MMI 2: Mobile Human-Computer Interaction

Sensor-Based Mobile Interaction

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Lectures

#	Date	Topic
1	19.10.2011	Introduction to Mobile Interaction, Mobile Device Platforms
2	26.10.2011	History of Mobile Interaction, Mobile Device Platforms
3	2.11.2011	Mobile Input and Output Technologies
4	9.11.2011	Mobile Input and Output Technologies, Mobile Device Platforms
5	16.11.2011	Mobile Communication
6	23.11.2011	Location and Context
7	30.11.2011	Mobile Interaction Design Process
8	7.12.2011	Mobile Prototyping
9	14.12.2011	Evaluation of Mobile Applications
10	21.12.2011	Visualization and Interaction Techniques for Small Displays
11	11.1.2012	Mobile Devices and Interactive Surfaces
12	18.1.2012	Camera-Based Mobile Interaction
13	25.1.2012	Sensor-Based Mobile Interaction
14	1.2.2012	Application Areas
15	**8.2.2012**	**Exam**

Aktuelles

- Klausur am 8.2.2012
  - Anmeldung
- Fragen zur Klausur
  - jeweils zu Beginn der Vorlesungen

Review

- Problems of mobile UIs that use image recognition?
- What is mobile tagging? Example applications?
- Why need to resolve identifiers?
- Characteristics of marker recognition?
- How do image recognition algorithms work that are based on interest points?
- Why is target acquisition with camera phones more challenging than with the mouse?

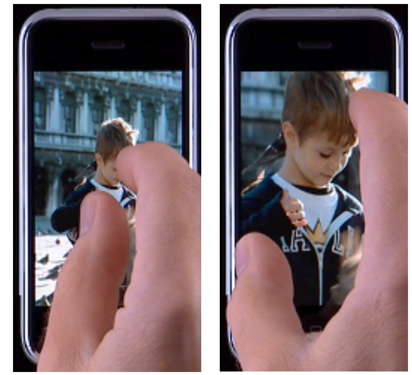
Preview

- Sensors for mobile devices

MOBILE SENSORS

Sensors in Current Mobile Devices

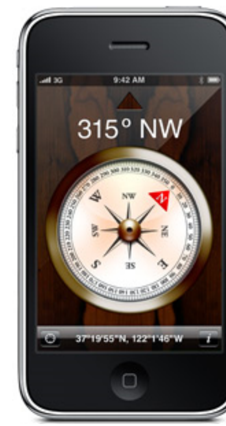
- Multi-touch display or keypad
- GPS sensor (location)
- Accelerometer (orientation)
- Magnetometer (heading)
- Distance sensor (proximity)
- Ambient light sensor (brightness)
- RFID/NFC readers (tags)
- Camera



Multi-touch (“pinch”)

GPS Receiver

Accelerometer

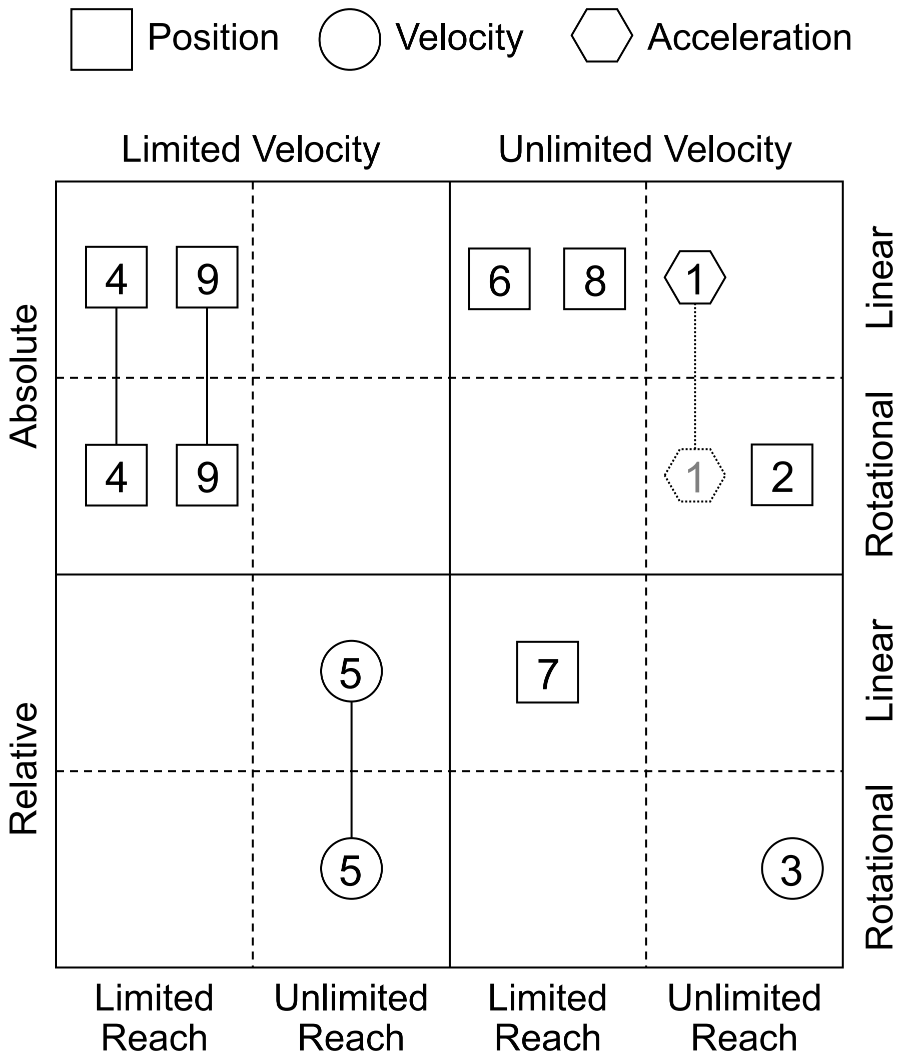


Magnetometer

Sensors that Might be Used in Mobiles

- Motion sensors
  - Accelerometer
  - Magnetometer (compass)
  - Gyroscope (rotation)
  - Tilt sensor
- Force / pressure / strain
  - Force-sensing resistor (FSR)
  - Strain gauge (bending)
  - Air pressure sensor
  - Microphone
- Position
  - Infrared range sensor (proximity)
  - Linear and rotary position sensors
- Light sensors
- Temperature sensor
- Humidity sensor
- Gas sensor

Design Space for Sensors in Mobiles



1. Accelerometer [m/s^2]
2. Magnetometer [Gauss]
3. Gyroscope [degree/s]
4. Visual marker tracking
5. Visual movement detection
6. Touch screen
7. Touch pad
8. Capacitive proximity sensor
9. Camera-based map tracking

Technical Characteristics of Sensors

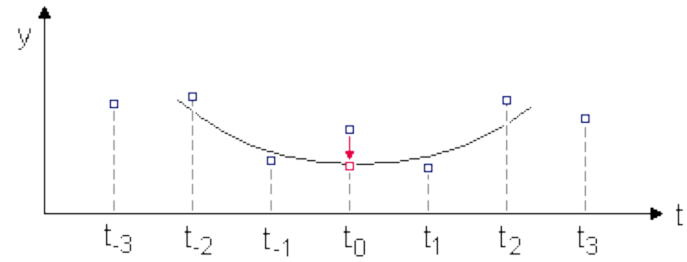
- Other dimensions relevant for interaction
  - Resolution / precision
  - Accuracy
  - Sample rates
  - Delay
  - Range
  - Noise
  - Reliability
  - Cost

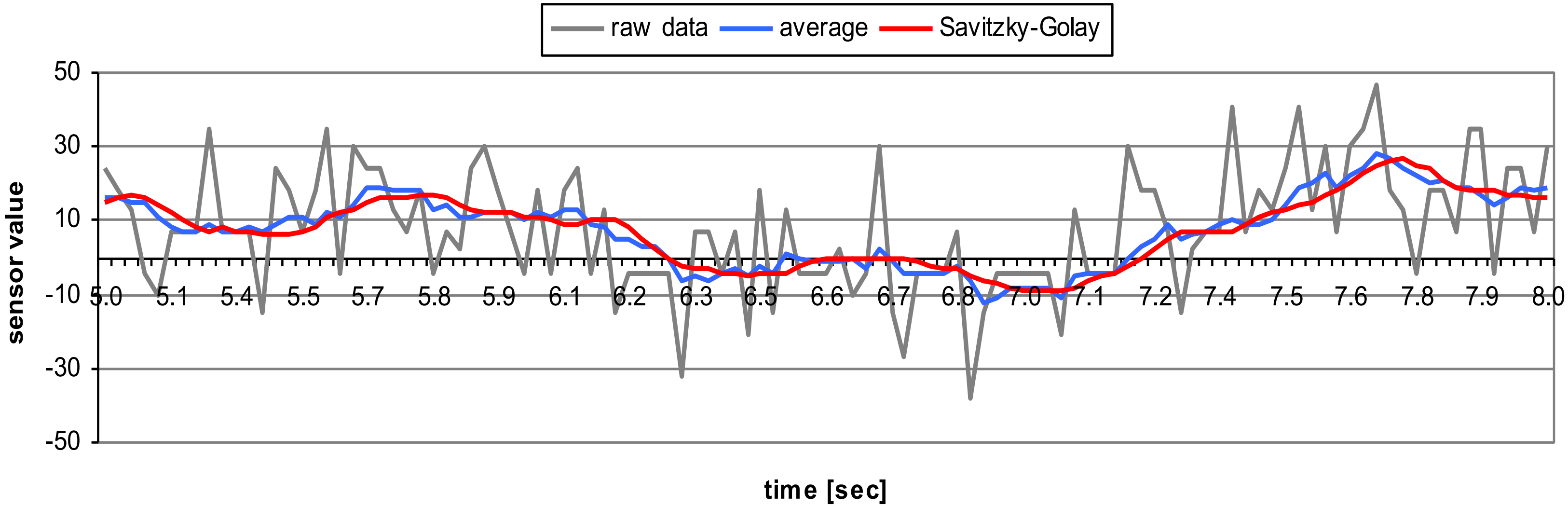
Name	Context	Constraints	Cost	Commodity
Accelerometer	Jolt-free environments	Drift	Low	Beginning
Magnetometer	Low EMI	Requires calibration	Low	Low
Gyroscope	Any	N/A	High	Very Low
Marker tracking	Sufficient lighting	Distance, range	Medium	High
Movement detection	Sufficient lighting	Velocity, drift	Medium	High
Touch screen	Any	Screen size	Medium	High
Capacitive proximity	Low EMI	Drift	Low	Low

Name	Type	Resolution	Sample Rates	Range	Noise	Reliability
Accelerometer	Electromechanical	High (1 mg [7])	0.5-2 kHz	± 6g	Low	High
Magnetometer	Electromagnetic	High (1 mGauss [7])	1 kHz	± 2 Gauss	Medium	Medium
Gyroscope	Electromechanical	High (0.1 deg/s [7])	≥ 1 kHz	± 500 deg/s	Low	High
Marker/grid tracking	Optical	High [11]	15-30 Hz	$150 \times 150 \times 30$ cm	Low	High
Movement detection	Optical	Medium [11]	15-30 Hz		Medium	Low
Touch screen	Electromechanical	High		4×5 cm	Low	High
Capacitive proximity	Electrostatic	High	1 kHz [7]	0-10 mm	Low	Medium

Sensor Data Filtering

- Savitzky-Golay filters
  - Efficient
  - Retain peaks better than sliding average
  - Fit data values to a polynomial
  - Convolution with fixed integer coefficients
- Tradeoff: More filtering usually means more delay



