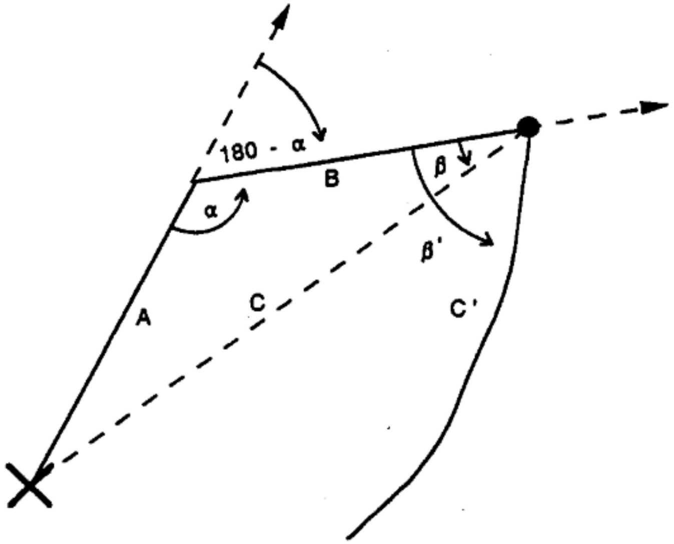
TINTI, C., ET. AL. 2006. Visual experience is not necessary for efficient survey spatial cognition: Evidence from blindness. *Quarterly Journal of Experimental Psychology*

SCHINAZI, V.R., THRASH, T., AND CHEBAT, D.R. 2016. Spatial navigation by congenitally blind individuals. *Wiley Interdisciplinary Reviews: Cognitive Science 7*, 1, 37–58.

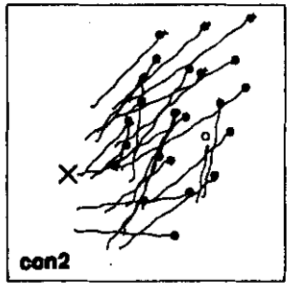
How do VI People Navigate?

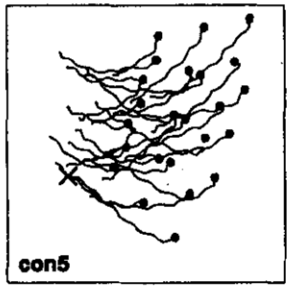


Sighted



VI





Limited **experimental comparisons** between location and navigation in VI and Sighted Persons

LOOMIS, J.M., KLATZKY, R.L., GOLLEDGE, R.G., CICINELLI, J.G., PELLEGRINO, J.W., AND FRY, P.A. 1993. Nonvisual Navigation by Blind and Sighted: Assessment of Path Integration Ability. *Journal of Experimental Psychology: General 122*, 1, 73–91.

"The slight performance differences between groups varying in visual experience were neither large nor consistent across tasks. Results provide little indication that spatial competence strongly depends on prior visual experience"

Why did Loomis do this experiment?

- To investigate how space is internally represented by people
- Does spatial ability rely on **prior** visual experience?
- Are congenital / early blind individuals at a navigational disadvantage?
  - Papadopoulos et al. 2017; Tinti et al. 2006.
  - We are still not sure…

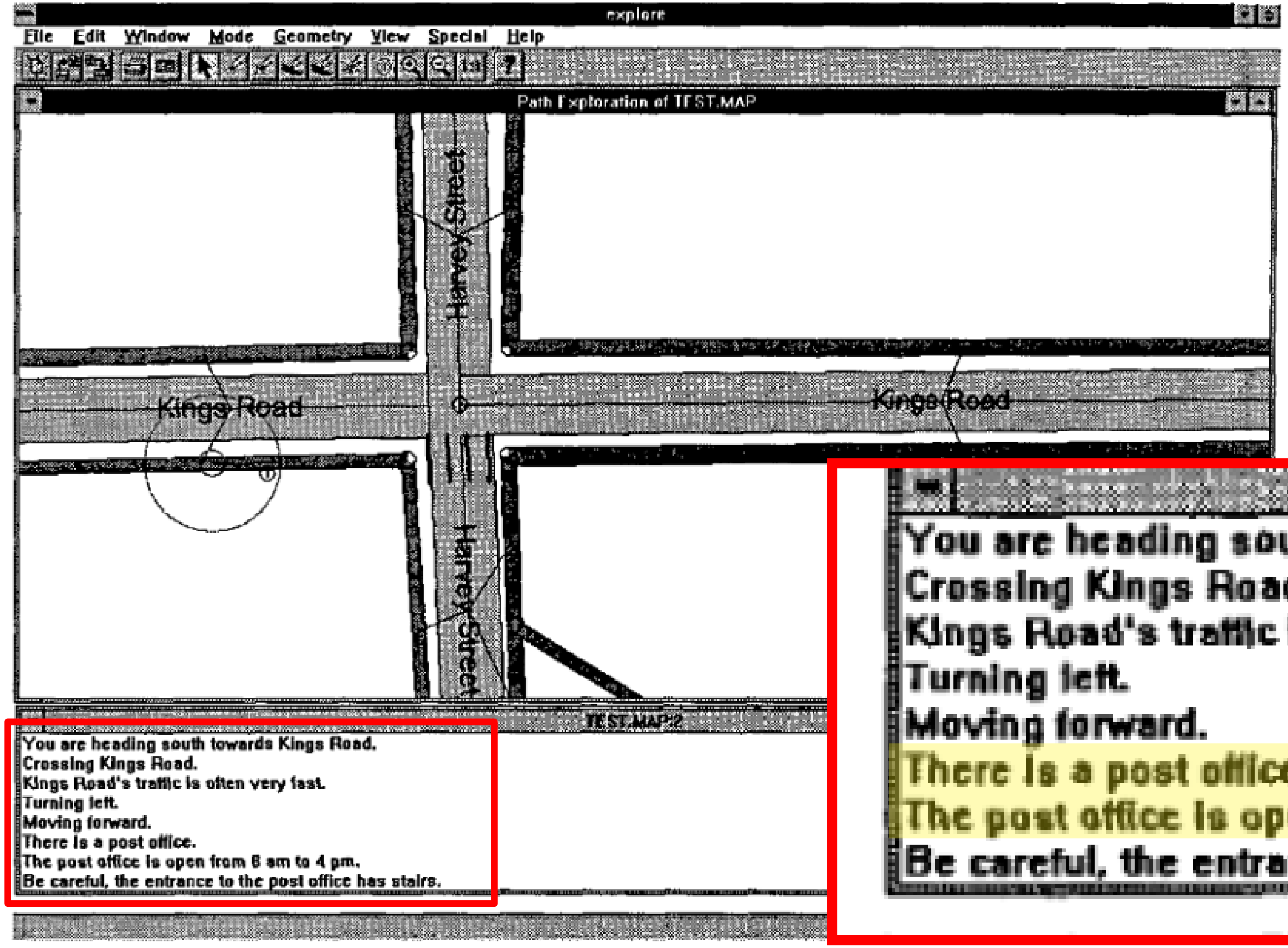
Verbal Spatial Representations

- Wayfinding directions **provided by VI people are difficult for sighted people to understand**
- The same applies in reverse.
- Individuals focus on different perceptual information
  - Based on their sensory abilities

BRADLEY, N. A. AND DUNLOP, M.D. 2005. An experimental investigation into wayfinding directions for visually impaired people. *Personal and Ubiquitous Computing 9*, 6, 395–403.

Class of contextual information	Example
1. Directional	Left/right, north/south
2. Structural	Road, monument, church
3. Environmental	Hill, river, tree
4. Textual-structural	Border's bookshop, Greaves Sports
5. Textual-area/street	Sauchiehall St., George Sq.
6. Numerical	First, second, 100 m
7. Descriptive	Steep, tall, red
8. Temporal/distance	Walk until you reach...or just before you get to...
9. Sensory	Sound of cars passing or smelling a bakery
10. Motion	Cars passing, doors opening
11. Social contact	Asking people or using a guide dog for help

THE MOBIC TRAVEL AID (1996)



