Mobile Information Systems

Lecture 04:
I/O on mobile devices (1/2)

© 2015-24 Dr. Florian Echtler
Bauhaus-Universität Weimar
Aalborg University

I/O on mobile devices

- Issues, revisited
  - Touch & motion
  - Vision & other I/O channels
- Solutions
  - Common (commercial) approaches
  - Research projects

I/O issues: touch (recap)

- Issues:
  - No haptic feedback (unlike keyboards)
  - Occlusion – hand/fingers covers part of display
  - Precision – user hits multiple pixels, covers target
  - No “hover” state – “Midas touch problem”
  - Reachability

Touch – haptic feedback (1)

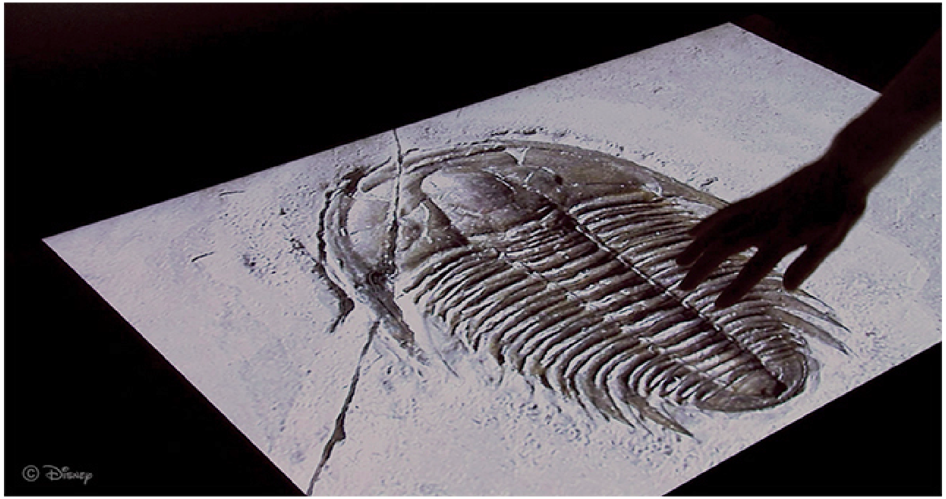
Image source (FU): http://tactustechnology.com/wp-content/uploads/2014/08/White-Paper-New-Tagged-PDF.pdf

- "Phorm" overlay by Tactus
  - Multiple layers of transparent foil
  - Thin channels allow fluid to flow into "bubbles"
  - All bubbles raise/lower simultaneously
  - Prototype with fixed bubble arrangement → only usable with one single keyboard layout

Touch – haptic feedback (2)

Image source (FU): https://dl.acm.org/citation.cfm?id=2502020

- “Tactile Touch Screen” using electrovibration
  - Static electric charge on whole screen, modulated relative to finger position
  - Modifies friction screen ↔ finger
  - Creates feeling of ridges & valleys
  - Only single-touch

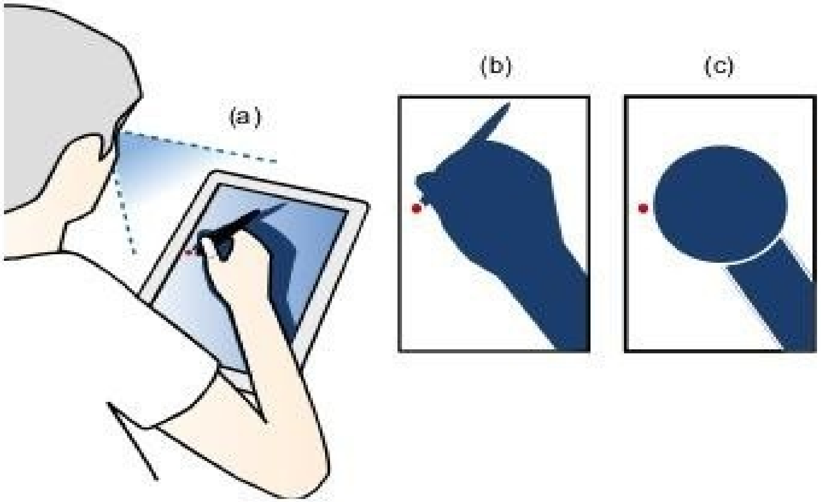


“Tactile Rendering of 3D Features on Touch Surfaces”, Kim et al., UIST 2013

Touch – occlusion (1)

Image source (FU): http://dl.acm.org/citation.cfm?id=1518787

- Create geometric model of user's hand/arm
- Use model to rearrange pop-ups etc.
- Rule of thumb: objects below/ right of touch point → higher chance of being overlooked

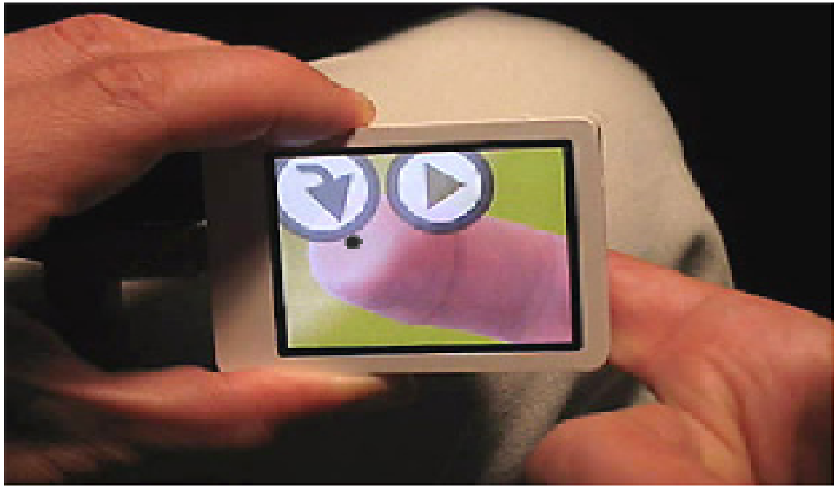


“Hand Occlusion with Tablet-sized Direct Pen Input”, Vogel et al., CHI 2009

Touch – occlusion (2)

Image source (FU): http://dl.acm.org/citation.cfm?id=1518995

- NanoTouch: back-of-device interaction
  - Second touch-/clickpad on device backside
  - “Virtual” finger shown on screen
    → illusion of “transparent” device
  - Enables very small screens

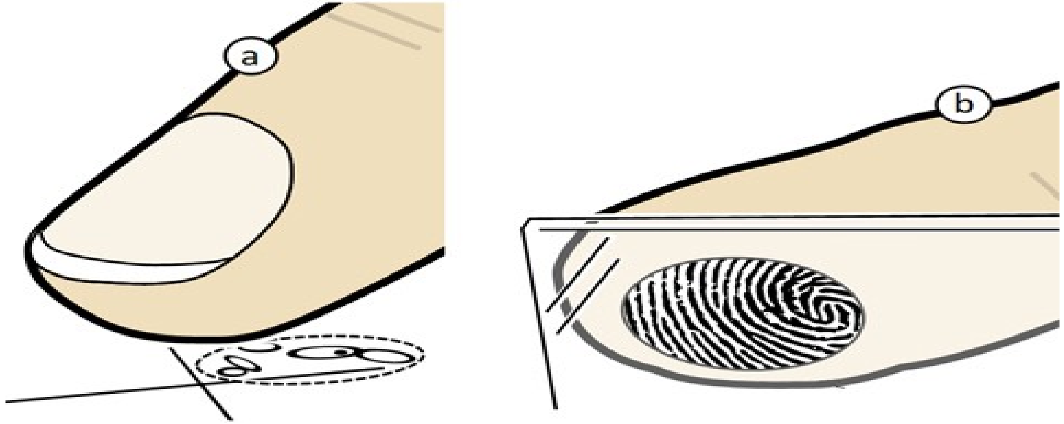


“Back-of-device Interaction allows creating very small touch devices”, Baudisch et al., CHI 2009