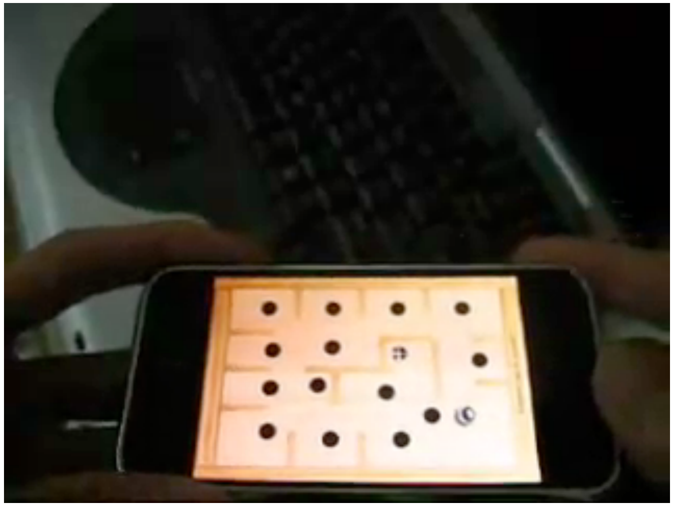


ACCELEROMETERS

Accelerometer Uses

http://www.youtube.com/watch?v=Wtcys_XFnRA

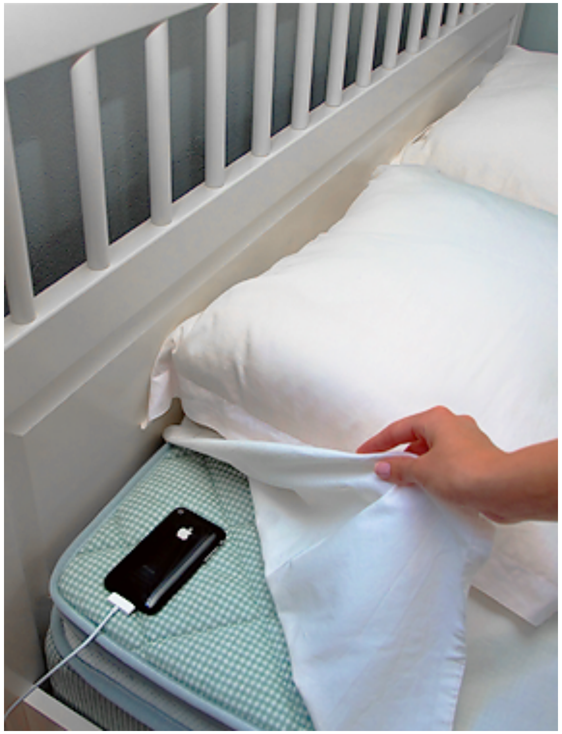
http://www.youtube.com/watch?v=Hh2zYfnvt4w

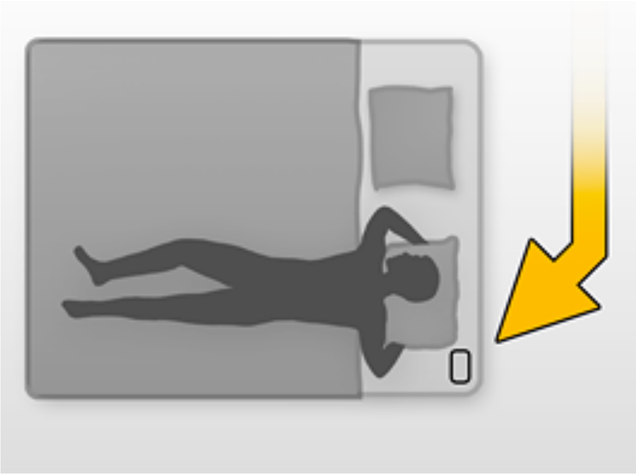


http://www.youtube.com/watch?v=KymENgK15ms

Accelerometers
Health & Fitness: "Sleep Cycle"

- Uses accelerometer to monitor movement during sleep
- Uses motion to find best time to ring alarm
  (within 30 min window)





Shoogle: Shaking Mobile Phones Reveals What's Inside

- Accelerometer input
- Sonification
- Vibrotactile display

Figure 2. The wireless SHAKE sensor, shown with a 2 Euro piece for size comparison. This Bluetooth device comprises a complete inertial sensing platform.

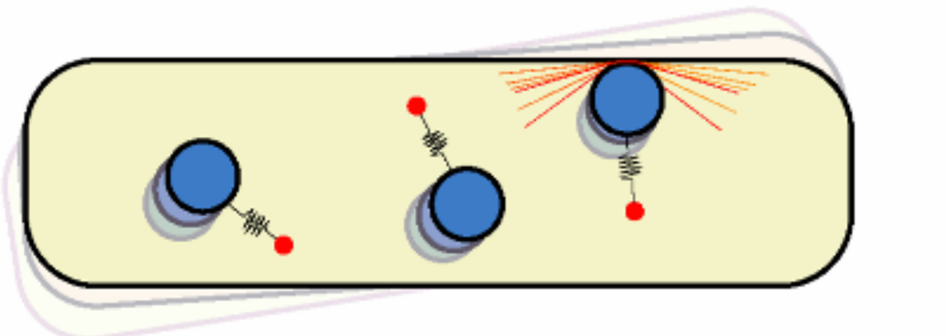


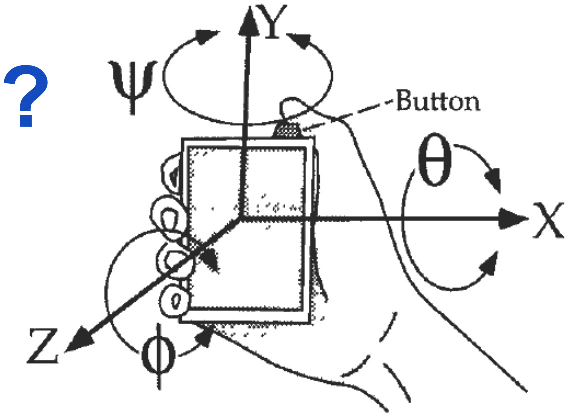
Figure 3. The simulated system. A number of balls, anchored via springs, bounce around within the virtual container. When they impact (as in the top right) sound and vibration are generated.

John Williamson, Dynamics and Interaction Group, Glasgow University

Shoogle: Shaking Mobile Phones Reveals What's Inside

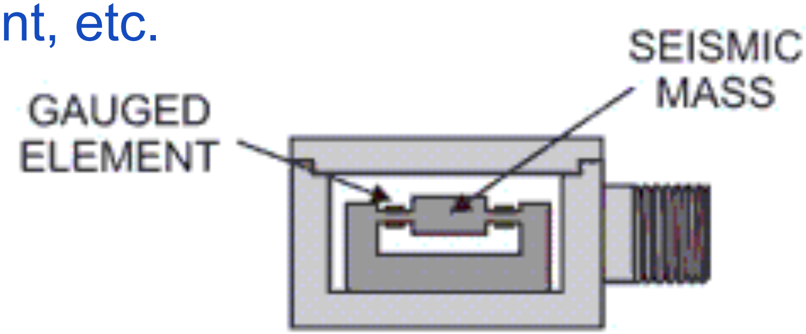
http://www.youtube.com/watch?v=AWc-j4Xs5_w

How do Accelerometers work?



Source: Rekimoto: Tilting Operations for Small Screen Interfaces, 1996

- Measure acceleration
  - Change of velocity
- Causes of acceleration
  - Gravity, vibration, human movement, etc.
- Typically three orthogonal axes
  - Gravity as reference

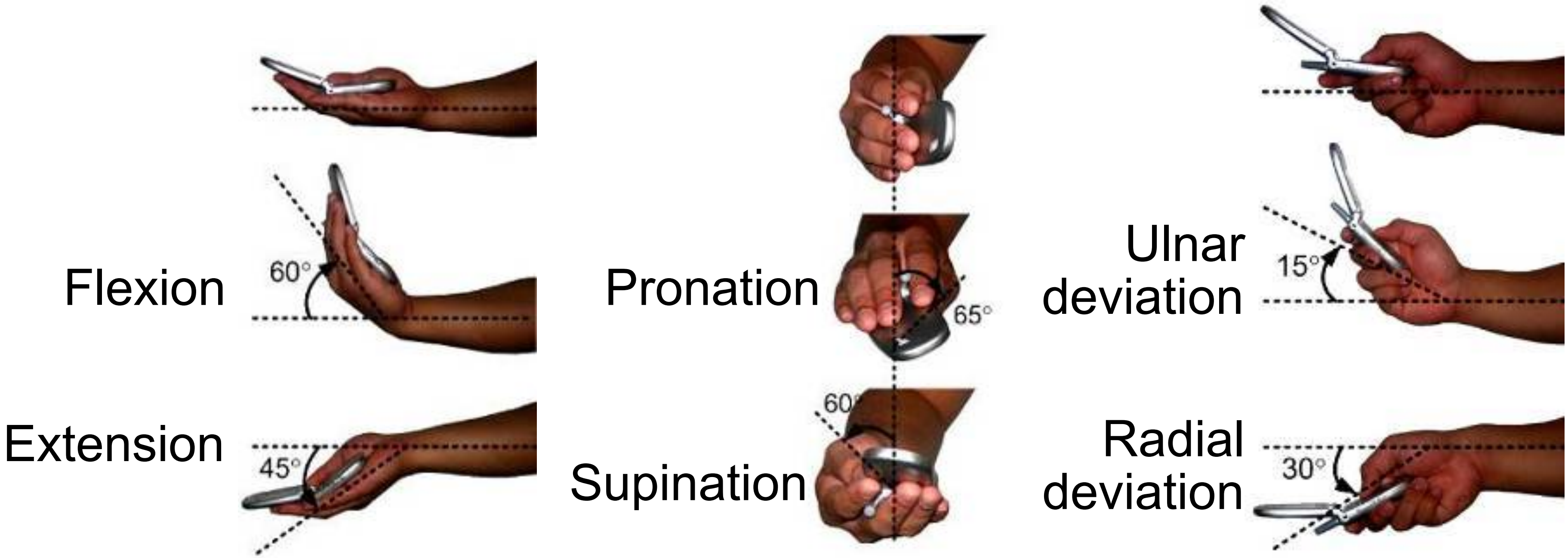


- Operating principle
  - Conceptually: damped mass on a spring
  - Typically: silicon springs anchor a silicon wafer to controller
  - Movement to signal: Capacitance, induction, piezoelectric etc.
- Derive position by integration
  - Problem: drift