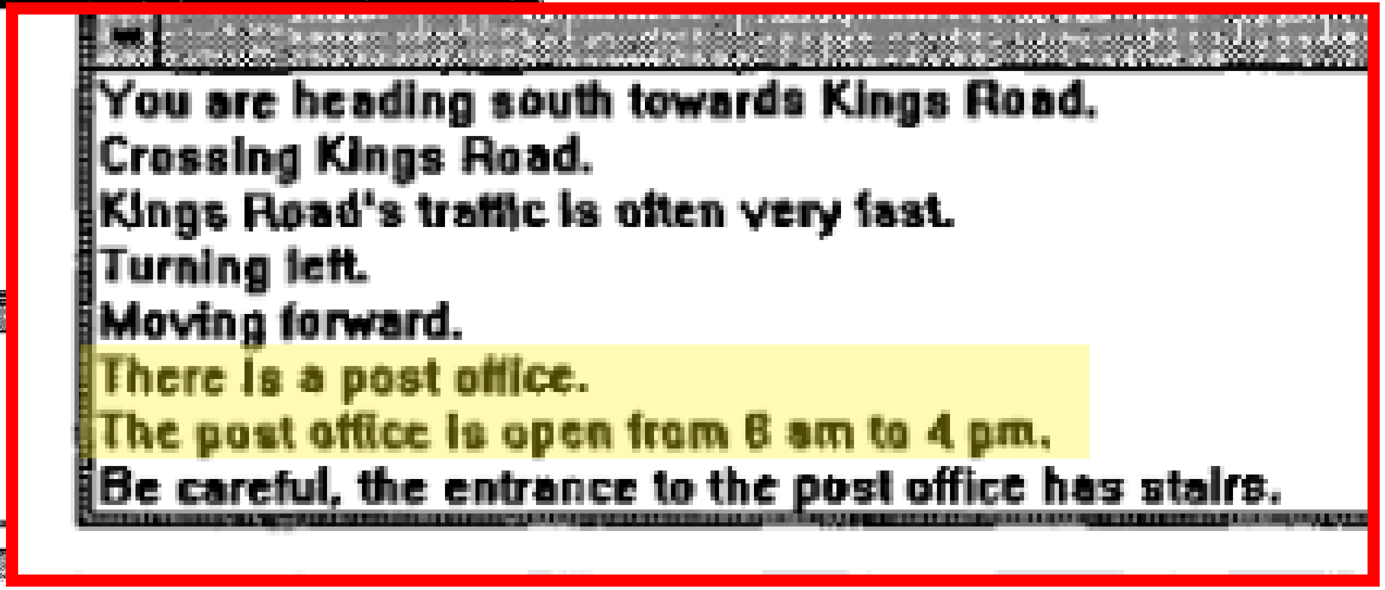
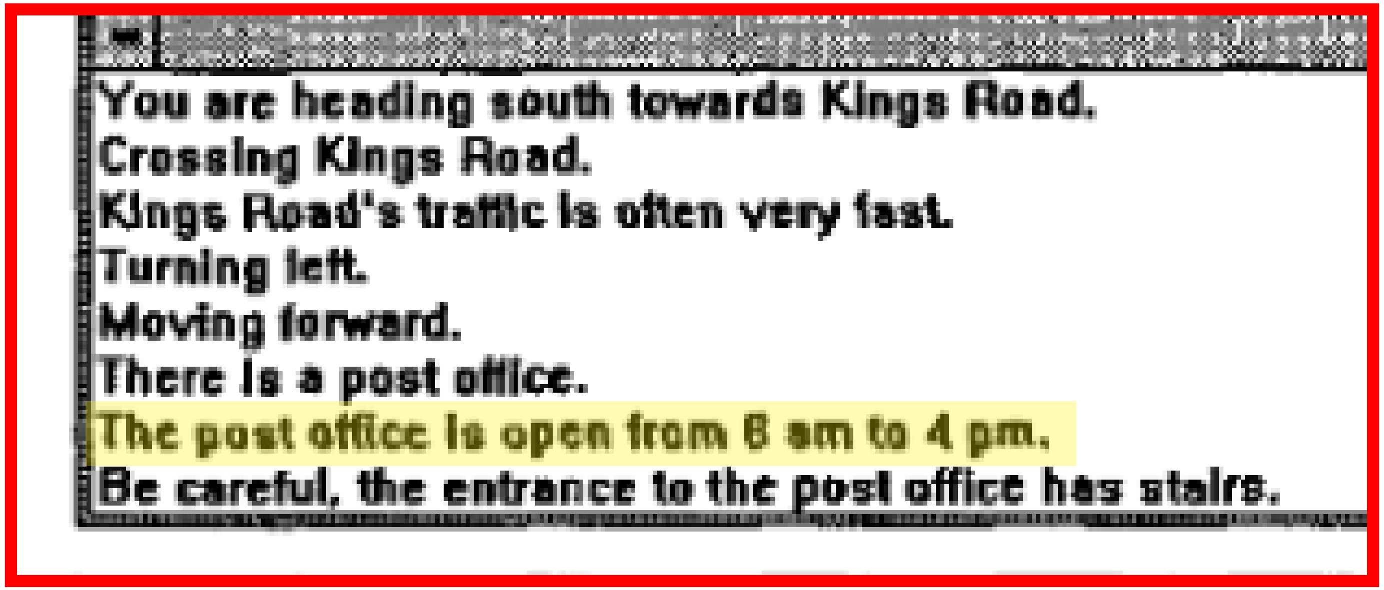
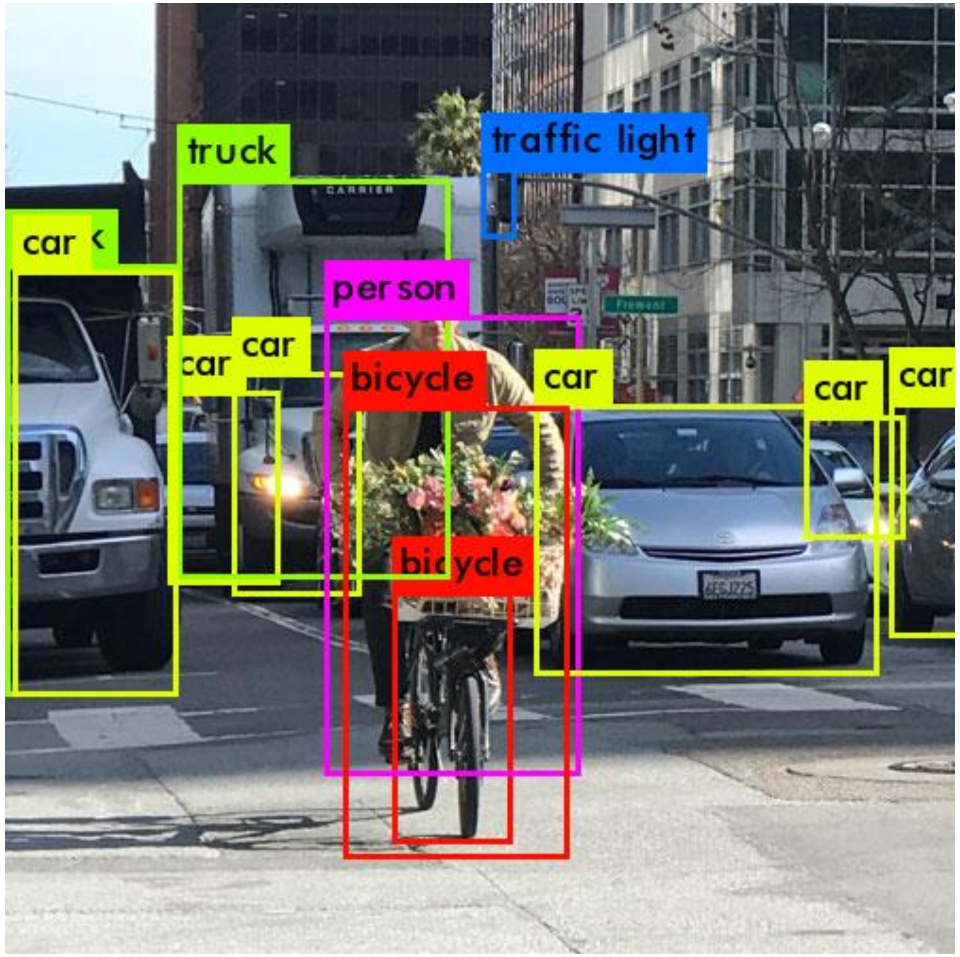
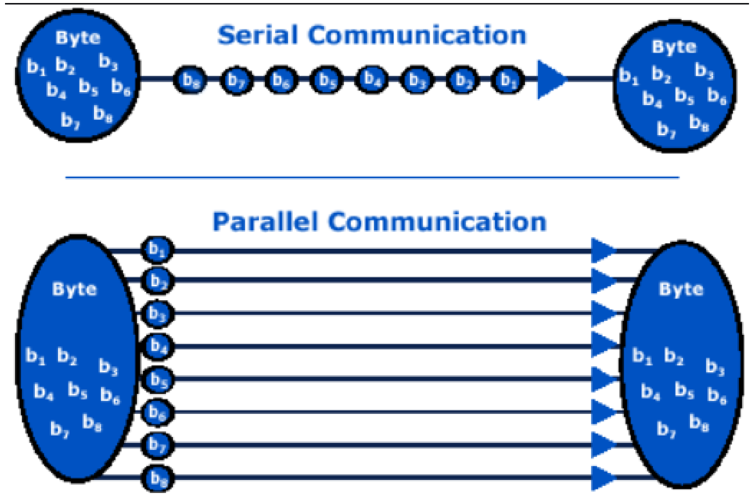


Figure 1: Example of the visual presentation of the digital map information


You are heading south towards Kings Road.
Crossing Kings Road.
Kings Road's traffic is often very fast.
Turning left.
Moving forward.
There is a post office.
The post office is open from 8 am to 4 pm.
Be careful, the entrance to the post office has stairs.