Touch – precision (1)

Image source (FU): http://dl.acm.org/citation.cfm?id=1753413

- "Perceived Input Point Model"
  - Different perception of touched point for different users and for different angles (a)
  - Possible solution: use high-resolution sensor (b) to extract fingerprints → detect touch angle → improve accuracy



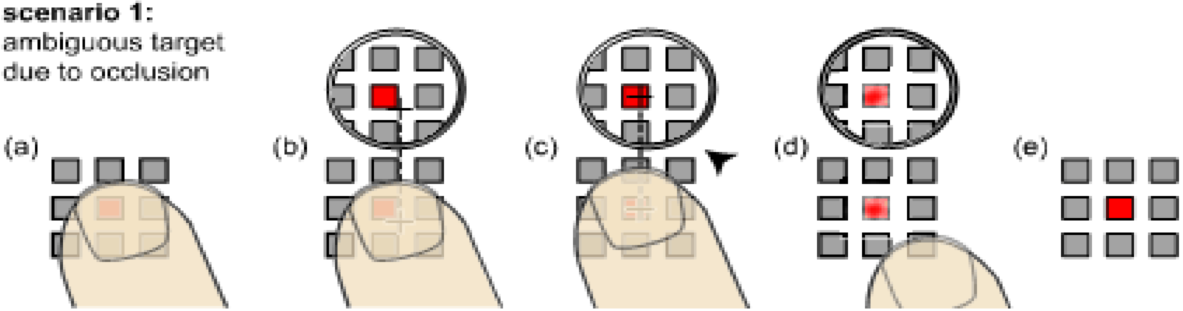
"The Generalized Perceived Input Point Model and How to Double Touch Accuracy by Extracting Fingerprints", Holz et al., CHI 2010

Touch – precision (2)

Right image source (FU): http://dl.acm.org/citation.cfm?id=1240727

- “Offset Cursor”: introduces fixed distance between touch point and actual target (e.g. Android selection handles, left)
- “Shift” - creates dynamic lens view over small targets (e.g. iOS text selection, right)

“Shift: A Technique for Operating Pen-Based Interfaces Using Touch”, Vogel et al., CHI 2007

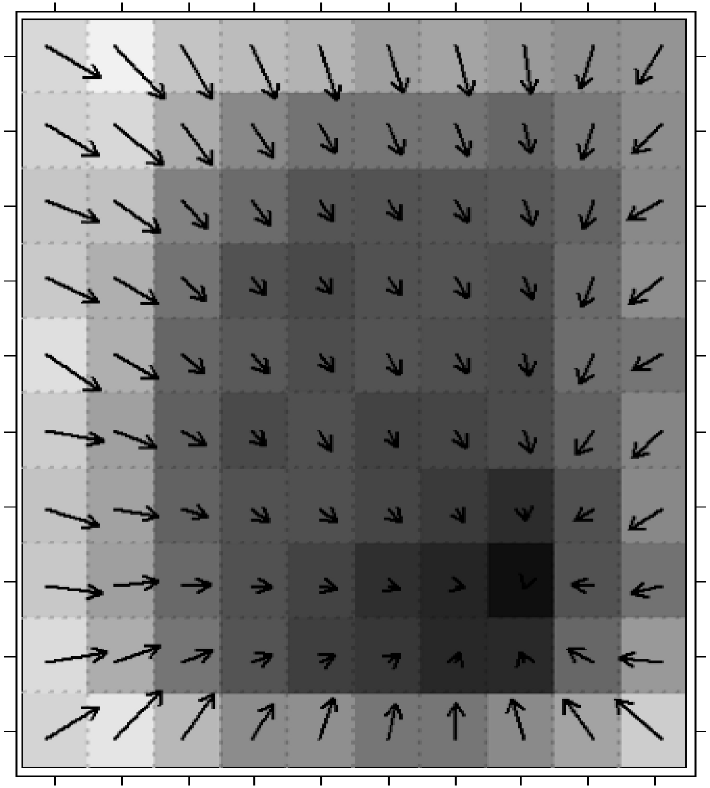


Touch – precision (3)

Image source (FU): https://dl.acm.org/citation.cfm?id=2037395

- “100 000 000 Taps”
  - Use mobile game to analyze high number of tap events
  - Create average offset maps for individual phone models
  - May still be context-specific

“100,000,000 taps: analysis and improvement of touch performance in the large”, Henze et al., MobileHCI 2011



Offset vectors for Samsung Galaxy S

Touch – reachability?

Image source (FU): https://www.androidauthority.com/note-3-one-handed-operation-how-to-280458/

- Problem for one-handed use
- Affects precision and reach
- Built-in “one-handed mode” (Android) or “reachability mode” (iOS)
- Precision still worse (why?)

Android

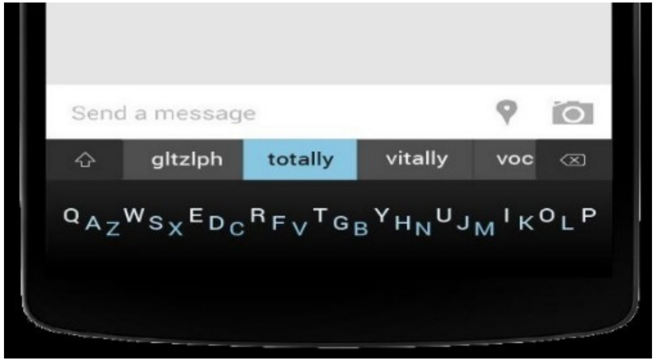
iOS

Touch – precision: keyboards

Image sources (FU): http://www.swype.com/, http://minuum.com/

- Less precise than physical keyboards

  → word prediction (WP) helps:
  - "classic" QWERTY + WP
  - Swiping across letters + WP (Swype/Swiftkey, left)
  - Single line of letters + WP (Minuum, right)



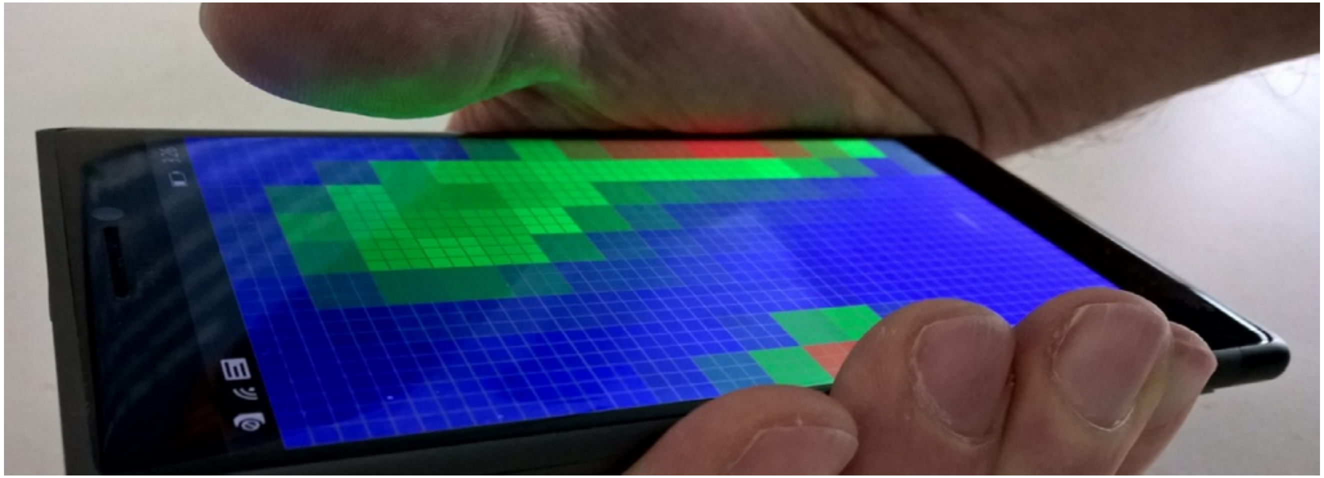
Touch – hover state (1)

- No hover state → “Midas Touch Problem”
- Also appears with some styli, eye tracking, …
- Solved by “lift-off strategy”
  - Touch down → screen starts giving feedback
  - Touch moves → continuous feedback
  - Touch up → action is triggered
- Developed in 1988, used everywhere now https://www.cs.umd.edu/hcil/touchscreens/

Touch – hover state (2)

Image source (FU): https://dl.acm.org/citation.cfm?doid=2858036.2858095

- "Pre-Touch Sensing"
  - Many capacitive screens *can* sense hover
  - Usually filtered out by touchscreen controller
  - Allows detection of hover, grip, touch force, ...