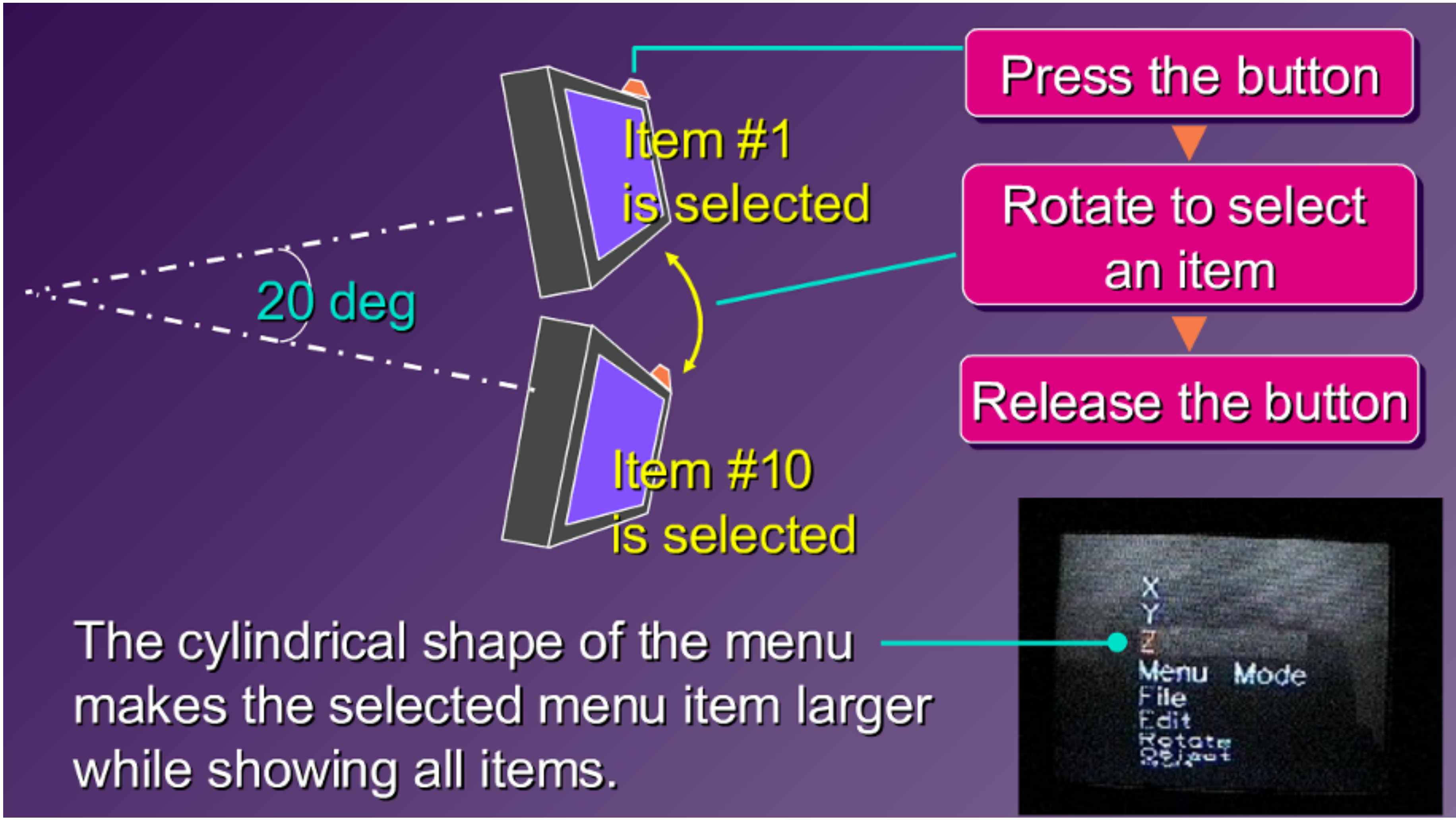
Ergonomics of Wrist-Based Input

- Accuracy
  - Within 2° for menu selection (Rekimoto)
- Range of wrist motion
  - Flexion / extension: 105°
  - Pronation / supination: 125°
  - Ulnar / radial deviation: 45°

Illustrations: Rahman, Gustafson et al.: Tilt Techniques: Investigating the dexterity of wrist-based input. CHI 2009.