Labelling the World

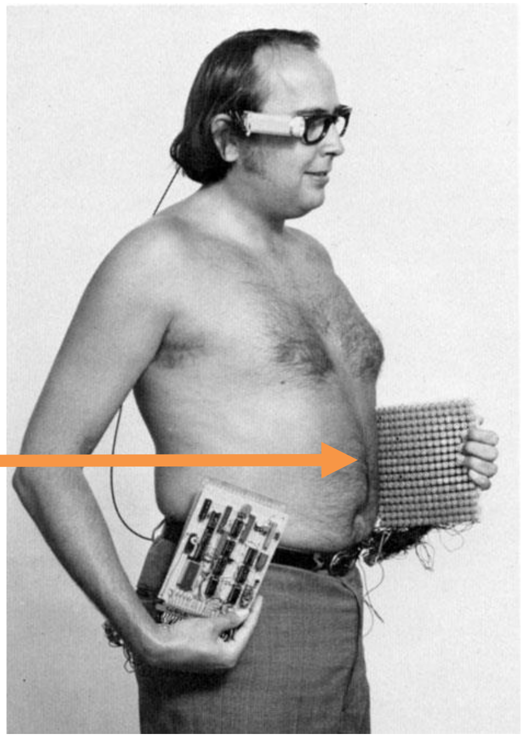




Designing Data for Different People

- Information for sighted people doesn't necessarily work for VI people.
- As Bach-y-Rita attempted with vibrotactile pixilation!

http://thispersondoesnotexist.com



Design Choices

1. What information should we deliver?
2. What sense should we target?
3. How should we deliver it?

Inclusive Design

- The biggest hurdle to advanced Assistive Technology products is **financial**:
  - Small Market
  - Not a wealthy demographic
  - Small profit margin
  - This can be seen in prosthetics

$50,000

- E.g. The smartphone is a great tool for VI people
  - But its success was driven by the sighted market
- My research is on navigation systems that **may benefit sighted and VI people**

Smartphones

- GPS enabled **Smartphones** have led to widespread **pedestrian** navigation assistance

- Yet, typical smartphone **interfaces** may not be optimal for this task

Smartphone Screens are Distracting for Sighted People

- An increasing cause of hospital admissions*

* Nasar & Troyer (2013)

Audio Interfaces

- Obscure / distract from important environmental **sound cues**
- Particularly for blind / visually impaired users*

* Borenstein & Ulrich 1997

Haptic Interfaces

- Target the sense of **touch**
  - Which is used less than **sight or sound** when walking
- Haptic sensations may be **less distracting** for people who are:
  - Sighted
  - Vision-impaired
  - Hearing-impaired
  - Deafblind

~50 years of Haptic Navigation Research

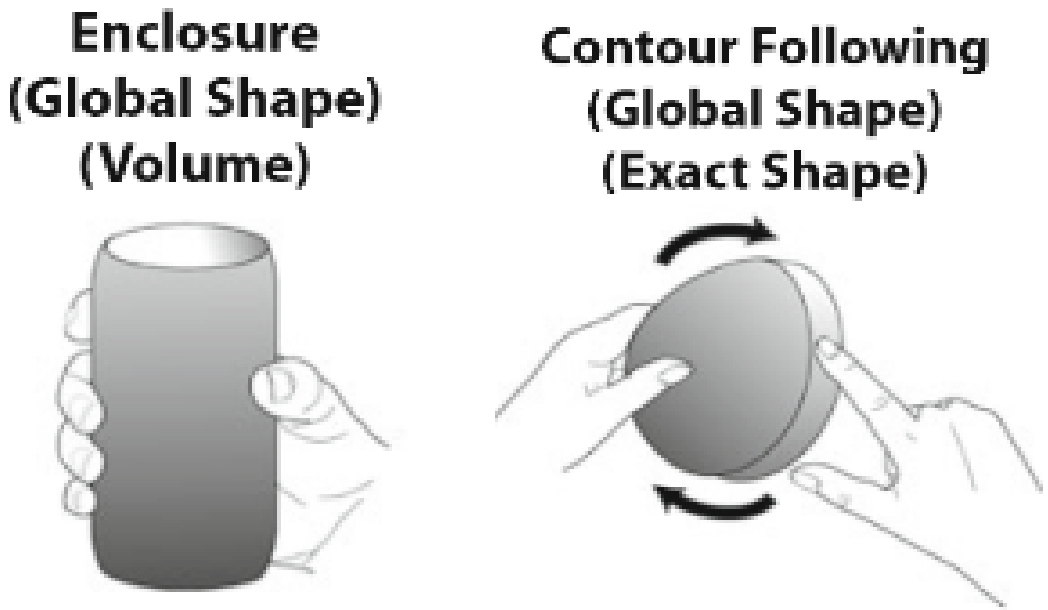
- Few outcomes *'outside of the lab'*
- Focus has mainly been on **vibration** feedback
  - Good at providing **alerts**
  - But alerts get **annoying** / **distracting** over **time**

Guide Dog & Cane

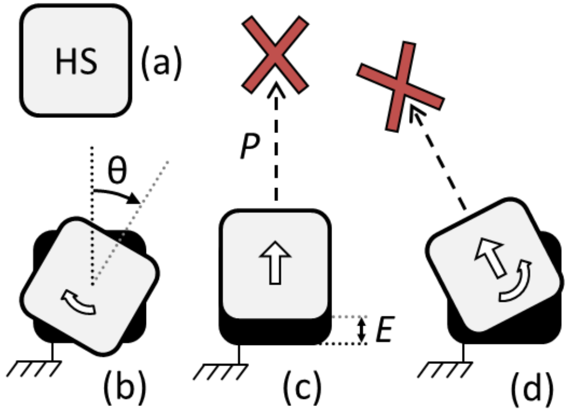
- Most **successful navigation tools** for blind / vision-impaired people
  - **Haptic** interfaces
  - Naturalistic **Mechanotactile** feedback

Haptic Shape Perception

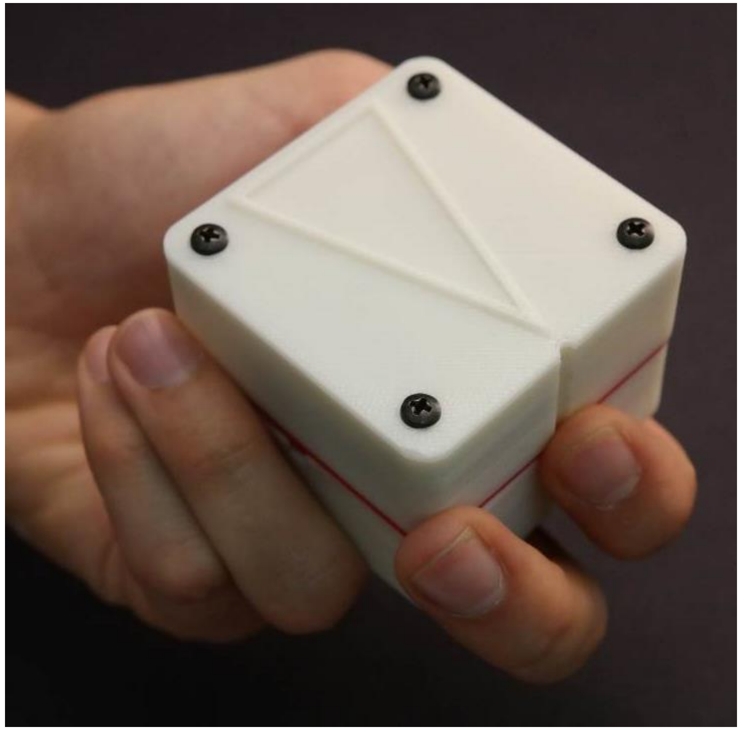
- A mechanotactile modality
- Frequent, Subtle and **Unobtrusive**