"Pre-Touch Sensing for Mobile Interaction", Hinckley et al., CHI 2016

Touch: summary

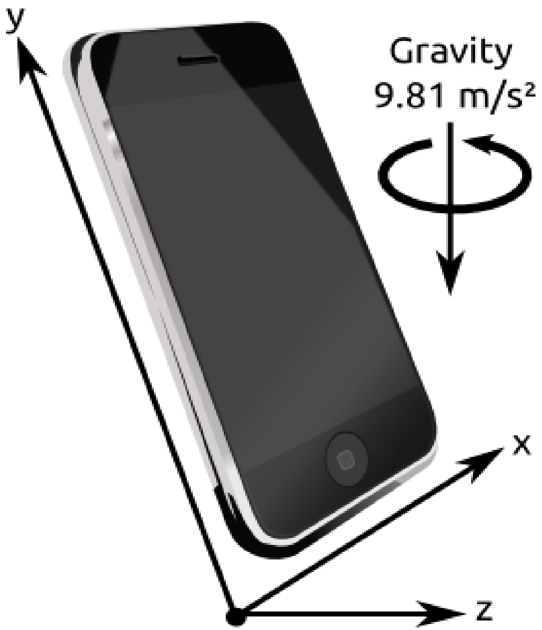
- Drawbacks ↔ Mouse:
  - Less precision
  - More occlusion
  - No hover state (mostly)
  - No haptic feedback
- 1:1 transfer of desktop UIs will almost certainly fail
- Needs new strategies

I/O issues: motion (recap)

- Motion as input
  - Motion of device: inertial measurement unit (IMU)
  - Motion of user: EMG, camera-based approaches
- Motion as output
  - Mostly vibration alerts (binary channel)
    - Extension: multiple vibration motors
  - Moving/shape-changing phones
  - Moving the user itself?

Motion input – device sensors (1)

- IMU (Inertial Measurement Unit) contains:
  - Accelerometer (3 axes/DOF*)
    - Measures acceleration, including gravity (“down”)
    - Cannot sense rotation around “gravity axis”



(*) DOF = Degrees Of Freedom

Motion input – device sensors (2)

- IMU (Inertial Measurement Unit) contains:
  - Magnetometer/compass (3 axes/DOF)
    - Measures earth's magnetic field (“north”)
    - Distorted by large metal objects, power lines etc.
  - Gyroscope (3 axes/DOF)
    - Measures rate-of-turn
    - Compensates sudden magnetometer errors

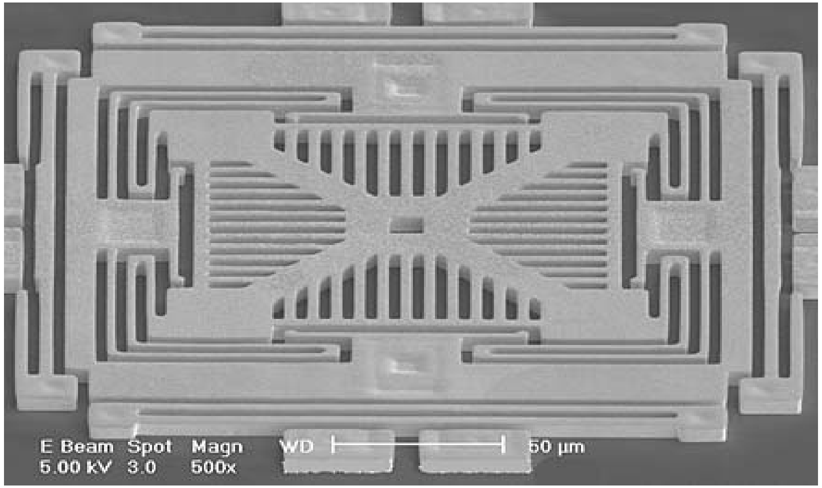
Motion input – device sensors (3)

- 9 total measurements → sensor fusion algorithm
→ 3 DOF absolute orientation
- Combine with position (GPS) → 6 DOF “pose”
- IMU data can also be used to estimate position *relative* to some starting point
- High power consumption for all 3 sensors
→ only accelerometer enabled by default,
at low update rate (~ 1 measurement/sec.)

Motion input – MEMS (1)

Image source (FU): http://archives.sensorsmag.com/articles/1203/20/fig1.jpg

- *MEMS* = Micro ElectroMechanical Systems
  - Microscopic springs, weights, actuators etc. etched on silicon wafer
  - Same manufacturing process as for regular ICs
    → directly integrated with read-out electronics



MEMS Accelerometer
(electron microscopy)

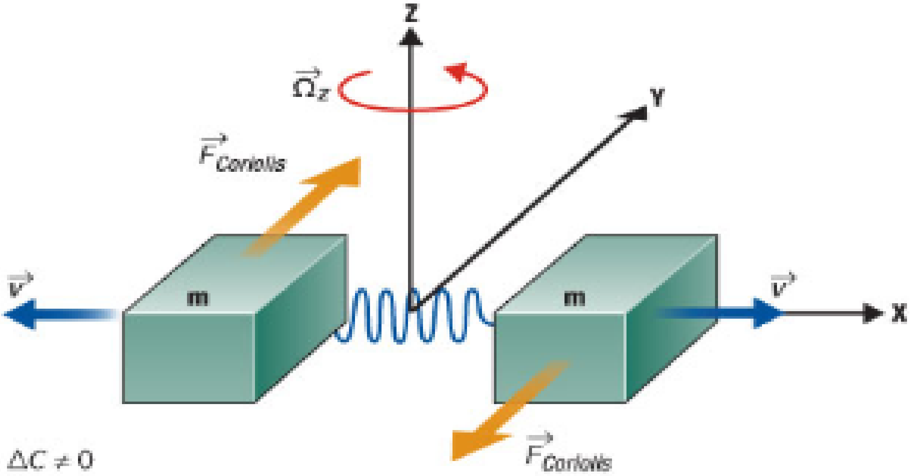
Motion input – MEMS (2)

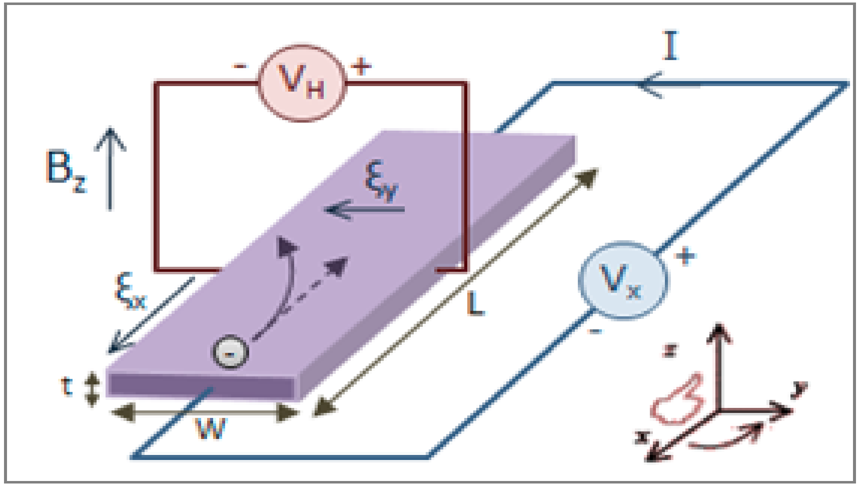
- Example measurements:
  - Force on spring-loaded weight → acceleration
    - Spring "stiffness" limits senseable range
  - Lateral force on vibrating weight → rotation
    - No rotating elements, despite "gyroscope" name
  - Hall effect current → magnetic field
    - Highly sensitive to stray magnetic fields, even from on-device power supply