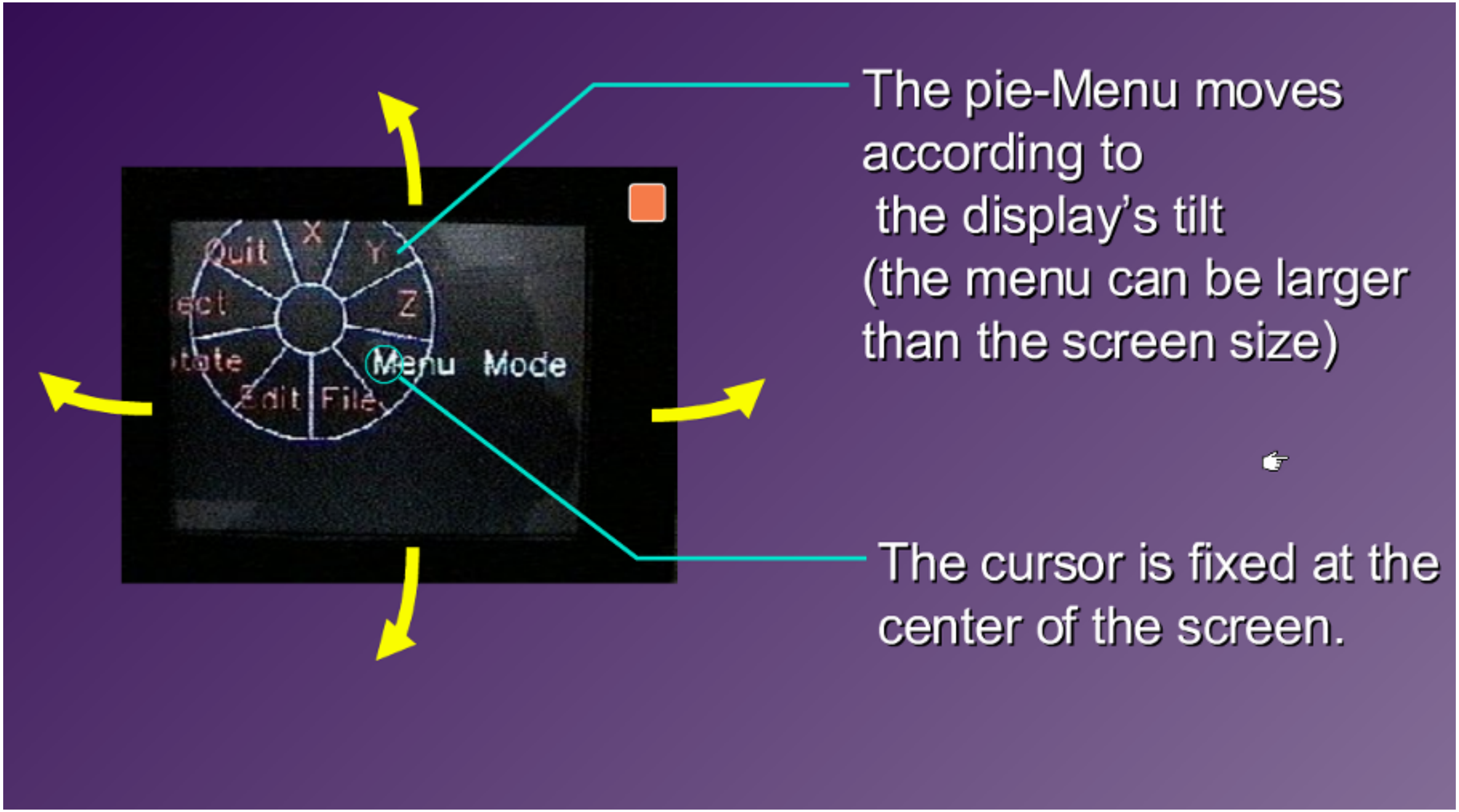


Example: Rekimoto's Tilting Menu



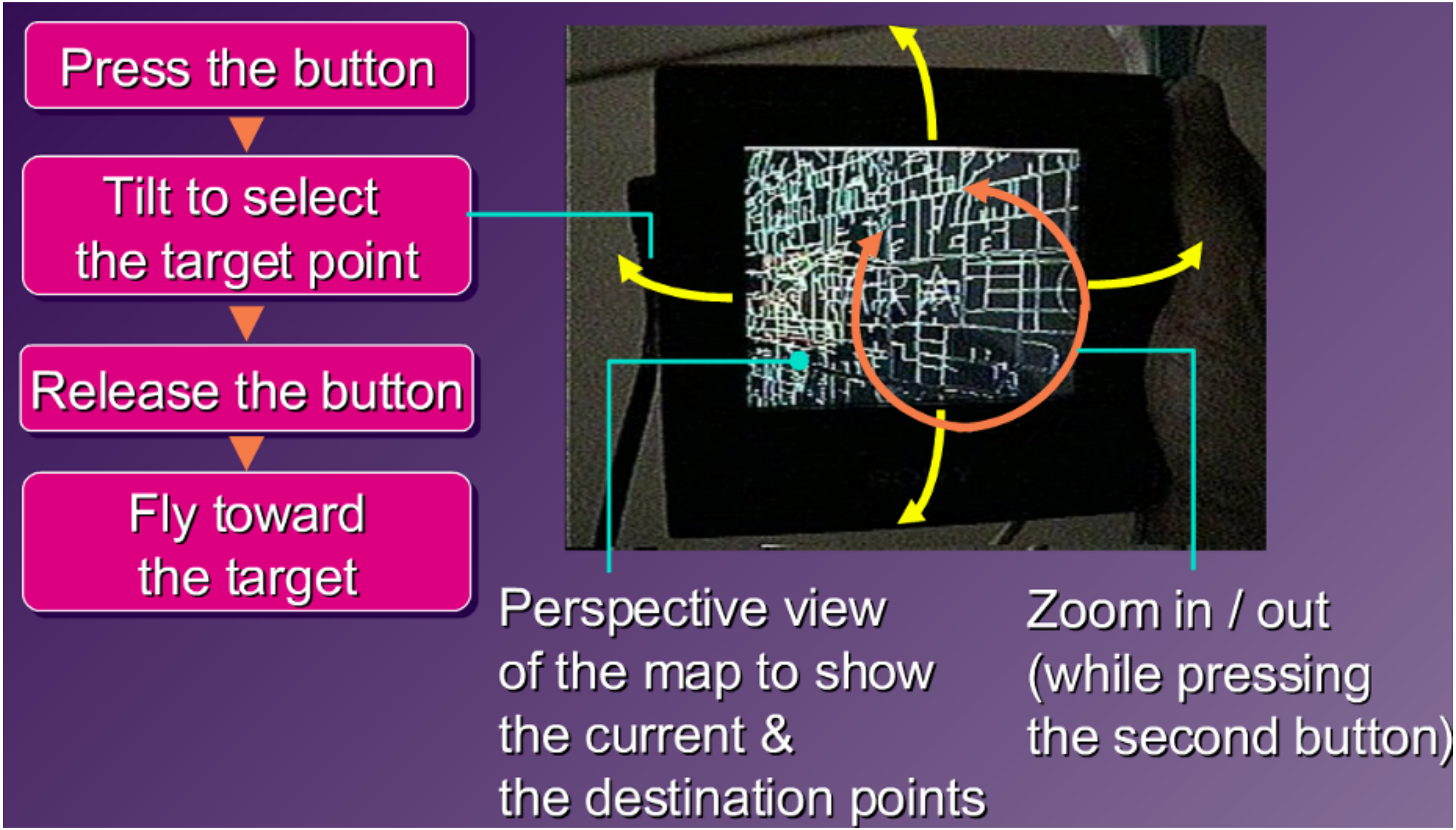
Source: Jun Rekimoto, UIST 1996

Example: Rekimoto's Tilting Pie Menu



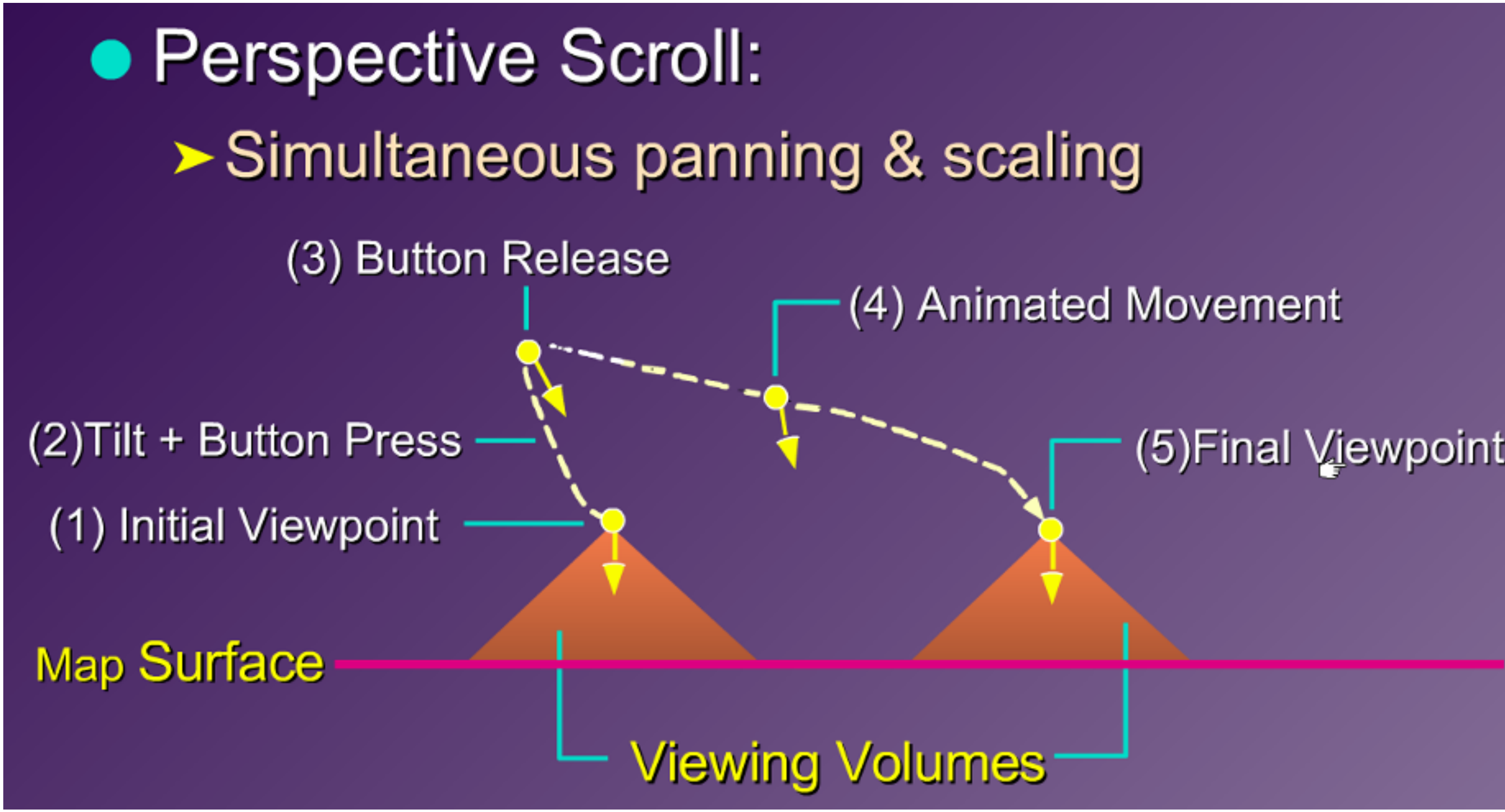
Source: Jun Rekimoto, UIST 1996

Example: Rekimoto's Tilting Map Browser



Source: Jun Rekimoto, UIST 1996

Example: Rekimoto's Tilting Map Browser



Source: Jun Rekimoto, UIST 1996

Throw and Tilt: Mapping Gestures to Meaning

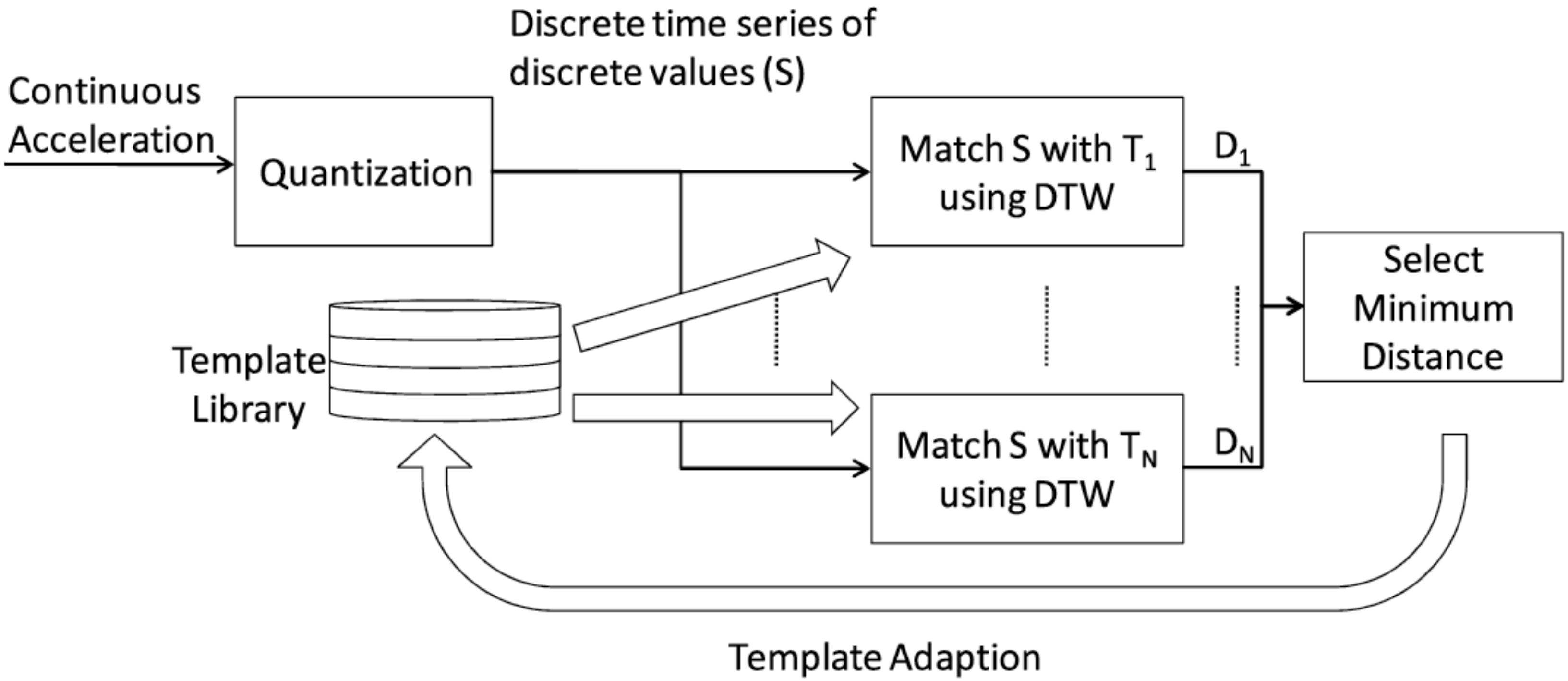
- Throw gesture to move content between display types
- Tilt gestures to navigate large display content

Source: Dachselt, Buchholz: Natural Throw and Tilt Interaction between Mobile Phones and Distant Displays. CHI 2009.

ACCELEROMETER GESTURE RECOGNITION

Gestures Recognition with Dynamic Time Warping (DTW)

- Template-based, small number of examples sufficient
- Quantization: non-linear mapping of input values into discrete quantities



Liu, Zhonga, Wickramasuriya, Vasudevan. uWave: Accelerometer-based personalized gesture recognition and its applications. Pervasive and Mobile Computing 5 (2009) 657-675.

Segmenting Gestures

- Finding the start and end of a gesture is difficult
- Look for segments with large signal variances (colored)
- Filter over short time period (e.g., sliding window)

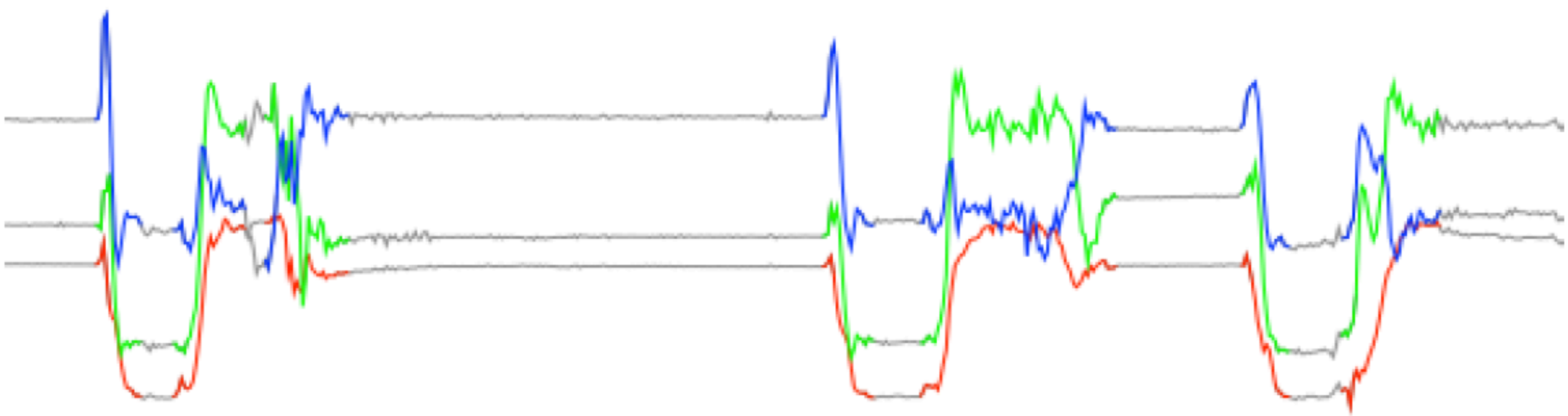
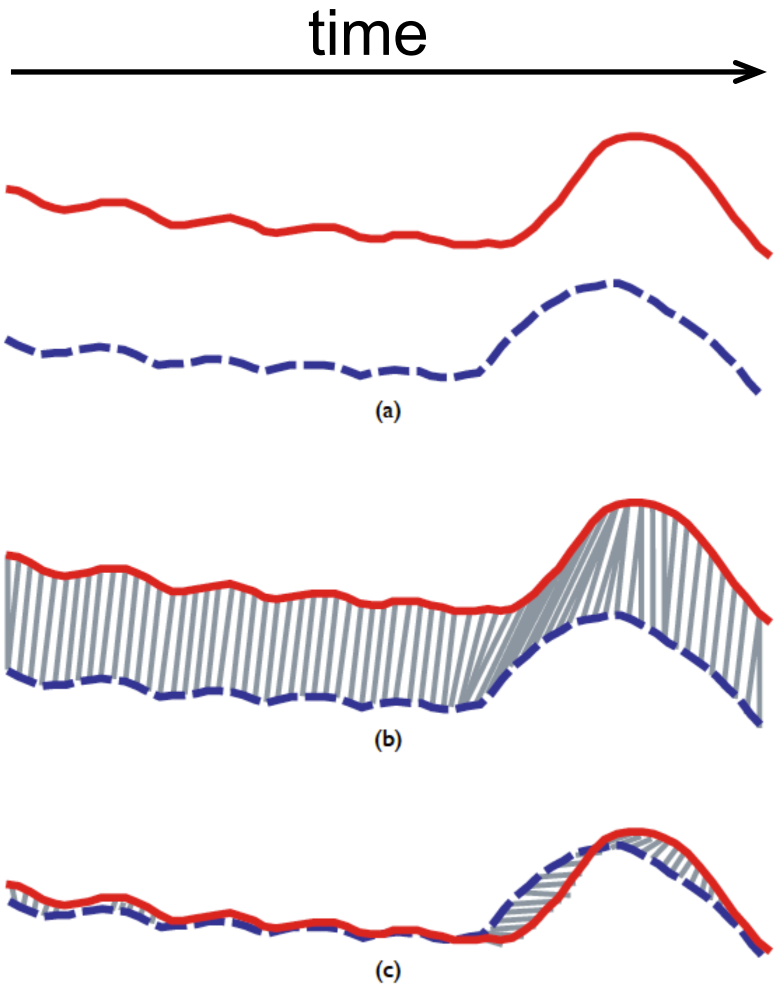


Figure 34: A segment of the Everyday Gesture Library, illustrating higher-energy segments—in color—that are checked for matches; the grey segments are skipped.

Daniel Ashbrook: Enabling Mobile Microinteractions. PhD thesis, Georgia Institute of Technology, May 2010.