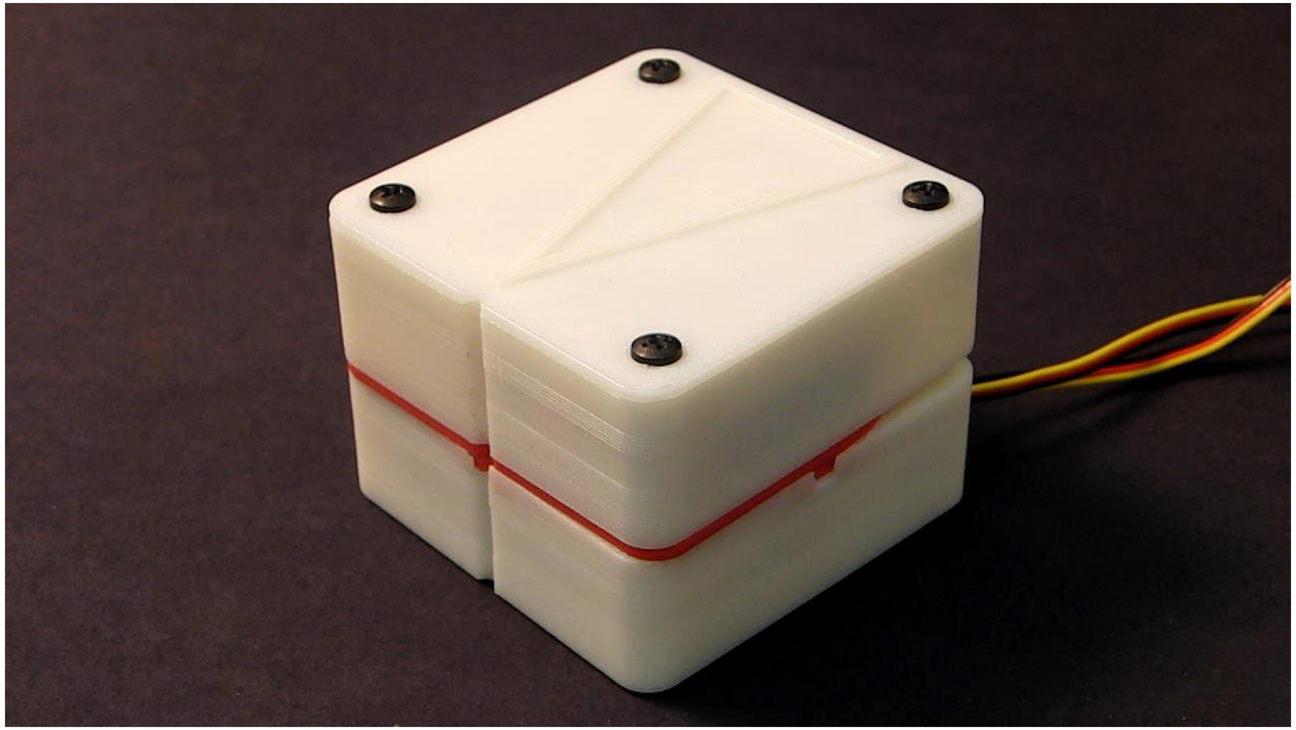


The Animotus

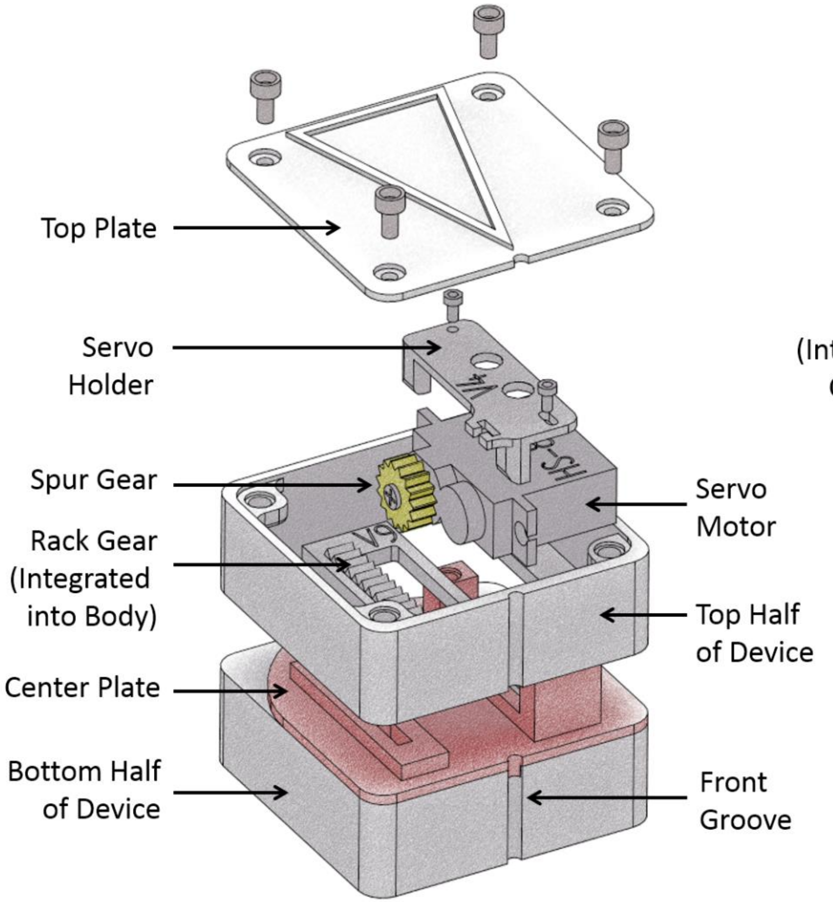


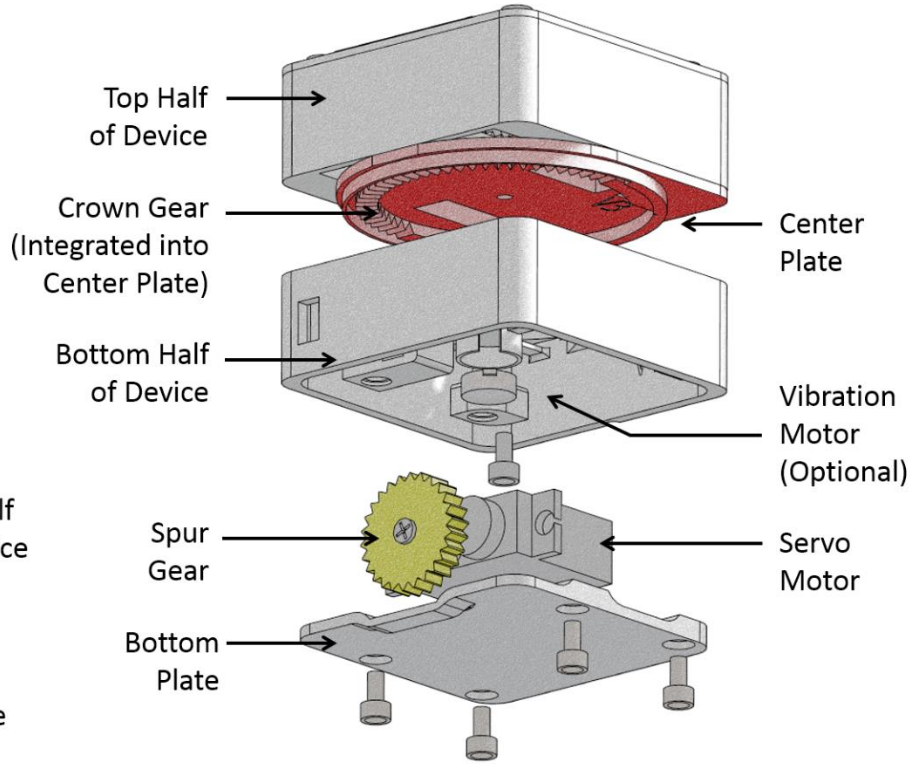
- 2DOF Handheld **Shape-Changing** Cube
- Communicates **heading and proximity** to waypoints