Motion input – MEMS (3)

Image source (FU): http://electroiq.com/blog/2010/11/introduction-to-mems-gyroscopes/
Image source (PD): https://en.wikipedia.org/wiki/Hall_effect

- Vibrating Structure Gyroscope: measure lateral force $F_{Coriolis}$ (= asymmetric displacement) on vibrating weights
- Hall effect sensor: measure V_H induced by magnetic field B_Z





Motion input – MEMS calibration

See also: https://electronics.stackexchange.com/questions/22144/magnetometer-%E2%88%9E-shaped-calibration

- Magnetic field strength of earth constant
  → independent of measurement angle
- In reality: angle-dependent offset
  (aka “hard iron”/”soft iron” effects)
- 8-shaped movement used for calibration
  → cover as many different angles as possible
  → calculate offsets and compensate errors

Motion input – add-on controllers

Image sources: (CC) own picture, (FU) https://www.litho.cc/

- Many flavours, usually with buttons, touchpad, IMU, BTLE
- e.g. Daydream controller (l), Litho (r), many clones

Motion input – muscle sensing

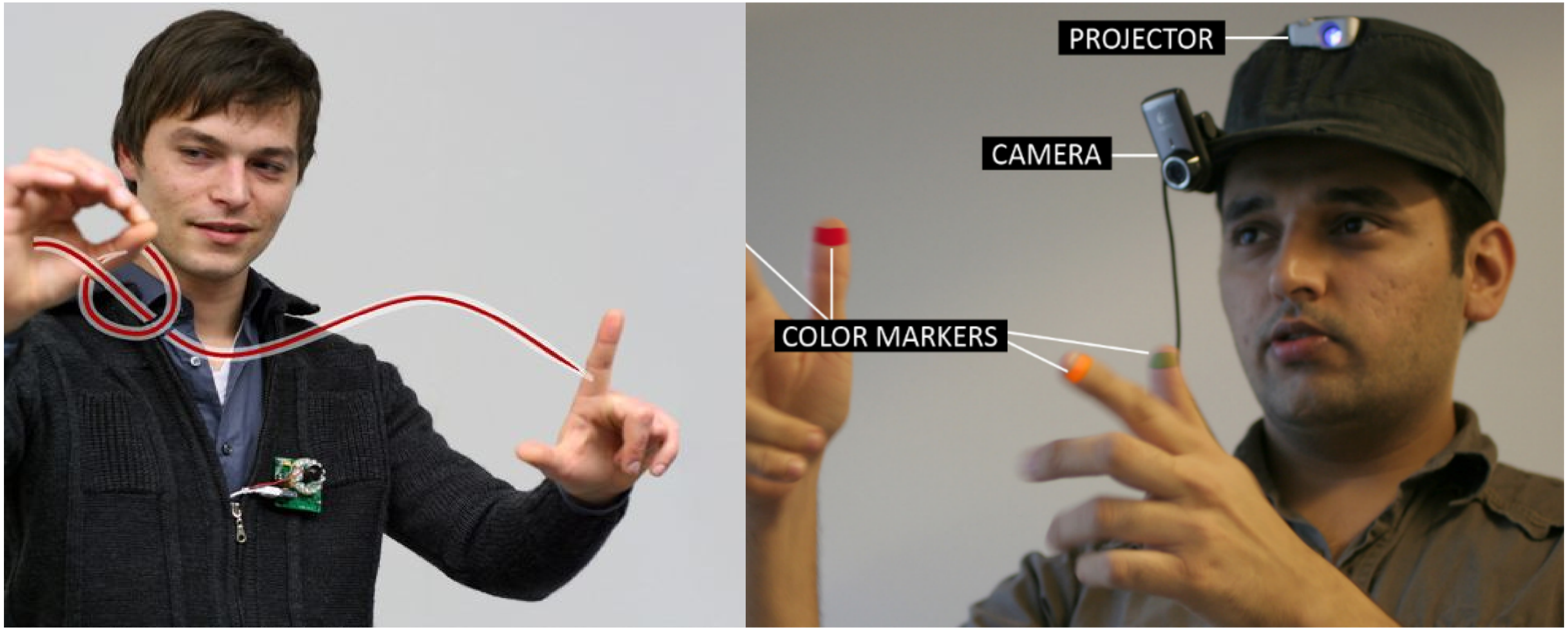
Image source (FU): https://www.thalmic.com/en/myo/

- Myo: EMG (electromyography) device
- Measures tiny electric currents created by muscle movement and tension
- Data can be used to infer hand/arm gestures
- Scenario: hands-free phone control

Motion input – free-air gestures

Image source (FU): http://dl.acm.org/citation.cfm?id=1866033, http://dl.acm.org/citation.cfm?id=1667160

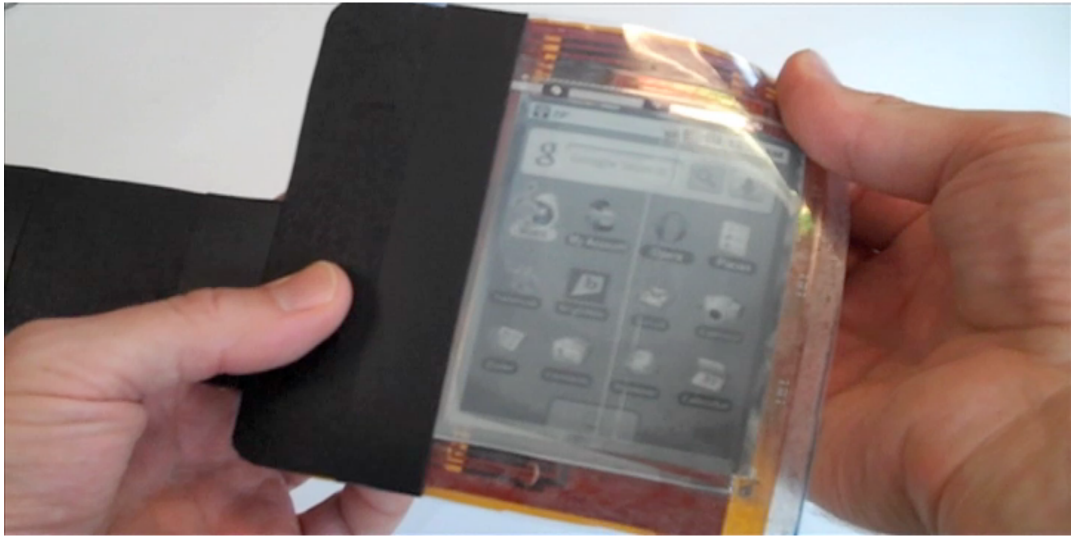
- Imaginary Interfaces (l) & SixthSense (r)
- Both based on body-worn cameras



Motion input – deformation

Image source (FU): https://dl.acm.org/citation.cfm?id=1979136

- PaperPhone: Bend Gestures in Mobile Devices
- Borrows metaphors from physical paper
  - Earmarking
  - Flipping pages
  - …