Stretching and Shrinking Signals in Time

- Not interested in exact signal, but "overall shape"
  - Speed/amplitude differences in gesture execution
- DTW provides a "distance" between signals
  - Similarity between signals
- Time warping
  - DTW transforms signals into each other by shrinking and stretching (in time domain)
  - Warp such that distance between points is minimized



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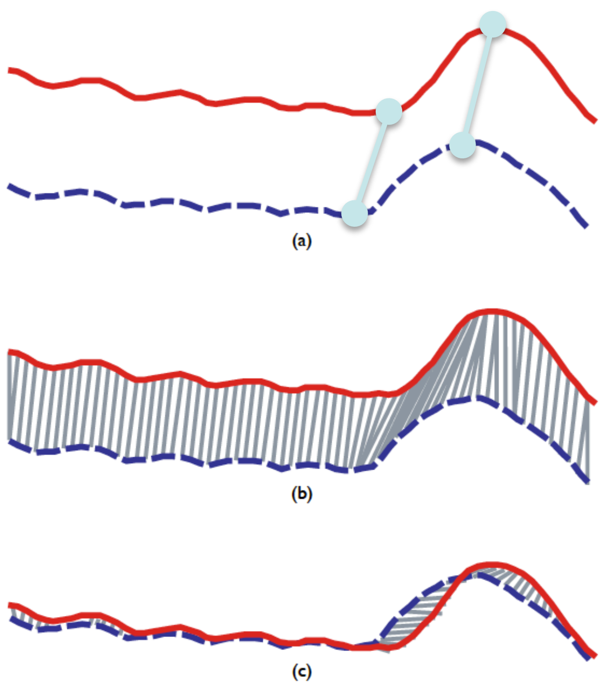
Template Matching with Dynamic Time Warping (DTW)

- Assume that signals consist of discrete data points
- How to assign data points of signal 1 (red) to signal 2 (blue) such that distance is minimized

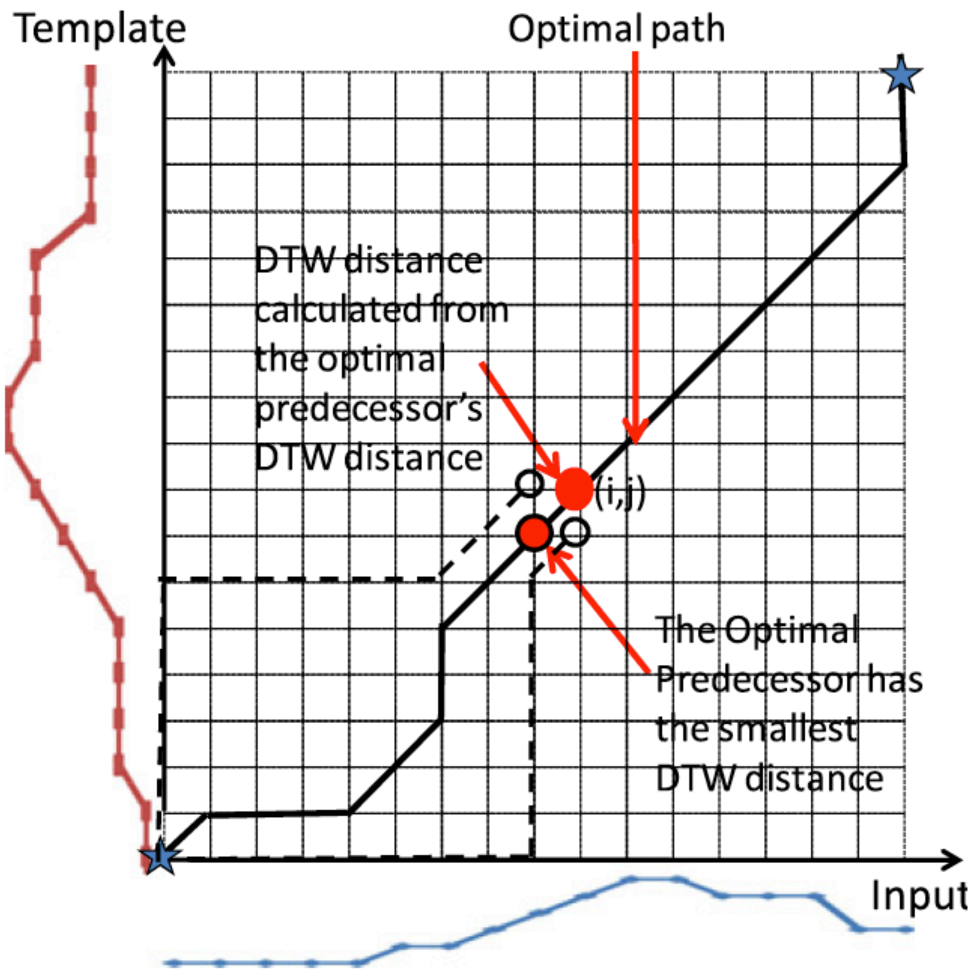
- input signal
- template signal
- best fit between the signals
- similarity between signals



Daniel Ashbrook: Enabling Mobile Microinteractions. PhD thesis, Georgia Institute of Technology, May 2010.

Dynamic Time Warping Algorithm

- Look for optimal path $W = \langle w_1, w_2, \ldots, w_L \rangle$ with minimal cost
  - $w_k=(i,j)$ means point i of template is matched to point j of input
- Cost is sum of distances between matched data points
  - typically Euclidean distance



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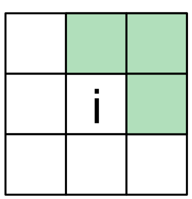
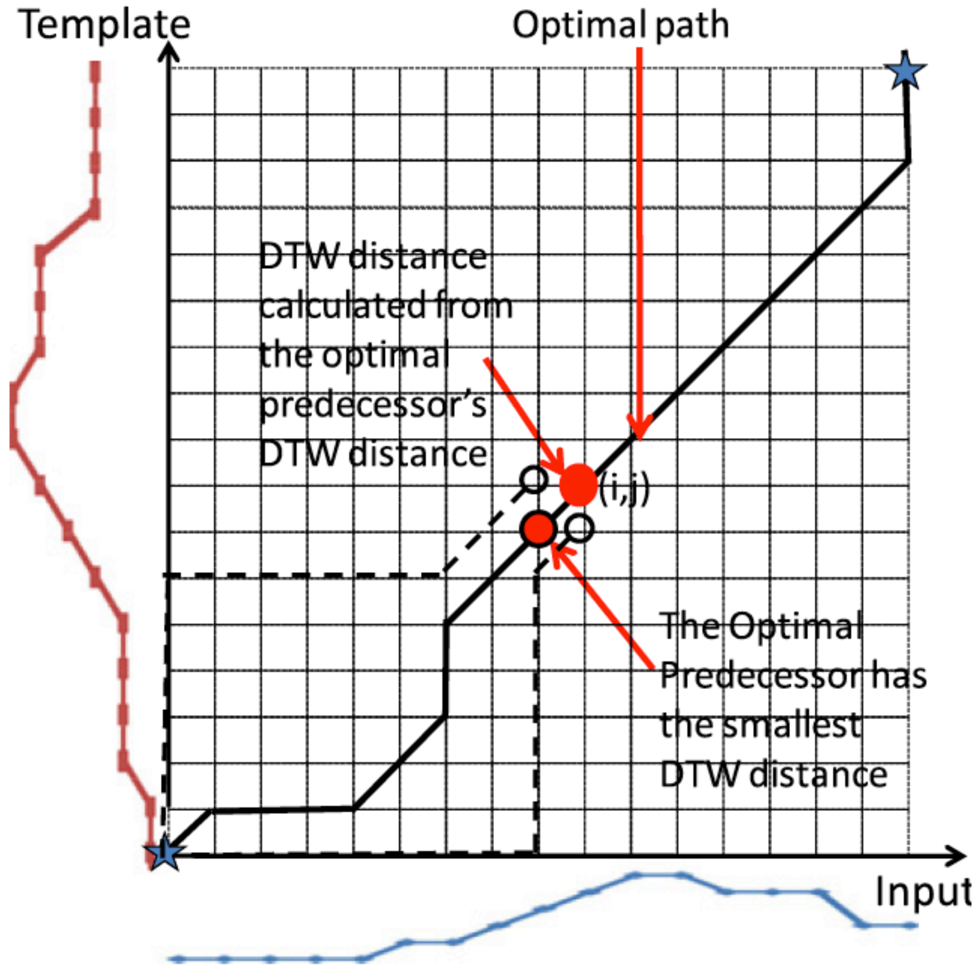
Dynamic Time Warping Algorithm

- Constraints
  - Boundaries:
    $w_1=(0,0)$, $w_L=(n,m)$
  - Monotonicity:
    $w_k=(i,j)$, $w_{k+1}=(i',j')$
    $i \le i'$, $j \le j'$
  - Continuity:
    $w_k=(i,j)$, $w_{k+1}=(i',j')$
    $i' \le i+1$, $j' \le j+1$



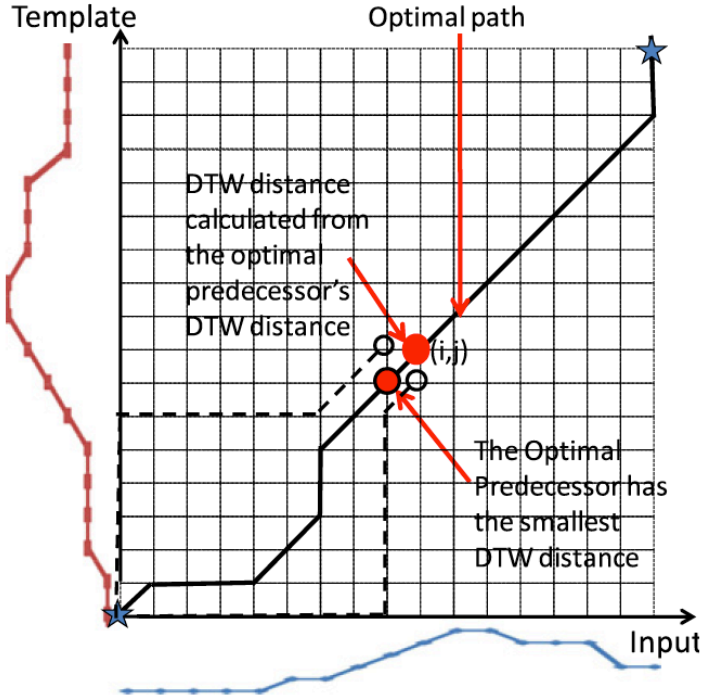


Liu, Zhonga, Wickramasuriya, Vasudevan. uWave: Accelerometer-based personalized gesture recognition and its applications. Pervasive and Mobile Computing 5 (2009) 657-675.

Dynamic Time Warping Algorithm

- Dynamic programming algorithm

$$D_{i,j} = \begin{cases} 0 & i = j = 0 \\ \min\left(D_{i-1,j-1}, D_{i-1,j}, D_{i,j-1}\right) + d_{i,j} & i > 0, j > 0 \\ \infty & otherwise \end{cases}$$