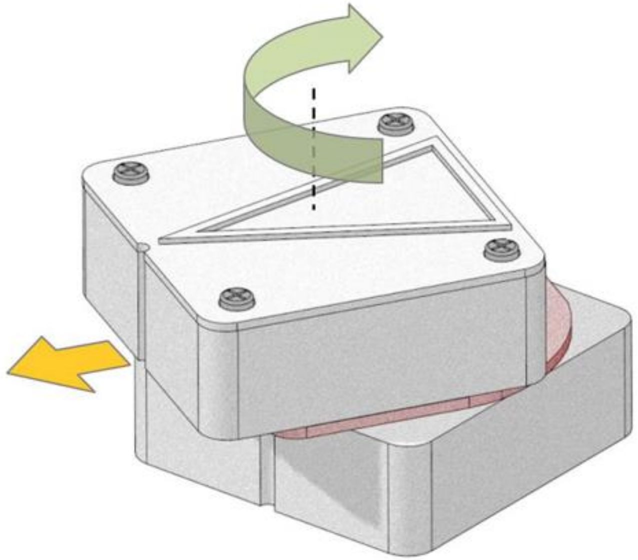




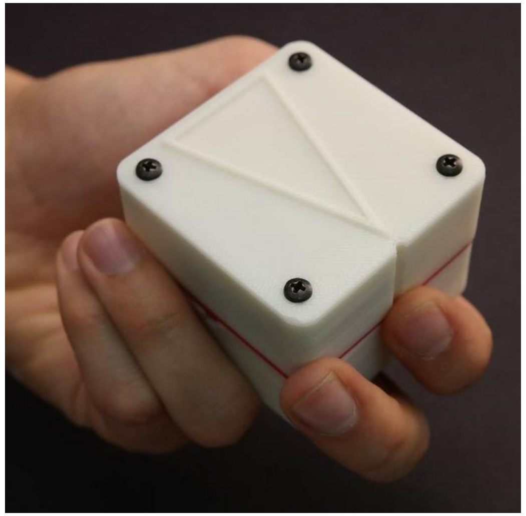
Mechatronic Design



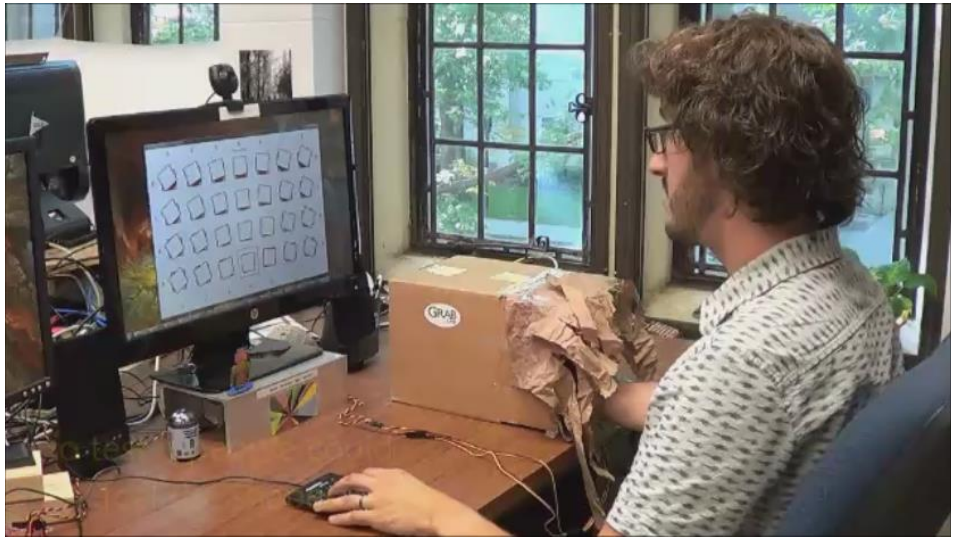


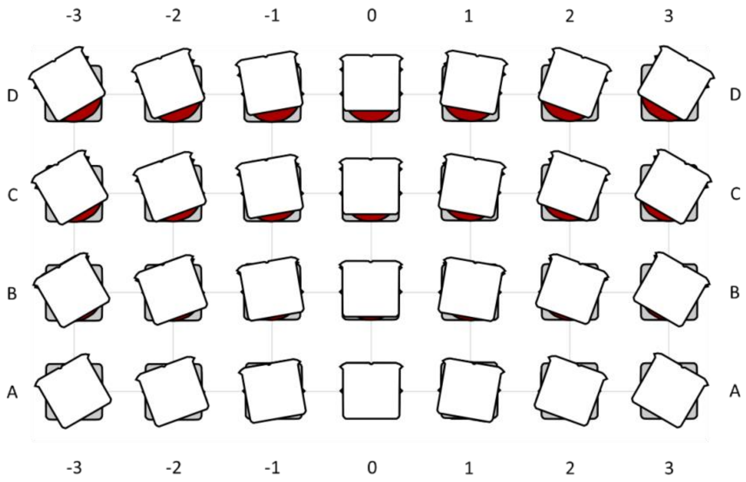


Testing Haptic Perception



- Device held by participant, hidden in a box
- Device assumes a shape (pose)
  - Via simultaneous or sequential actuator motion (equal number of each)
- Participants selected pose from a chart

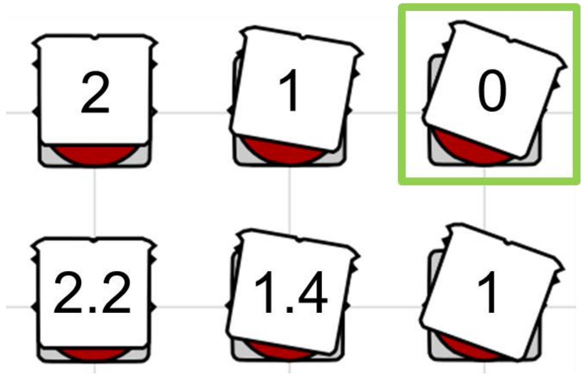


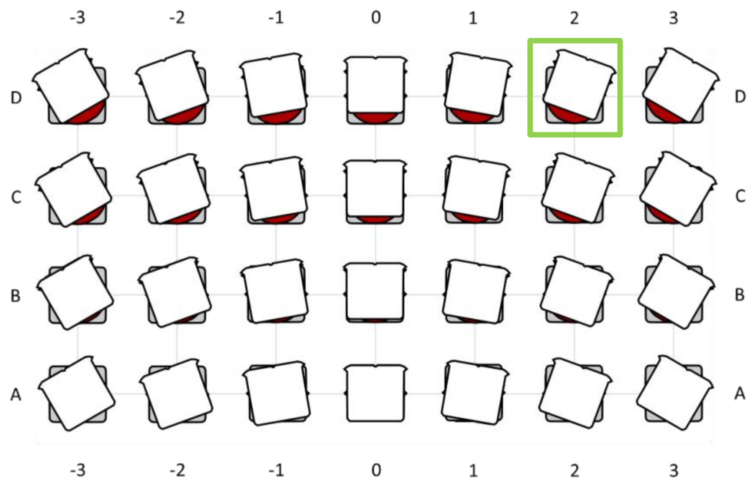


Results

- Scoring based on distance of selected pose from actual pose

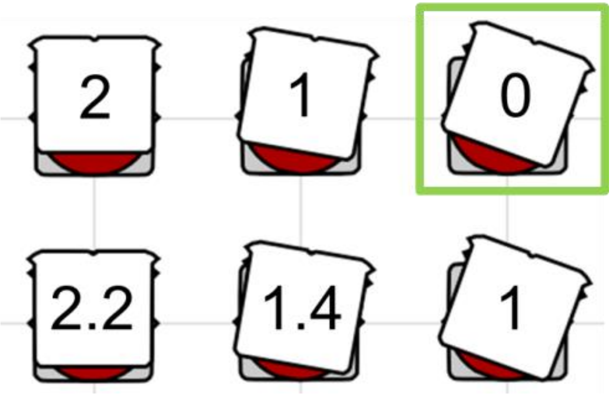
- 10 participants
- 108 poses per participant





Results

- Perception very good overall
  - Most errors are adjacent pose
  - Very few multi-DOF errors
  - Extension somewhat harder to perceive than rotation



Total Mean Error Score

0.37	0.33	0.25	0.08	0.34	0.48	0.43
0.37	0.24	0.35	0.08	0.37	0.43	0.53
0.21	0.25	0.14	0.08	0.11	0.18	0.41
0.11	0.26	0.00	H	0.03	0.16	0.50

Rotation Mean Error Score

0.16	0.11	0.08	0.08	0.11	0.24	0.13
0.16	0.08	0.08	0.08	0.11	0.11	0.08
0.03	0.05	0.08	0.03	0.05	0.03	0.03
0.00	0.03	0.00	H	0.00	0.00	0.00

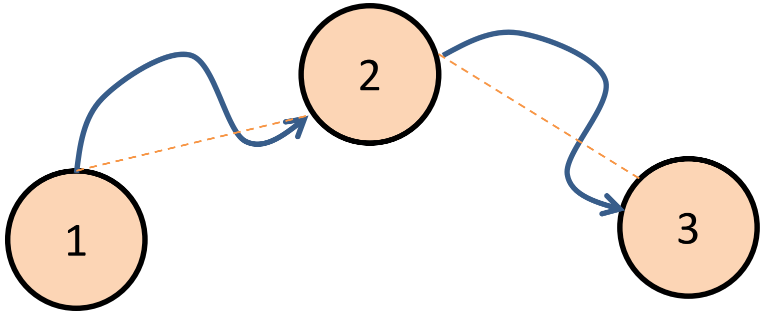
Extension Mean Error Score

0.24	0.26	0.18	0.00	0.26	0.37	0.39
0.16	0.21	0.26	0.00	0.29	0.34	0.42
0.16	0.21	0.11	0.05	0.05	0.13	0.34
0.08	0.24	0.00	H	0.03	0.16	0.37

Part 2- Navigation Study

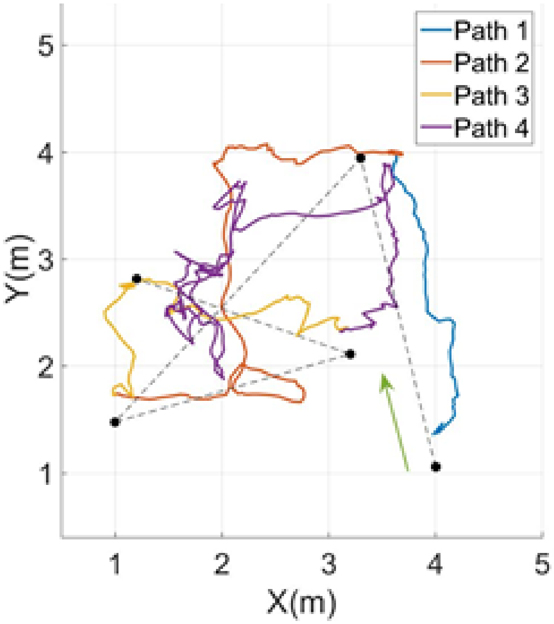
- Device used to locate invisible targets in an indoor environment