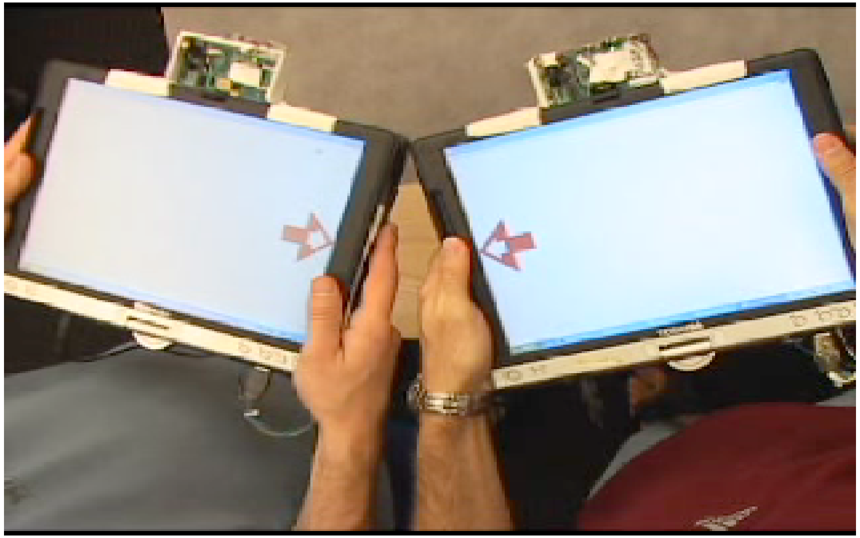


"PaperPhone: understanding the use of bend gestures in mobile devices with flexible electronic paper displays", Lahey et al., CHI 2011

Motion input – bumping

Image source (FU): http://research.microsoft.com/en-us/um/people/kenh/papers/ubicomp03abstract.pdf

- Bumping devices together creates connections/exchanges data
- Also (was) available as a contacts app
- How would you implement this?



"Bumping Objects Together as a Semantically Rich Way of Forming Connections between Ubiquitous Devices", Hinckley et al., Ubicomp 2003

Motion output – “Shoe me the way”

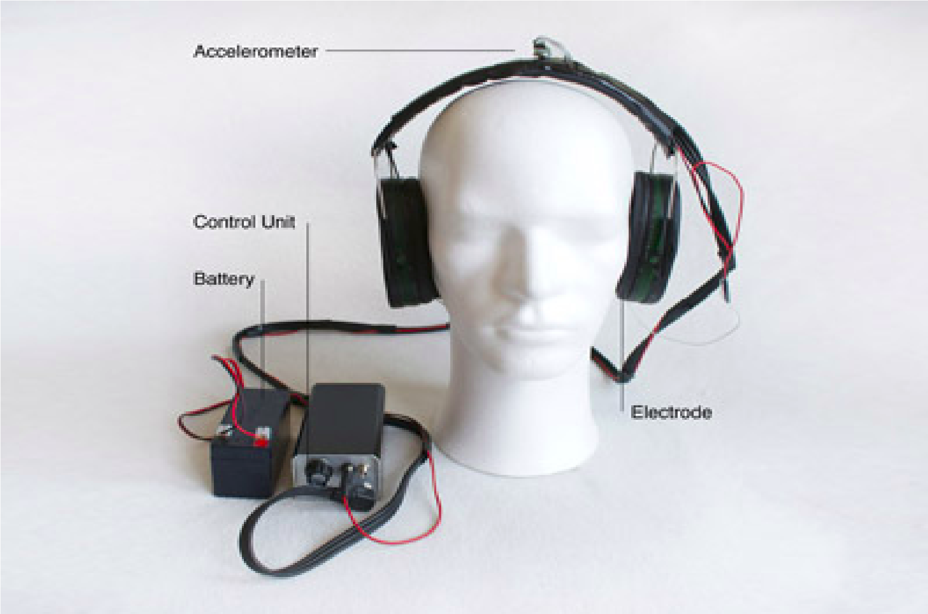
Image source (FU): “Shoe me the Way”, M. Schirmer et al., MobileHCI 2015

- Vibration output: only binary?
- Can still encode numerical information
- E.g. directions (left/right) → use multiple vibration sources as spatial cues
  - In shoes
  - On belt
  - On vest
  - ...

Motion output – user itself? (1)

Image source (FU): http://www.antalruhl.com/media_tech/gvs.htm

- Galvanic Vestibular Stimulation (GVS)
  - Low current stimulates inner ear
  - Affects sense of balance
  - Can (theoretically) be used for navigation and to compensate motion sickness in VR



Motion output – user itself? (2)

Image source (FU): https://dl.acm.org/citation.cfm?id=2481355

- Muscle-propelled Force Feedback
  - Electrodes cause involuntary muscle movement
  - Feels like force exerted by device on its own
- Issues:
  - Electrode attachment
  - Safety considerations

“Muscle-propelled force feedback: bringing force feedback to mobile devices”, Lopes et al., CHI 2013

Motion output – "breathing phone"

Image source (CC): http://www.fabianhemmert.com/projects/shape-changing-mobiles

- Change various parameters of mobile device
  - Shape, thickness, center of gravity, …
- Use them to convey "ambient information"
  - E.g. slow, regular breathing
    → no missed calls,
    no new texts

Motion: summary

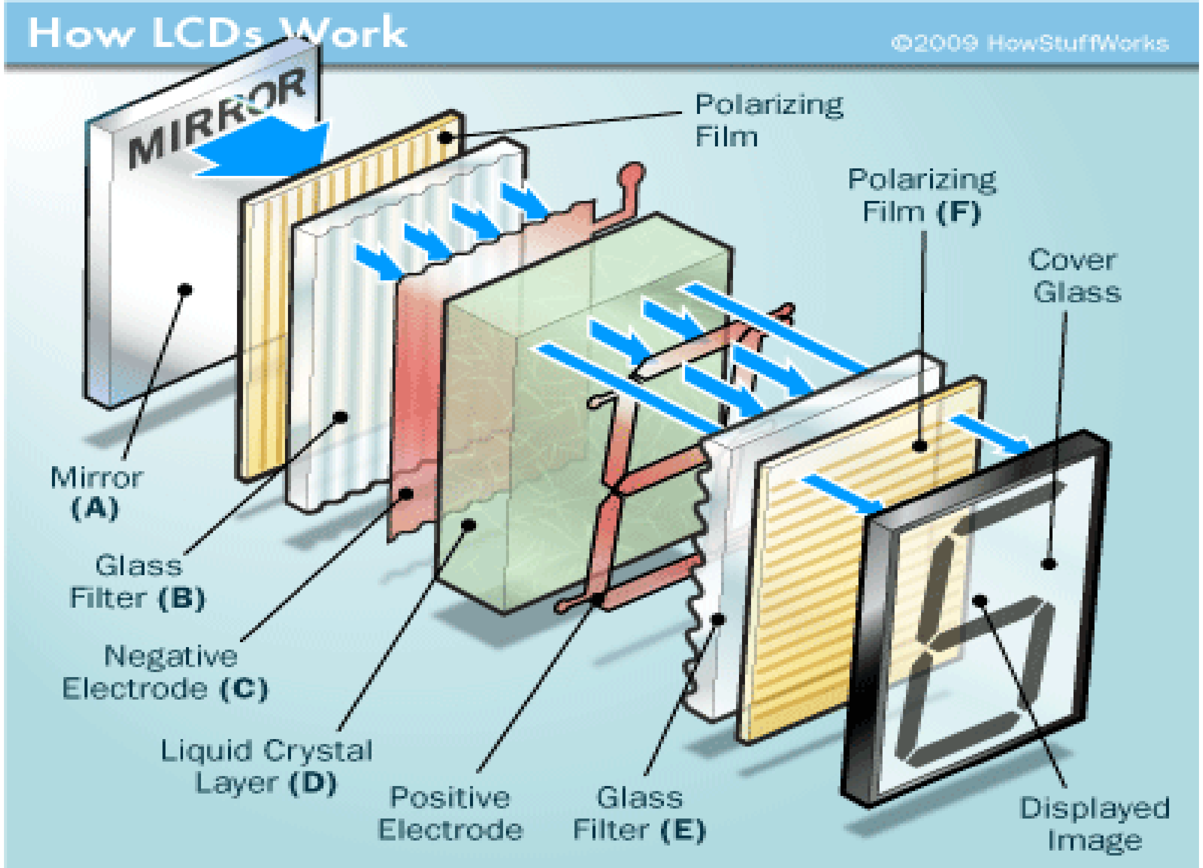
- Motion input:
  - Device motion sensed by 3-9 MEMS sensors
  - User motion sensed via device or camera
- Motion output:
  - Mostly vibration in commercial devices
  - Some weird/interesting research concepts