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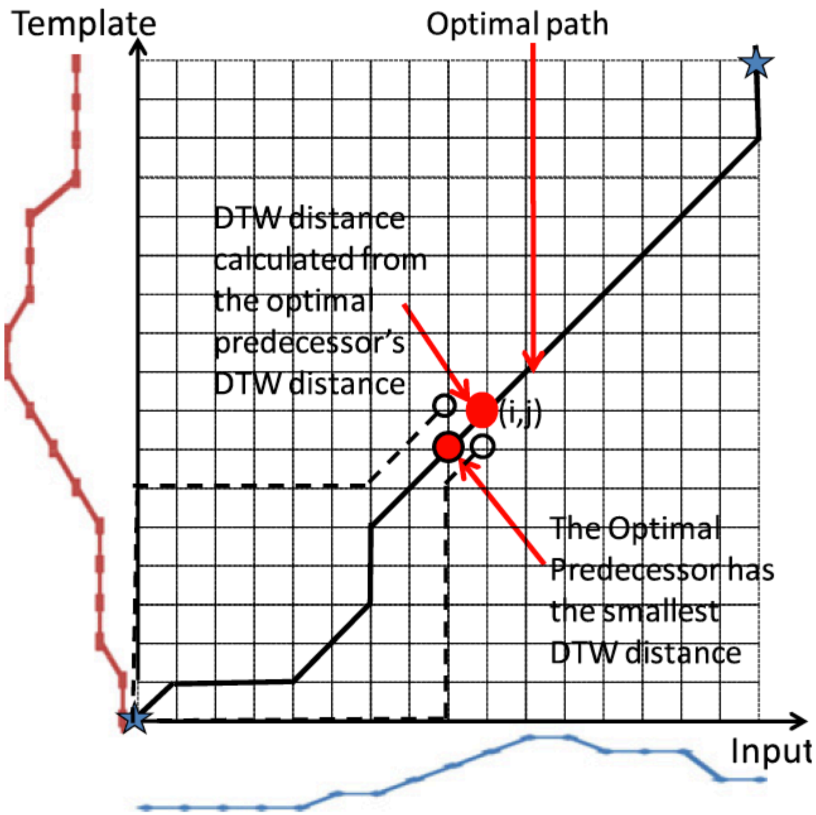
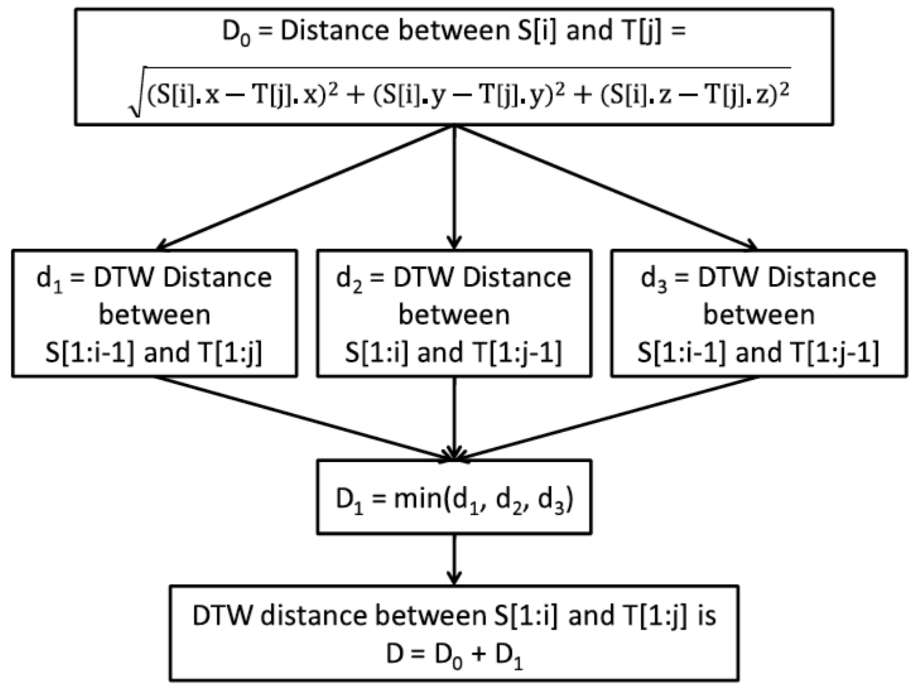
Dynamic Time Warping Algorithm



(a) Graphic illustration of the recursive algorithm.

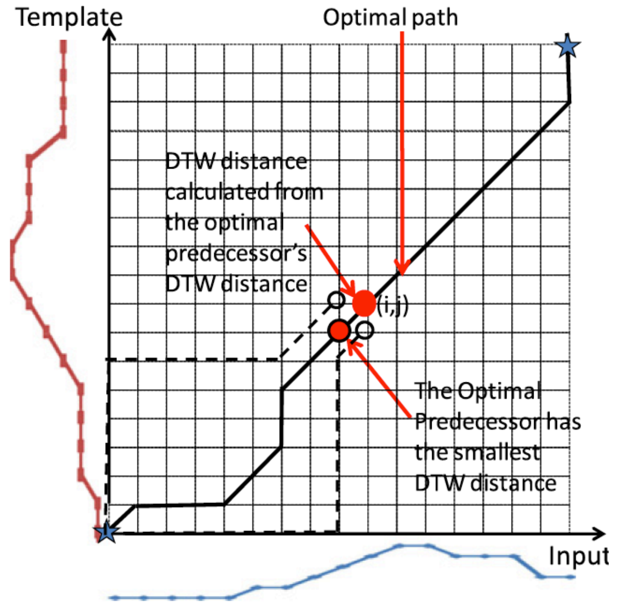


(b) Algorithm for computing the DTW distance between $S[1:i]$ and $T[1:j]$.

Liu, Zhonga, Wickramasuriya, Vasudevan. uWave: Accelerometer-based personalized gesture recognition and its applications. Pervasive and Mobile Computing 5 (2009) 657-675.

Dynamic Time Warping Algorithm

Constrain to window w to avoid excessive warping




```
int DTWDistance(char s[1..n], char t[1..m], int w) {
    int DTW[0..n, 0..m]
    int i, j, cost
    set all DTW[i,j] = infinity
    DTW[0,0] = 0
    for i = 1 to n
        for j = max(1, i-w) to min(m, i+w)
            cost := d(s[i], t[j])
            DTW[i,j] := cost + minimum(DTW[i-1,j], DTW[i,j-1], DTW[i-1,j-1])
    return DTW[n, m]
}
```

Liu, Zhonga, Wickramasuriya, Vasudevan. uWave: Accelerometer-based personalized gesture recognition and its applications. Pervasive and Mobile Computing 5 (2009) 657-675.

Quantifying Recognition Performance

- Overall recognition rate
- Confusion matrix

			→	←	↑	↓		
	92.1	0.1	2.4	1.9	0.1	2.9	0.6	0.1
	1.6	91.6	1.3	1.1	0.7	0.4	2.7	0.6
→	0.5	0	95.9	1.2	0.7	1.7	0	0
←	0.3	0	1.6	96.2	0.7	1.1	0	0.1
↑	0.3	0	1.5	0.6	97.0	0.5	0	0.1
↓	2.4	0	2.4	2.3	1.0	91.7	0.1	0
	3.4	1.9	2.6	1.7	0.4	0.7	89.2	0
	1.1	0.6	1.7	0.9	0.8	0.7	0	94.2

Liu, Zhonga, Wickramasuriya, Vasudevan. uWave: Accelerometer-based personalized gesture recognition and its applications. Pervasive and Mobile Computing 5 (2009) 657-675.

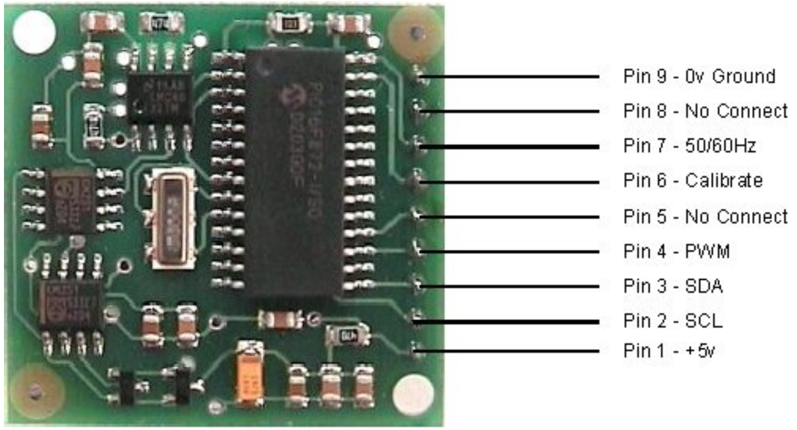
MAGNETOMETERS

Magnetometer

- T-Mobile G1 Android phone with Google Street View
- Combined with GPS

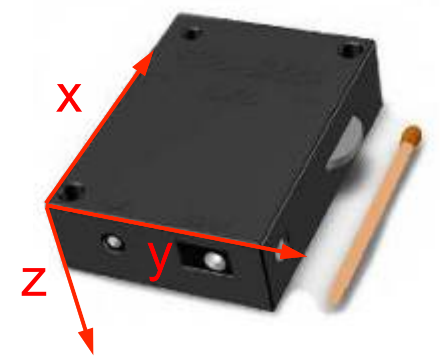
How do Magnetometers work?

- Measure strength and direction of magnetic field
  - Have to be calibrated
- Causes of magnetic fields
  - Earth's magnetic field (varies from place to place)
  - Electro magnetic interference (EMI)
- Typically three orthogonal axes
  - Magnetic north as reference
- Operating principle
  - Rotating coil, hall effect, etc.
- Technical parameters
  - Sensitivity to EMI
  - Update rate

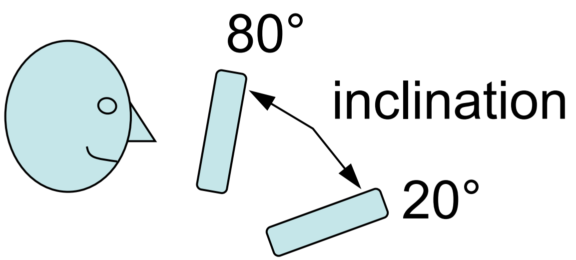


KM51 Magnetic Field Sensor

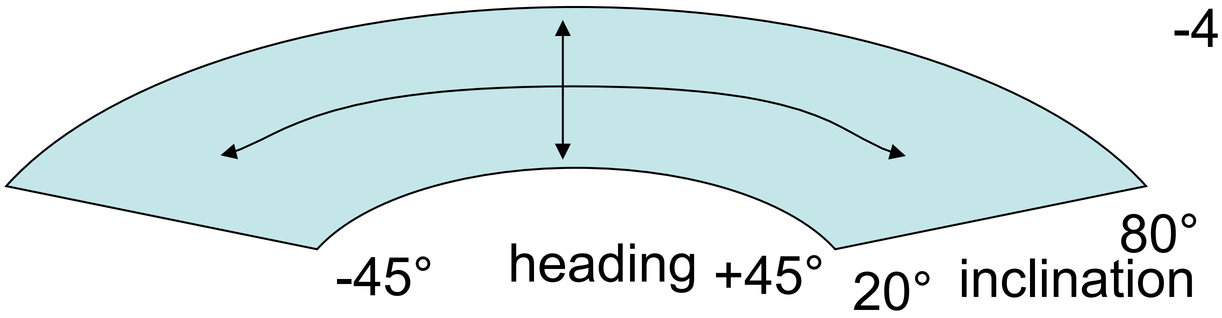
Peephole Displays

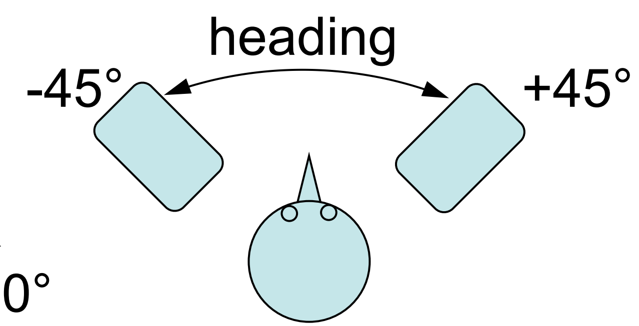


- Accelerometers and magnetometers
- Mapping sensor readings to workspace position
  - Accelerometer
    - inclination 20° → lower workspace border
    - inclination 80° → upper workspace border
  - Magnetometer
    - heading -45° → left workspace border
    - heading +45° → right workspace border



- Curved physical interaction space

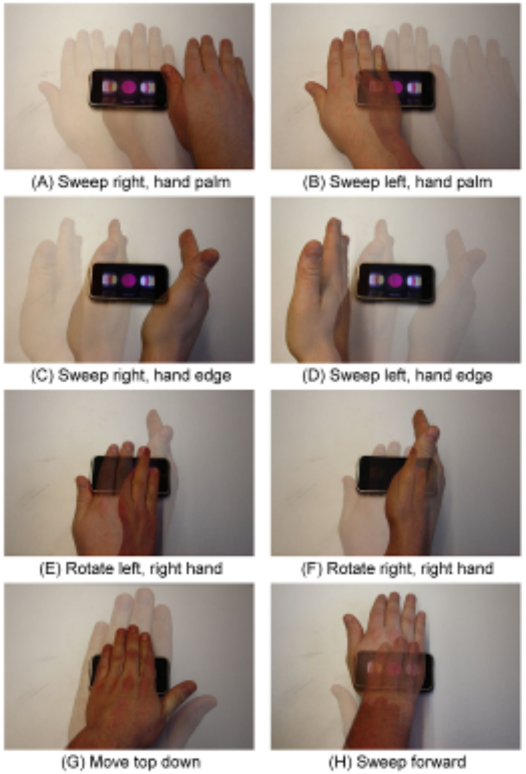


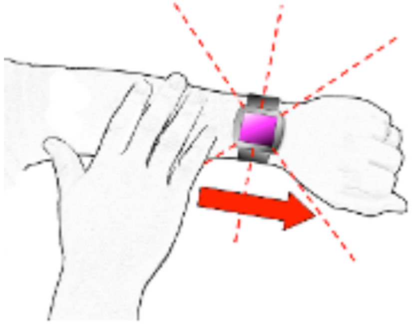


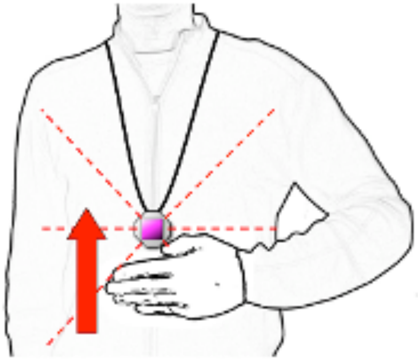
DISTANCE SENSORS, MICROPHONES, PRESSURE SENSORS, ETC.