- Indoor localization system
- Wireless device control

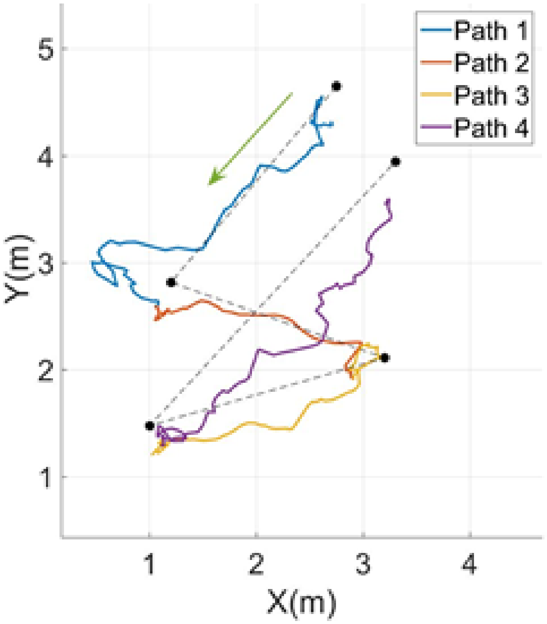


Walking Paths

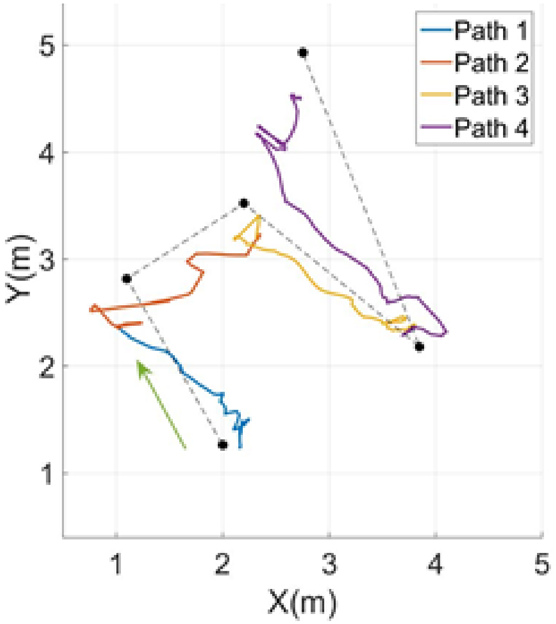
Proximity Only Extension

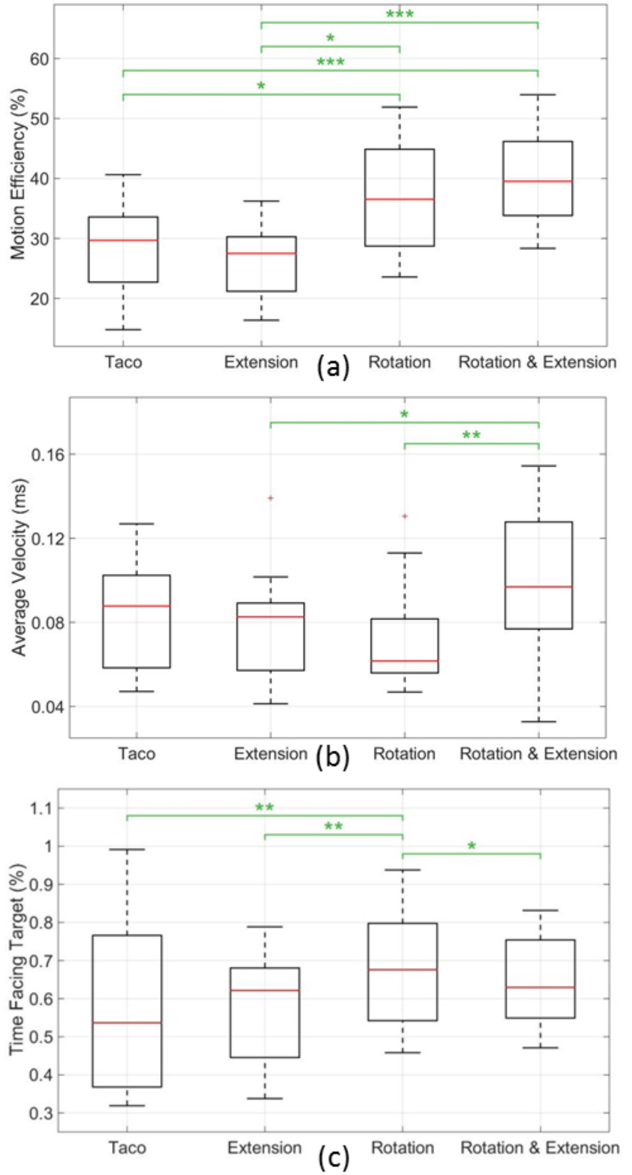


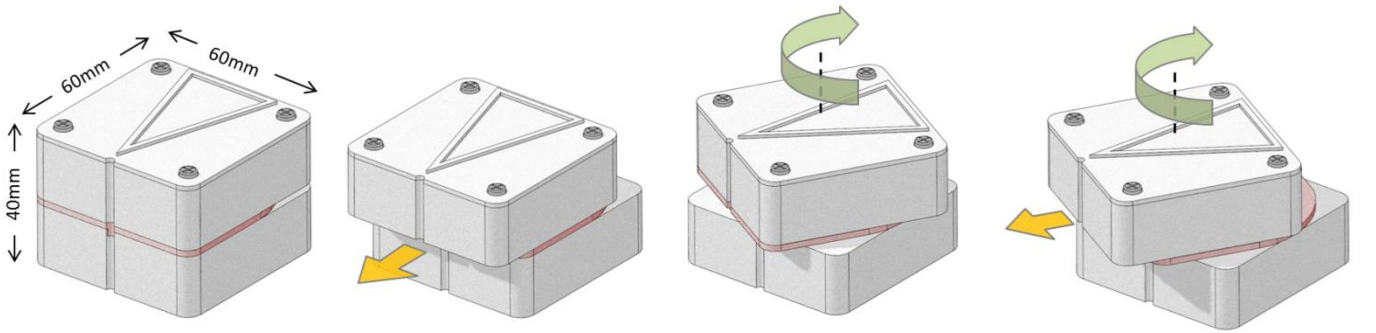
Rotation



Extension + Rotation



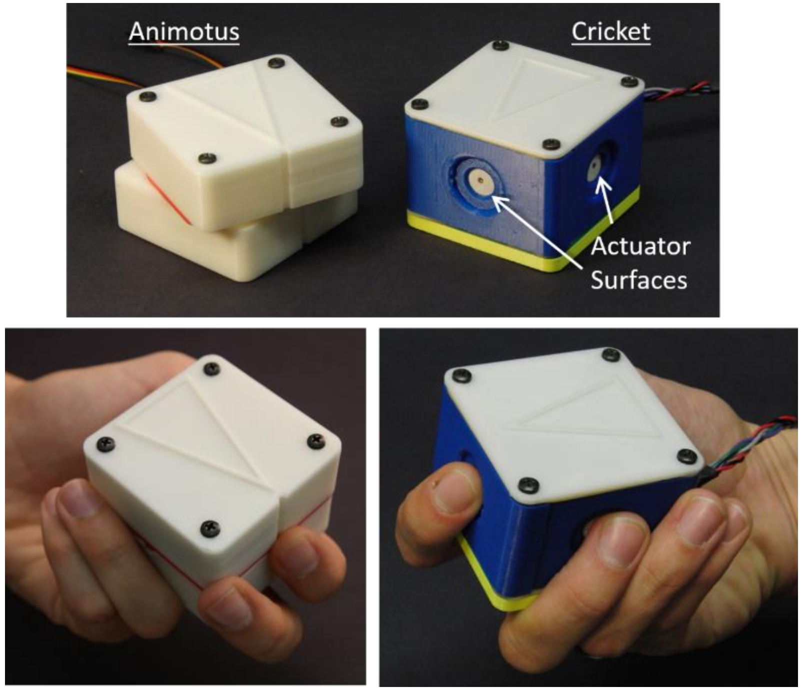




(a) Home (b) Extension (c) Rotation (d) Rotation & Extension

Part 3 - Outdoor Navigation

- Participants are guided along different path with
  - A Shape Changing Device
  - A Vibrotactile Device



Participant is in the center of the video

Results

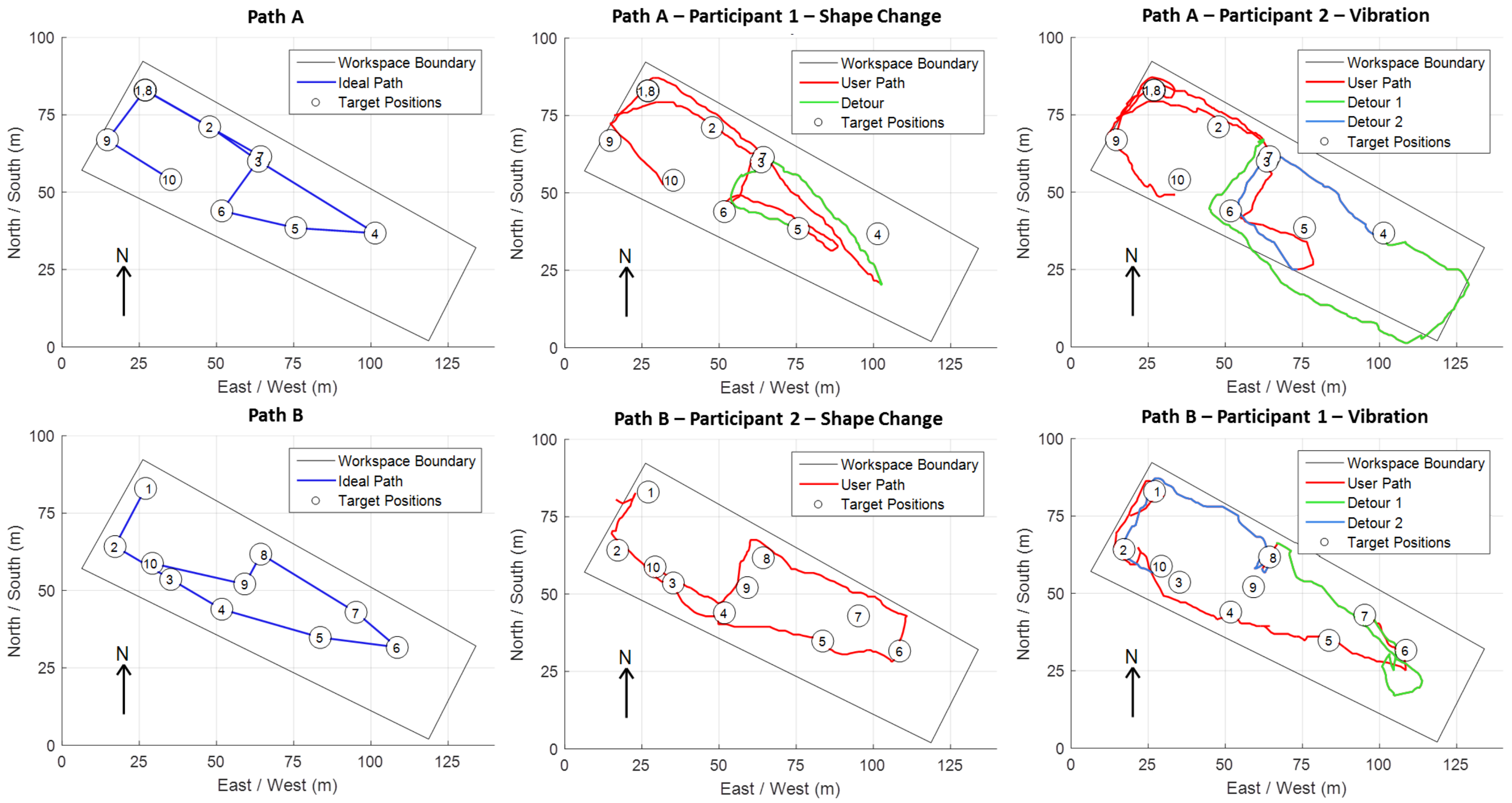


Table 1: Walking Path Efficiency

Participant	Shape (S)	Vibro (V)	Difference
P1	14.5%	15.8%	1.3% (V)
P2	27.1%	10.1%	16.9% (S)
P3	21.4%	12.6%	8.8% (S)
P4	16.0%	17.7%	1.7% (V)
Average	19.7%	14.1%	5.7% (S)