Visual output

- Preface: technology
  - LCD/AMOLED screens
  - E-Ink, 3D displays
- Information visualization

Visual output – Screens: LCD (1)

Image source (FU): http://electronics.howstuffworks.com/lcd2.htm



Visual output – Screens: LCD (2)

- LCD = Liquid Crystal Display
  - Requires constant power to operate
  - Monochromatic on its own → uses color filters
- Usually has own backlight across whole screen
  - Backlight competes with ambient light
    → bad sunlight readability
  - Display absorbs part of white light from backlight
  - Alternative: *transflective* LCD (can use environment light, but more complex/expensive → rarely used)

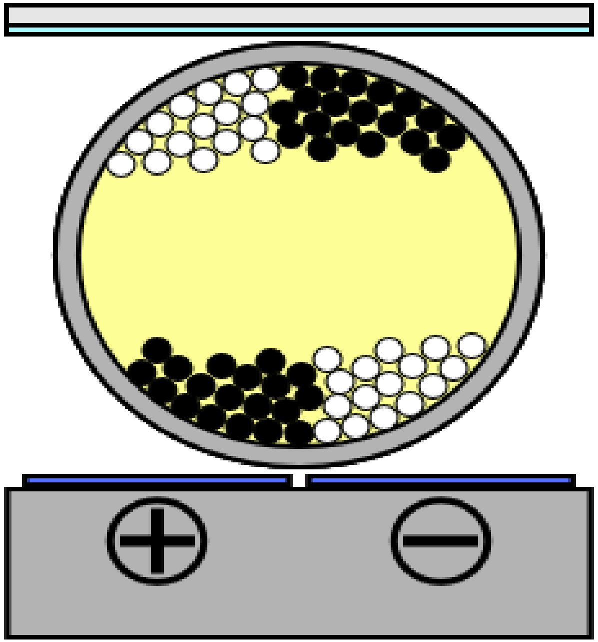
Visual output – Screens: AM(O)LED

- LCDs slowly replaced by AM(O)LED displays
  - Active Matrix (Organic) Light Emitting Diodes
  - Every pixel is a small light source on its own
  - Long-term lifetime issues
- Generally more efficient than LCDs
  - Only generates light which is actually required
  - Lower total brightness (currently)

Visual output – E-Ink displays

Image source (CC): https://commons.wikimedia.org/...Side_view_of_Electrophoretic_display%29_in_svg.svg

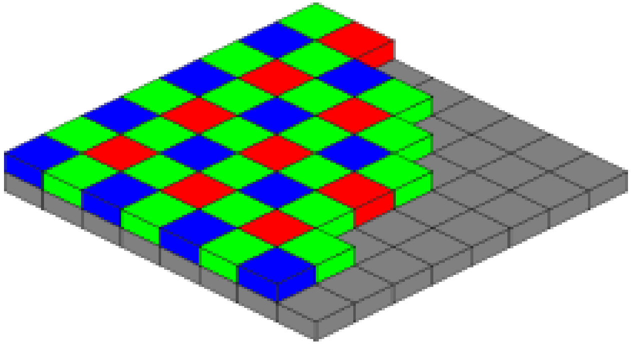
- Only particles on the top are visible
- Electric field moves white/black particles to the top
- No energy needed to keep images, only to change (bi-stable)
- High contrast, sunlight readable
- Drawback: too slow for video etc.

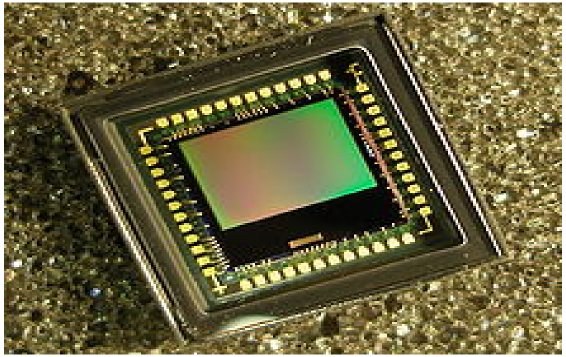


Visual input – camera

Image sources (CC): https://wikipedia.org/Charge-coupled_device, https://wikipedia.org/Active_pixel_sensor

- Hardware (right)
  - CCD – higher sensitivity, more expensive
  - CMOS/APS – cheaper, no global shutter (center)
- Only greyscale, uses Bayer color filter (left)
  - 2 x green pixels due to human eye sensitivity





Visual input – camera: barcodes

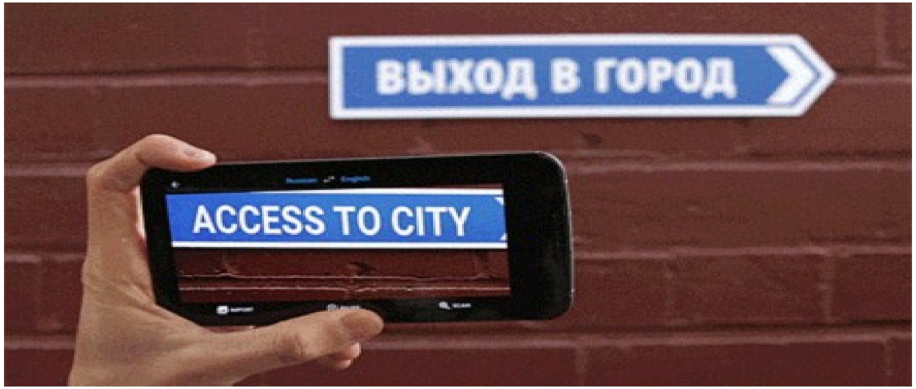
Image source (CC): https://en.wikipedia.org/.../File:Scanning_QR_codes_on_business_cards.jpg

- Two common types of barcodes:
  - EAN product codes (linear, little data, ~ 15 chars)
  - QR codes (2D, up to 3 kB, error correction)
- (Relatively) simple computer vision problem
- “Barcode Scanner” app
  - Can be integrated into own apps as module

Visual input – camera: OCR

Image source (FU): http://cdn1.theweek.co.uk/.../public/9/26/150116-google-translate_0.jpg

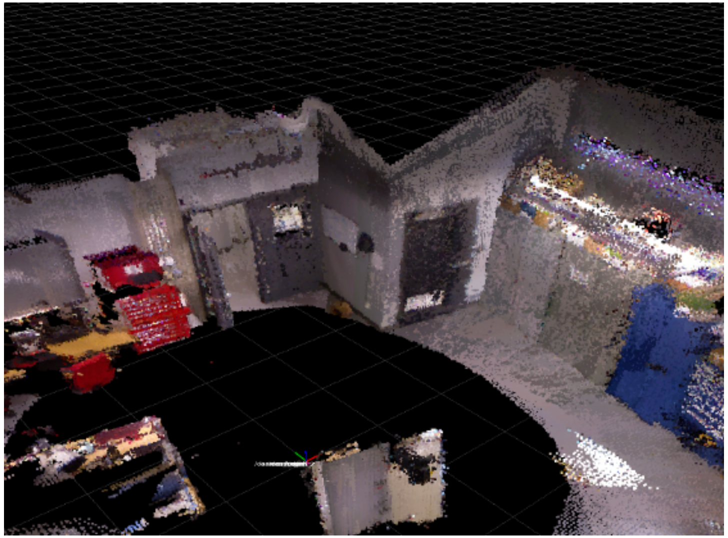
- OCR = Optical Character Recognition
- Complex CV problem (different fonts etc.)
- Can be used to …
  - Scan & *index* documents (just scanning doesn't require OCR)
  - Translate foreign languages (cf. Augmented Reality)