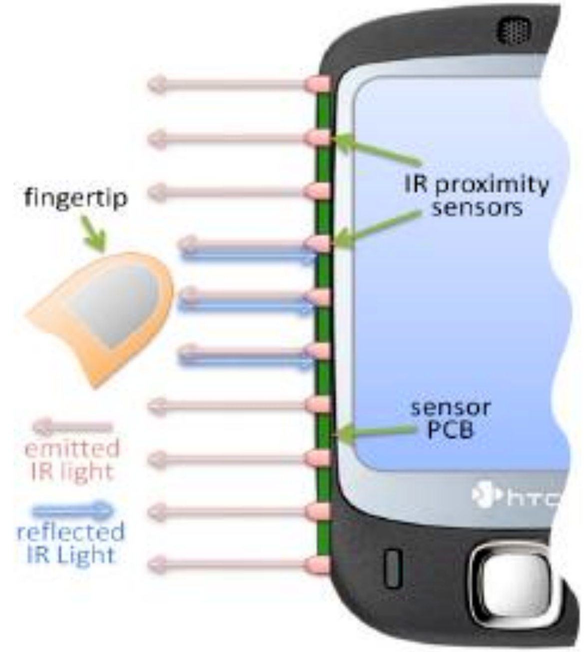
Infrared Range Sensors

- Around-device interaction







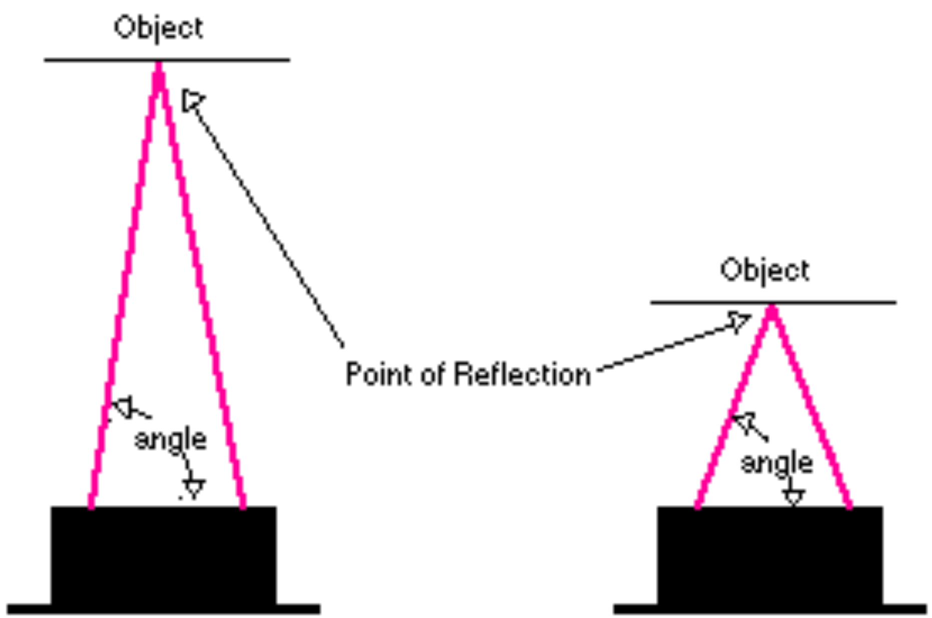


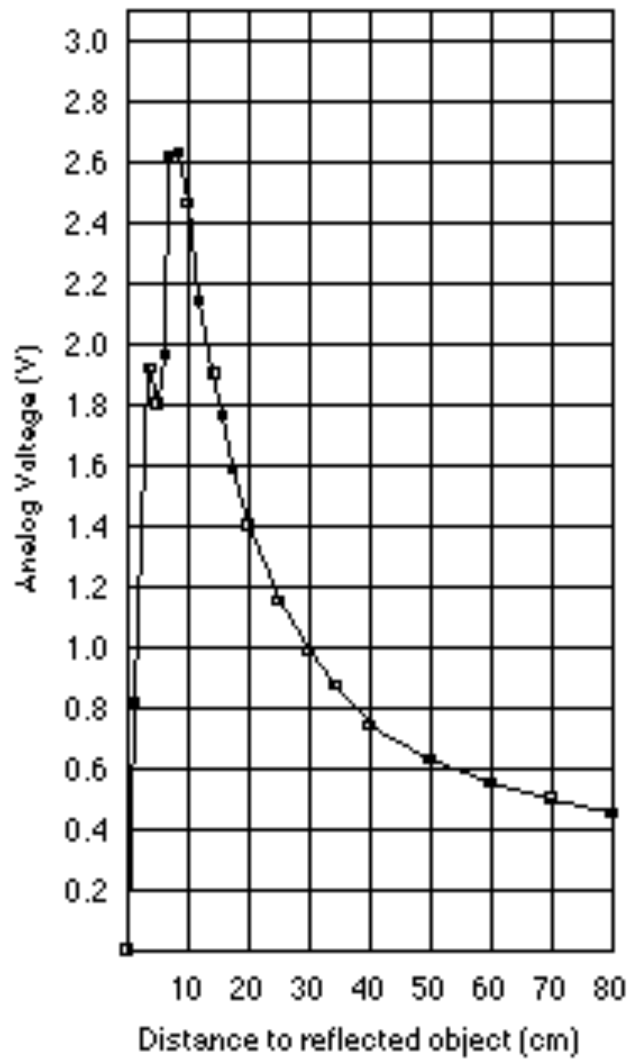
Sven Kratz, Michael Rohs: HoverFlow: Expanding the Design Space of Around-Device Interaction. MobileHCI 2009.

Butler, Izadi, Hodges: SideSight: Multi-“touch” Interaction Around Small Devices. UIST’08.

Infrared Range Sensors

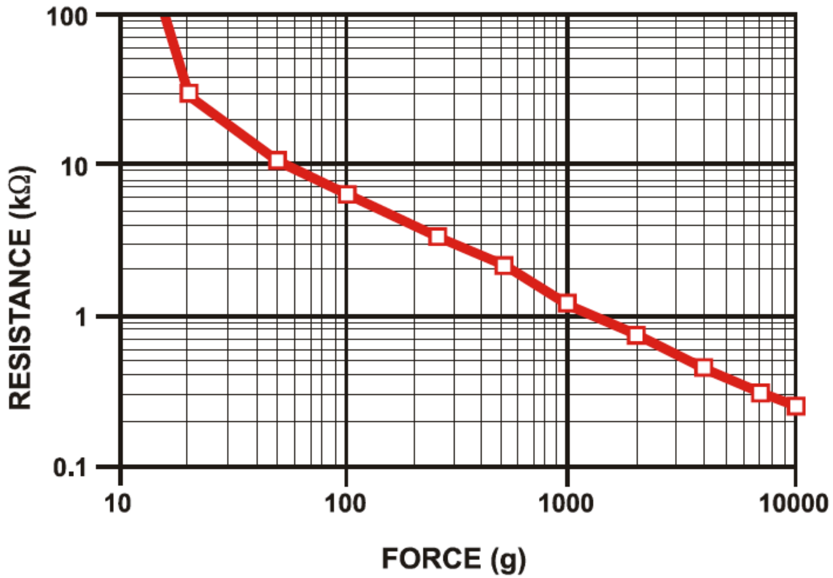
- An emitter sends out light pulses
- A linear CCD array receives reflected light
- The distance corresponds on the triangle formed





Force Sensing Resistors (FSRs)

- Force Sensing Resistors
  - Composed of multiple layers
  - Flat, sensitive to bend
  - Force changes resistance
  - Non-linear response curve
- Example: Interlink FSR-402



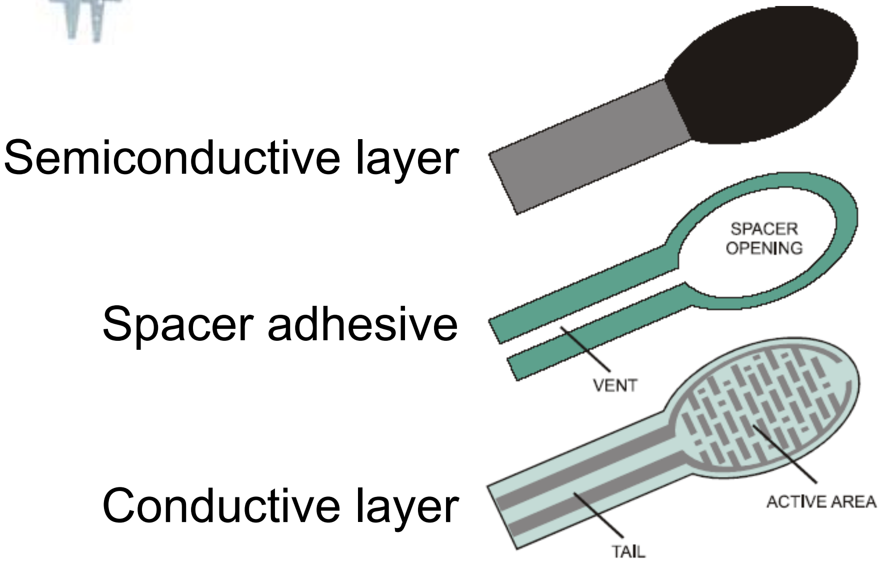


Figure 1: FSR Construction

FSR Characteristics

- Low force range 0..1kg important for human interaction
- Not very precise: force accuracy 5..25%
- But humans are even worse in judging pressure