Table 2: Time to complete course (seconds)

Participant	Vibro (V)	Shape (S)	Difference
P1	1098	462	+238% (V)
P2	1034	422	+245% (V)
P3	1297	737	+176% (V)
P4	1287	521	+247% (V)
Average	1179	535	+220% (V)

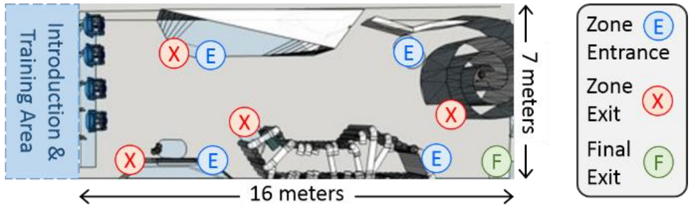
Table 3: Average questionnaire results: 1 = Strongly Disagree, 3 = Neutral, 5 = Strongly Agree. Brackets indicate standard deviation.

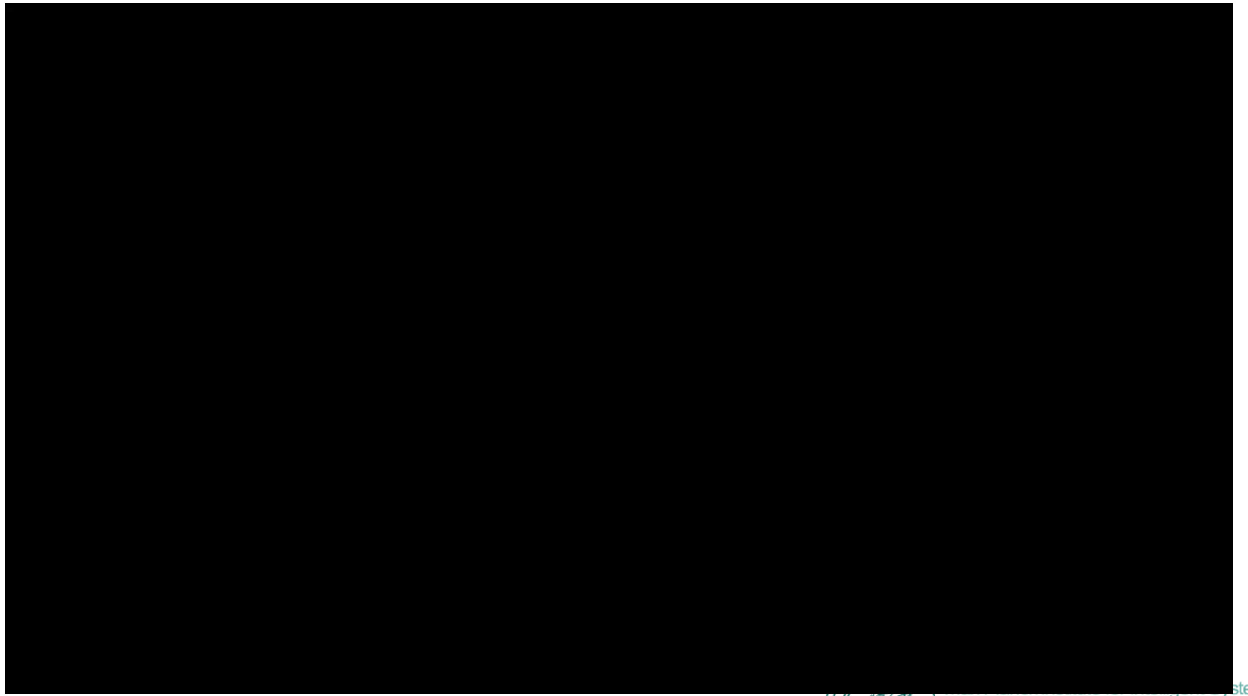
Questions	Shape	Vibro
The device was **confusing**	1.25 (0.4)	3 (0.7)
The device was **intuitive**	4.75 (0.4)	2.75 (0.8)
Direction was easy to interpret	4.75 (0.4)	2.5 (0.5)
Distance was easy to interpret	4.25 (0.8)	2.75 (1.3)
The instructions felt **accurate**	4 (0.0)	3 (0.0)
I got **mentally tired** using the device	2 (0.8)	3.5 (0.9)
I **enjoyed** using the device	3.75 (1.6)	2.75 (0.4)
I felt **confident** in the device	4 (0.7)	2.25 (0.4)
I found the device **annoying**	1.75 (0.4)	3.5 (0.5)
I think I could **navigate a city** with this	4 (0.7)	2.25 (0.4)
I paid less **attention** to my surroundings	2.25 (1.1)	3.5 (0.9)

LOTTERY FUNDED
Supported using public funding by ARTS COUNCIL ENGLAND

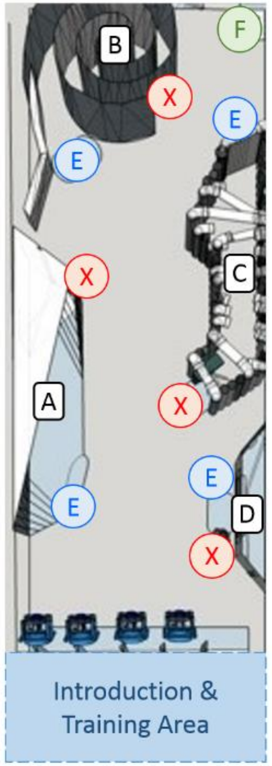
Art meets Science

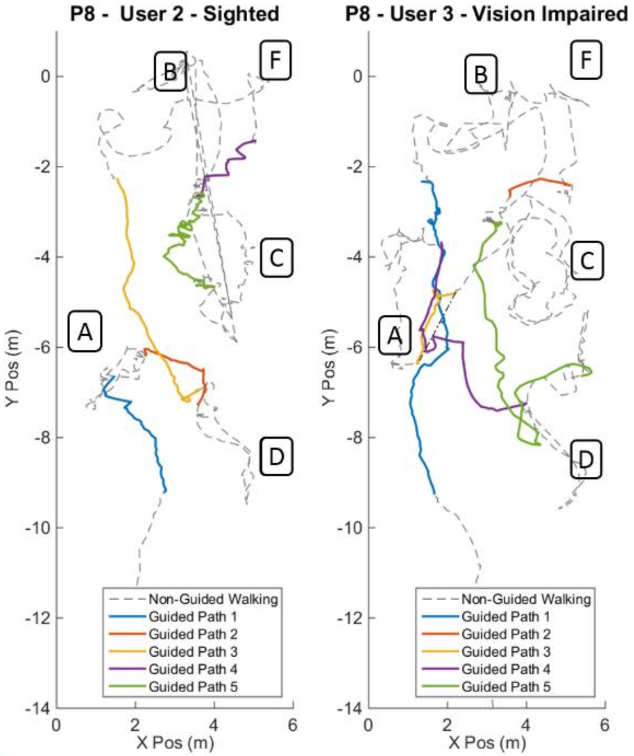
- Immersive theatre installation set in complete darkness
- Collaboration with a London based VI theatre group (Extant)
- Sighted (n = 79) & visually impaired (n = 15) audience
- Guided by the Animotus