Visual input – camera: SLAM

Image source (FU): https://code.google.com/p/rtabmap/wiki/SLAMDemo

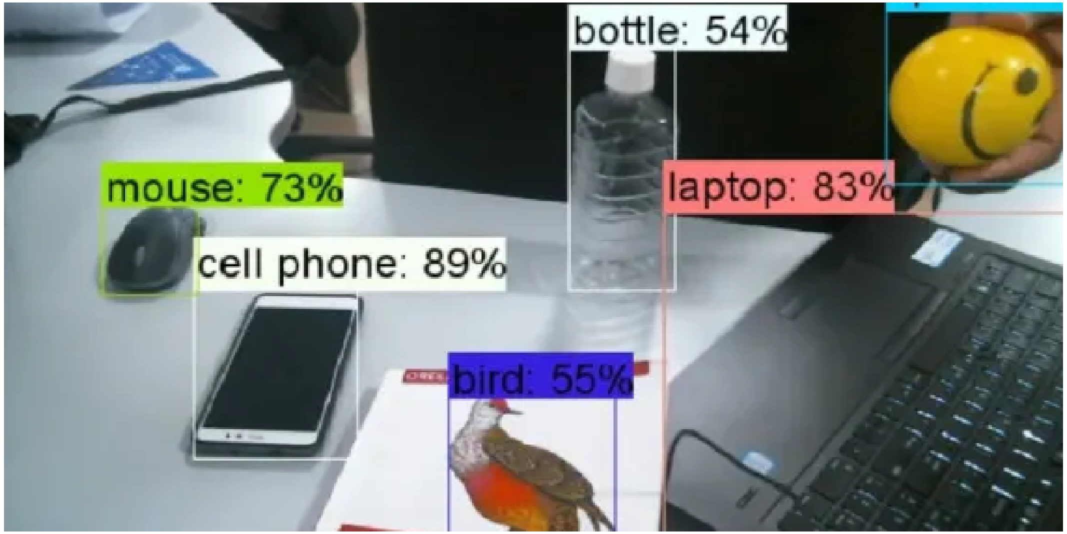
- SLAM = Simultaneous Location And Mapping
  - Creates 3D environment map on-the-fly …
  - … and locates device relative to map
- Usage scenarios:
  - “Inside-out”: device moves within environment → map
  - “Outside-in”: devices moves around object → 3D scan



Visual input – camera: object detection

Image source (FU): https://www.youtube.com/watch?v=MoMjIwGSFVQ

- Usually based on CNN (Convolutional Neural Network)
- Training/learning phase: offline on GPU cluster with large dataset, 10 000+ images with ground-truth labels
- Inference phase: on mobile device, also GPU/TPU accelerated
- CNN needs to be for mobile Tensorflow Lite)



Visual I/O – Touch Projector

Image source (FU): https://dl.acm.org/citation.cfm?id=1753326.1753671

- All-in-one approach:
  - Multi-screen visual output
  - Visual + touch input
- Touches on mobile device are "projected" onto larger screen

"Touch projector: mobile interaction through video", Boring et al., CHI 2010

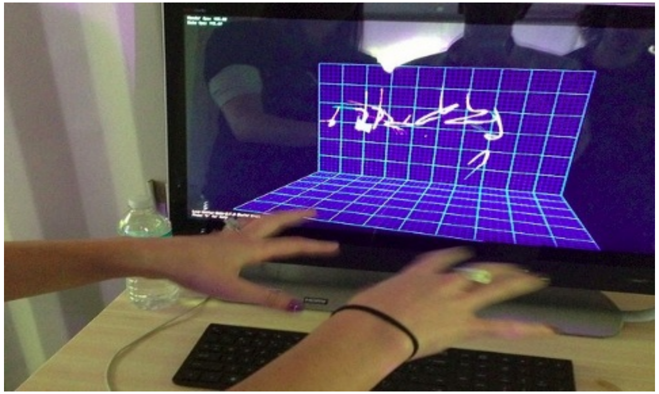
I/O issues: other channels

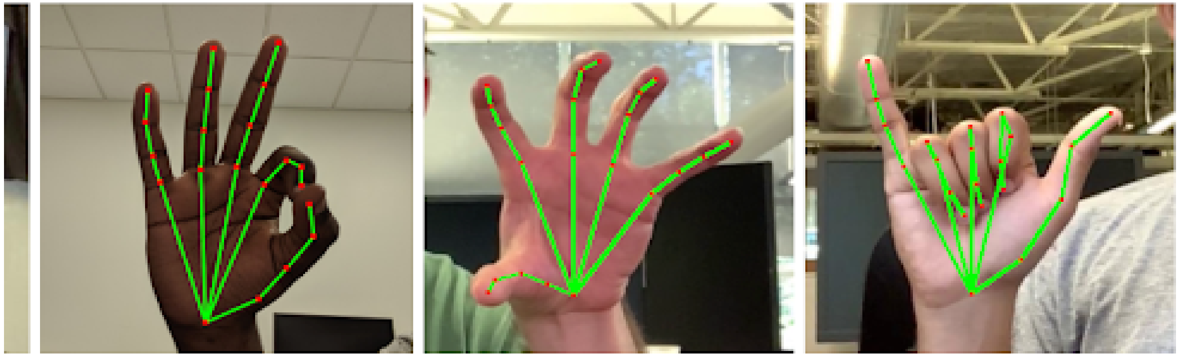
- Bio sensors
  - Fingerprint, heart rate, skin conductivity
  - Privacy issues?
- Spoilt for choice? Too “exotic” for user?

Other channels – Hand/Body Stance

Image source (CC): https://www.flickr.com/photos/davidberkowitz/8598269932/
Image source (FU): https://ai.googleblog.com/2019/08/on-device-real-time-hand-tracking-with.html

- Complex model of human skeleton required
  - Computationally intensive
  - Needs external sensors (e.g. Leap Motion – left) or CNN (right)

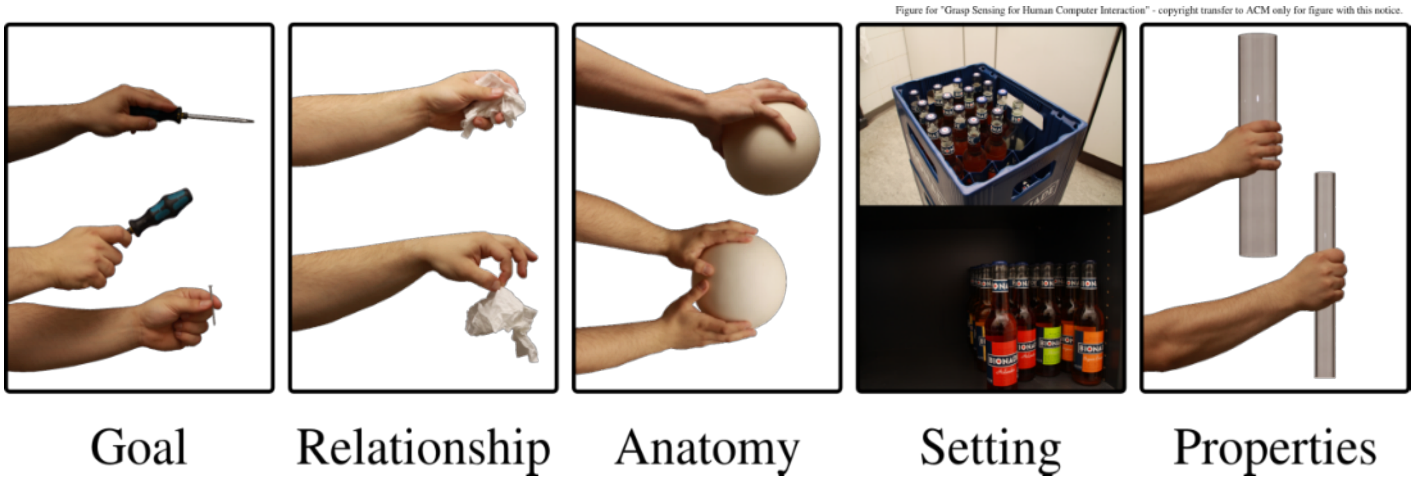




Other channels – Grasp

Image source (FU): https://dl.acm.org/citation.cfm?id=1935701.1935745

- Alternative to full body stance: grasp shape
  - Can use *on-device* sensing (capacitive/optical)
  - Enables conclusions about many facets of context