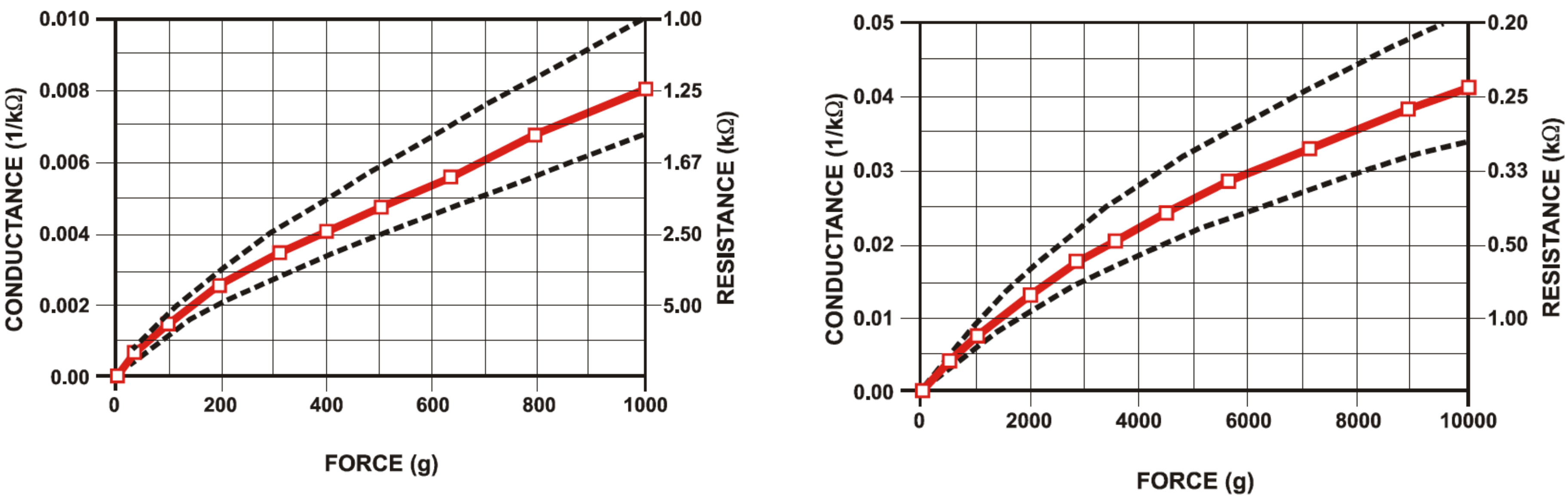
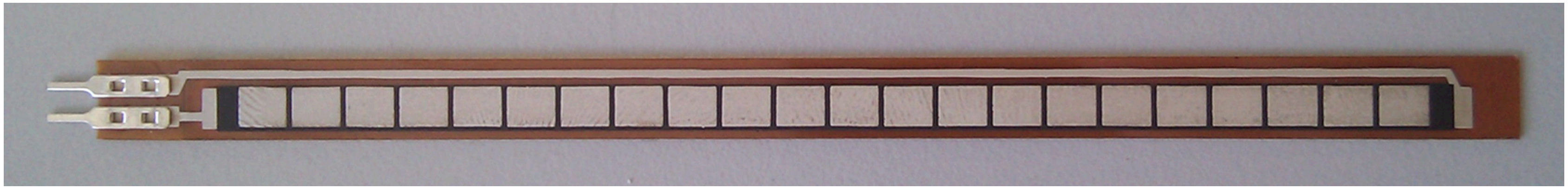


Figure sources: Interlink

FSR Bend Sensors

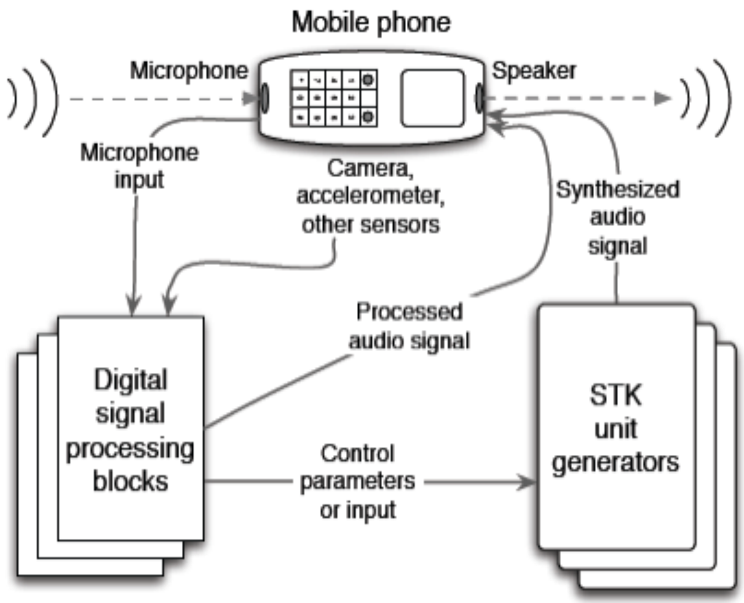
- Change resistance when bent
- Un-flexed: 10kΩ Flexed / bent 90°: 30..40kΩ

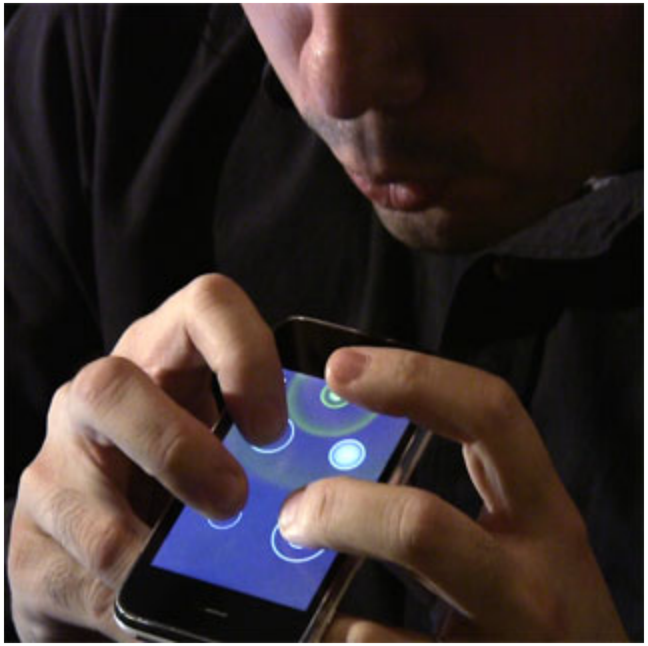


- Sensor glove
  - http://www.tufts.edu/programs/mma/emid/projectreportsS04/moerlein.html

http://www.tufts.edu/programs/mma/emid/projectreportsS04/moerlein.html

Microphone-Based Interactions



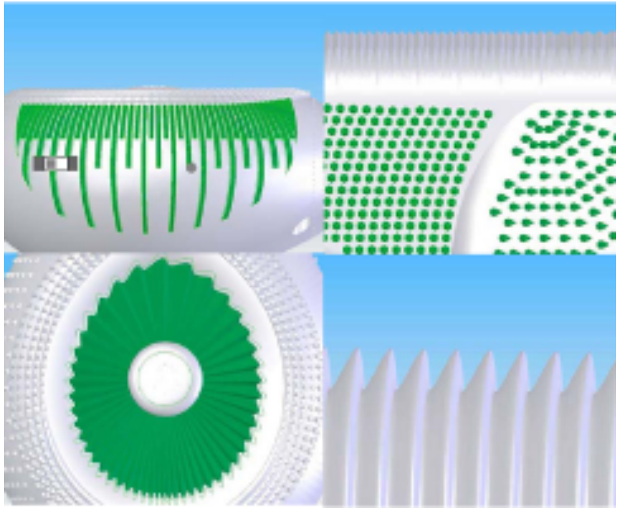


- Microphone as abstracted sensor
- Noise level corresponds to blowing intensity
- Expressive music performance
  - Commercial product: Ocarina

http://www.youtube.com/watch?v=glrpGjFit1k
http://www.youtube.com/watch?v=RhCJq7EAJJA

Stane: Scratch-based Input Concept

- Rub, scratch, or tap the case
  - Requires little visual attention
  - Provides natural tactile feedback
- Varying textures around the device
- Sensors
  - Contact microphones
  - Capacitive sensing
  - Inertial sensing
- Actuators
  - Audio
  - Vibrotactile

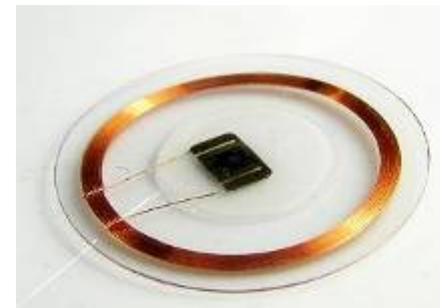


Microphones

- Translate air vibrations into electronic signals
- Condenser (capacitor) microphone
  - Membrane is one side of capacitor
  - Can be very high quality
  - Need to be powered
- Electret microphone
  - Uses charged material
  - In principle not powered, but amplification needed
  - “Mass-market” microphone technology
- Dynamic microphone
  - Uses electromagnetic induction
  - Robust under changed environmental conditions
  - “Outdoor microphone”

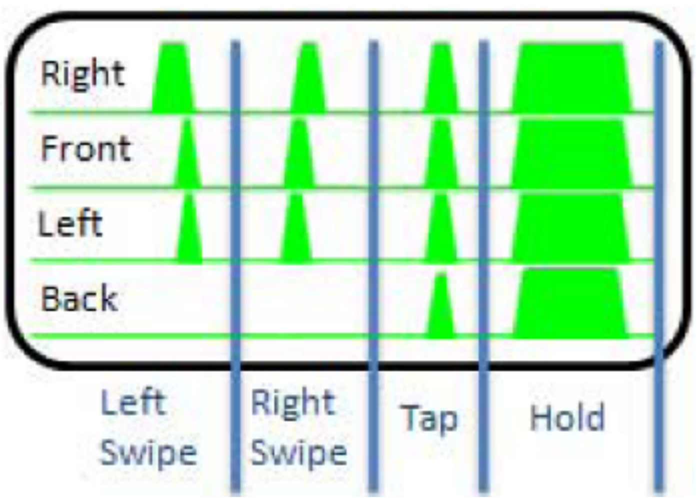
Near Field Communication (NFC)

- Extension of radio frequency identification (RFID)
  - Tag = IC + antenna
  - Very short range communication (< 10cm)
- Applications
  - NFC-enabled payment services
  - Bluetooth-enabled NFC:
    device pairing by touching two devices

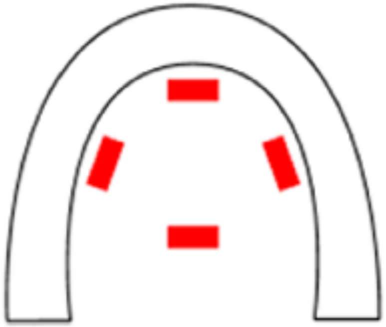


The Future: Tongue Movement Sensing?

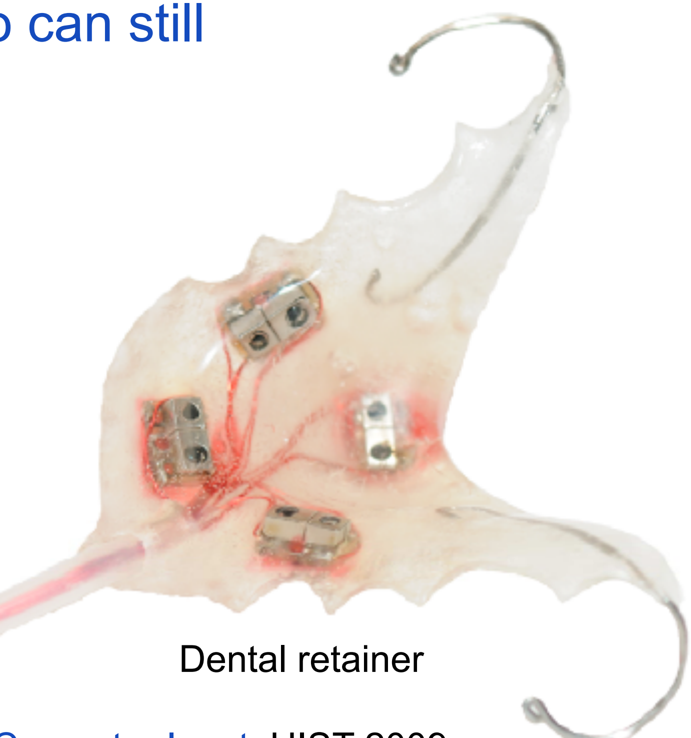
- Infrared distance sensors embedded within a dental retainer to sense tongue gestures
  - User study: 90% accuracy for detecting four simple gestures, playing Tetris with tongue
  - For patients with paralyzing injuries who can still control the eyes, jaw, and tongue



Sensor data



Sensor positions



Dental retainer

Saponas et al.: Optically Sensing Tongue Gestures for Computer Input. UIST 2009

Discussion

What is the most used “sensor” we have omitted?

The End