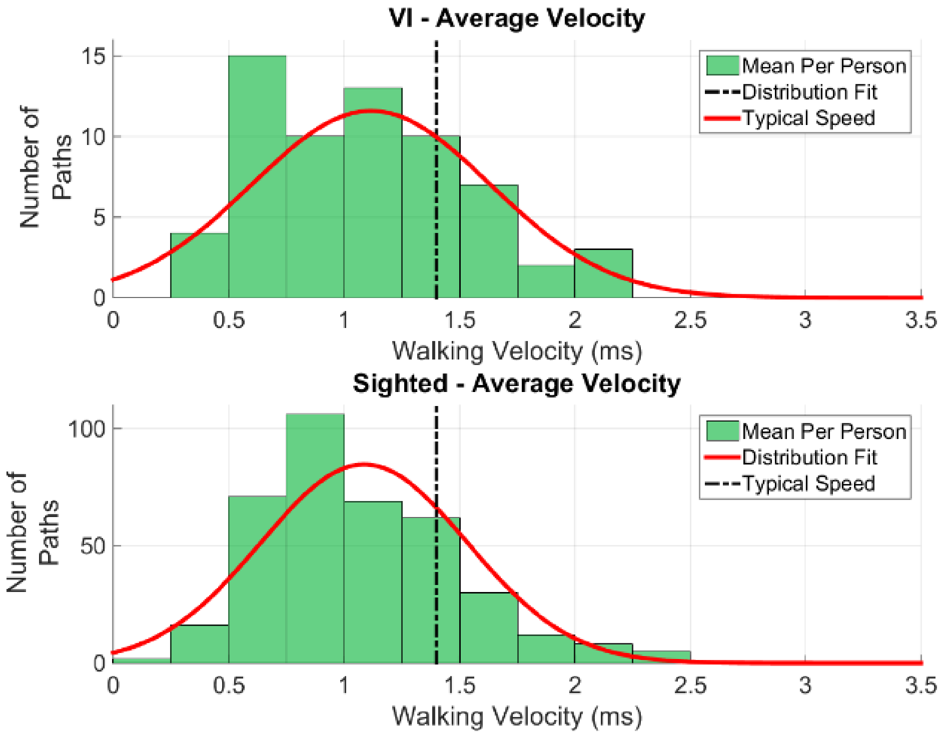




Data Collection During Installation



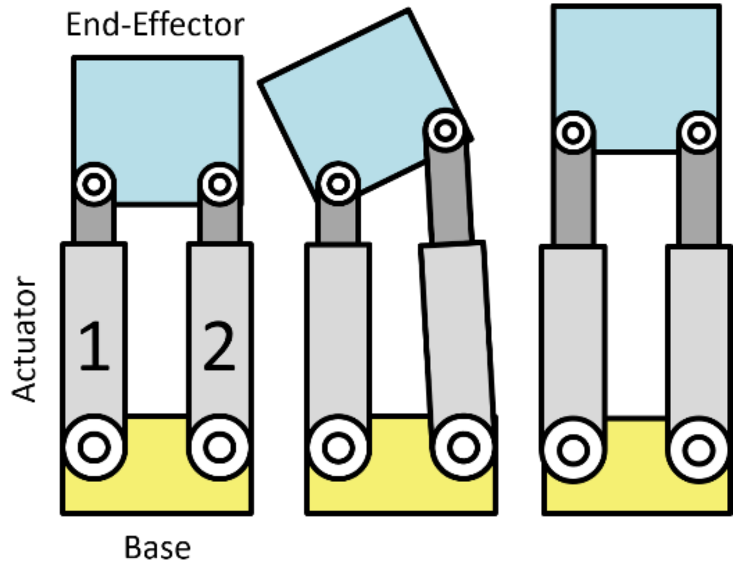


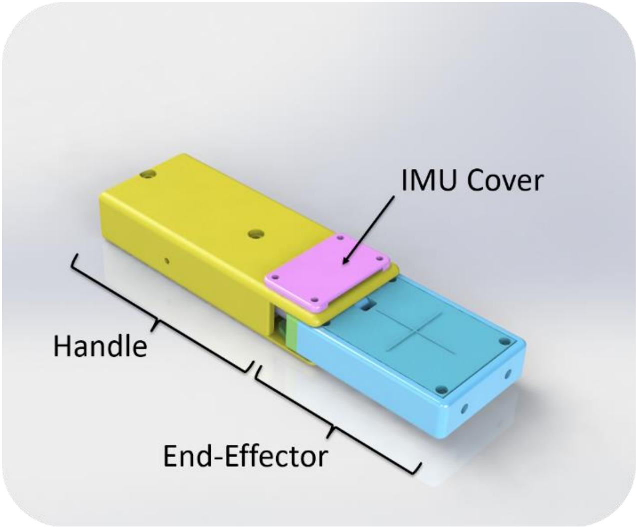


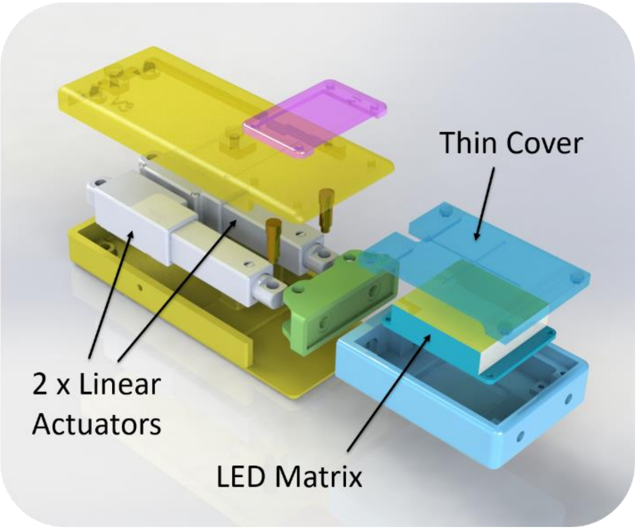
- No significant difference between VI & sighted **movement efficiency** or **average walking pace**

Latest Device

- **S-BAN**: Shape-Based Assistance for Navigation
- Parallel Actuation Scheme
  - Compact, ergonomic design

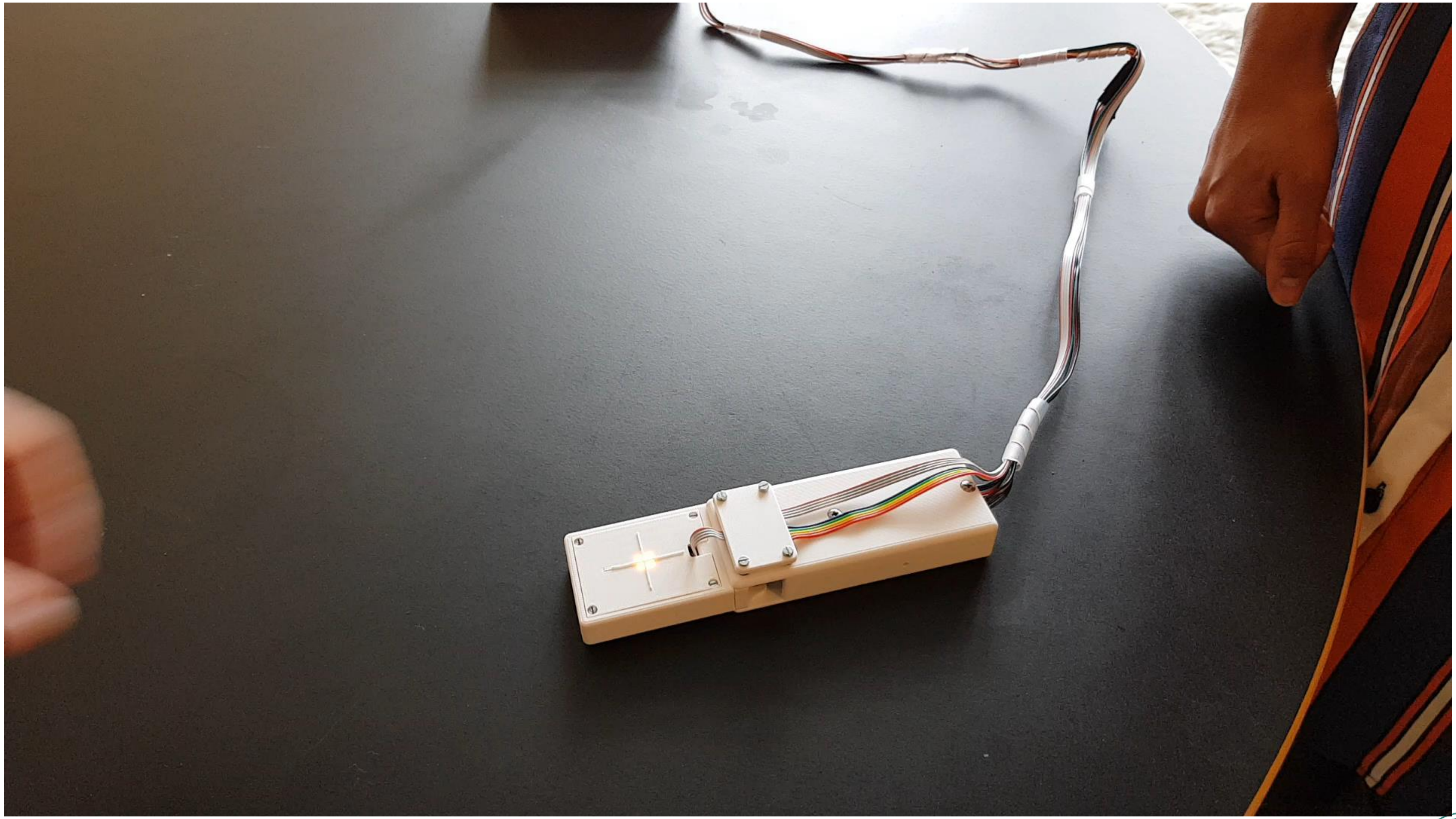






An S-Bahn

Coupled Distance and Heading



Final Thought: A Combined Solution is Needed

Figure 1: Examples of challenges found by visually impaired participants navigating at the Pittsburgh International Airport using a smartphone-based navigation system.

Thank You

- Questions?

- Email:

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