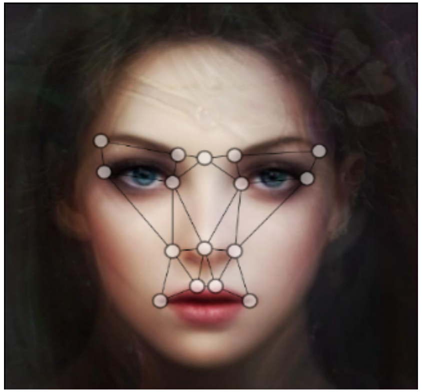


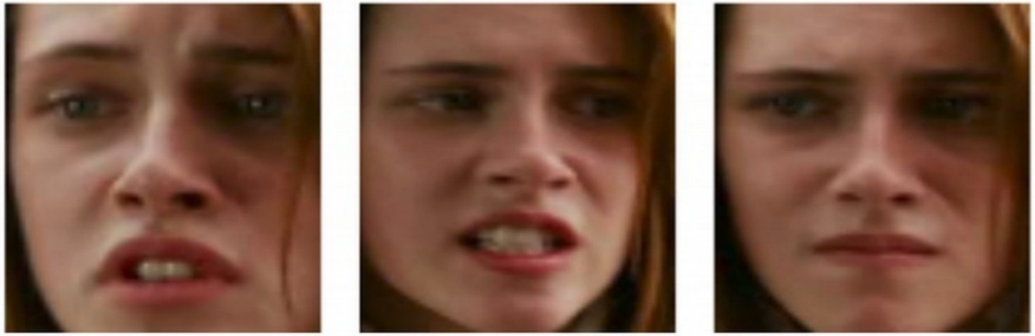
“Grasp sensing for human-computer interaction”, Wimmer et al., TEI 2011

Other channels – facial expression

Image source (CC): https://www.flickr.com/photos/averageface/8260432583/
Image source (FU): https://cvhci.anthropomatik.kit.edu/publications_924.php

- Active area of research in computer vision
  - Still unreliable for multiple different persons
  - Context issues: lighting, motion?
- Usage: mood (= context) detection, security





(a) sad (b) anger (c) disgust

Other channels – facial expression

Image source (FU): https://static.giga.de/wp-content/uploads/2017/11/animoji-iphone-x.png

- *Interpretation* of facial expression is difficult (even for humans)
- *Mapping* to an avatar is easier ("Animoji")
- Usually also solved with CNN to detect feature points in face

Other channels – eye/gaze tracking

Image source (CC): https://www.flickr.com/photos/smieyetracking/14970688193/
Image source (CC): https://www.flickr.com/photos/andyed/387442396/

- Dedicated device or integrated into phone
  - Determines gaze direction of user (i.e. also provides pointing device, attention level)
  - Also: concentration level (pupil dilation, saccade frequency = involuntary eye movements)

Other channels – Heart rate/ECG

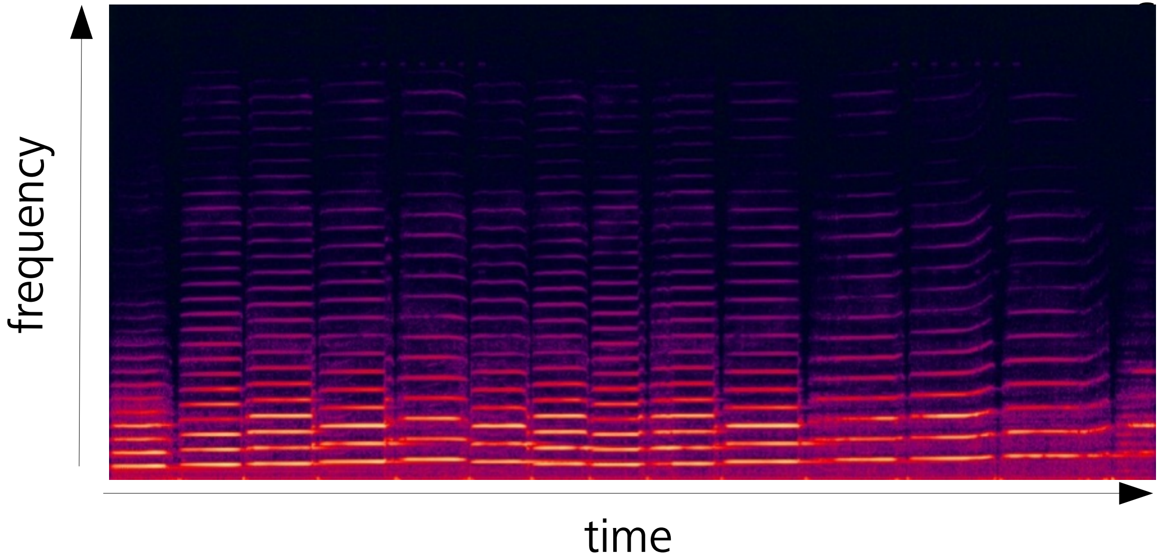
Image source (PD): https://commons.wikimedia.org/wiki/File:Wrist-oximeter.jpg

- Heart rate/blood oxygen saturation can be measured using IR light (pulse oximeter)
- Built into recent smartwatches/fitness bands
- Even possible with smartphone camera! (How?)

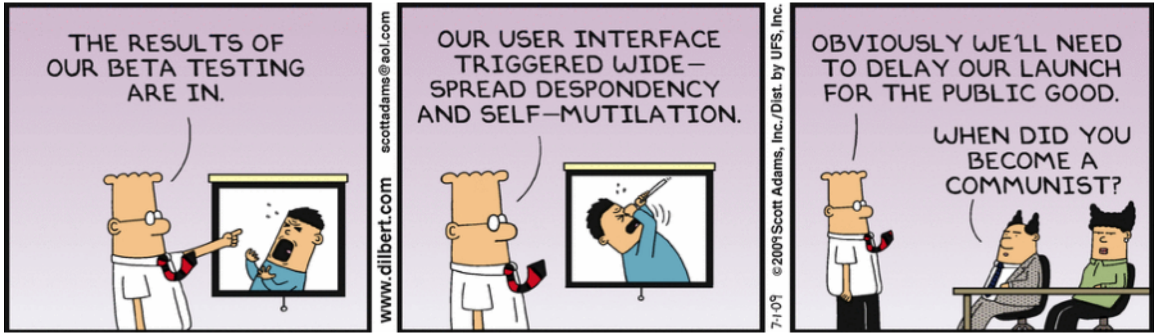
Other channels – sound input (*not* speech)

Image source (CC): https://en.wikipedia.org/wiki/File:Spectrogram_of_violin.png

- e.g. whistling ("keyfinder")
- Music recording (Shazam etc.)
- Generally based on *fast Fourier transform* (FFT)
- Creates "fingerprint" audio data, com- with database



The End


THE RESULTS OF OUR BETA TESTING ARE IN.
scottadams@aol.com
www.dilbert.com
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