Instrumented Environments

Andreas Butz, butz@ifi.lmu.de, www.mimuc.de

Fri, 12:15-13:45, Theresienstr. 39, Room E 045

Topics today

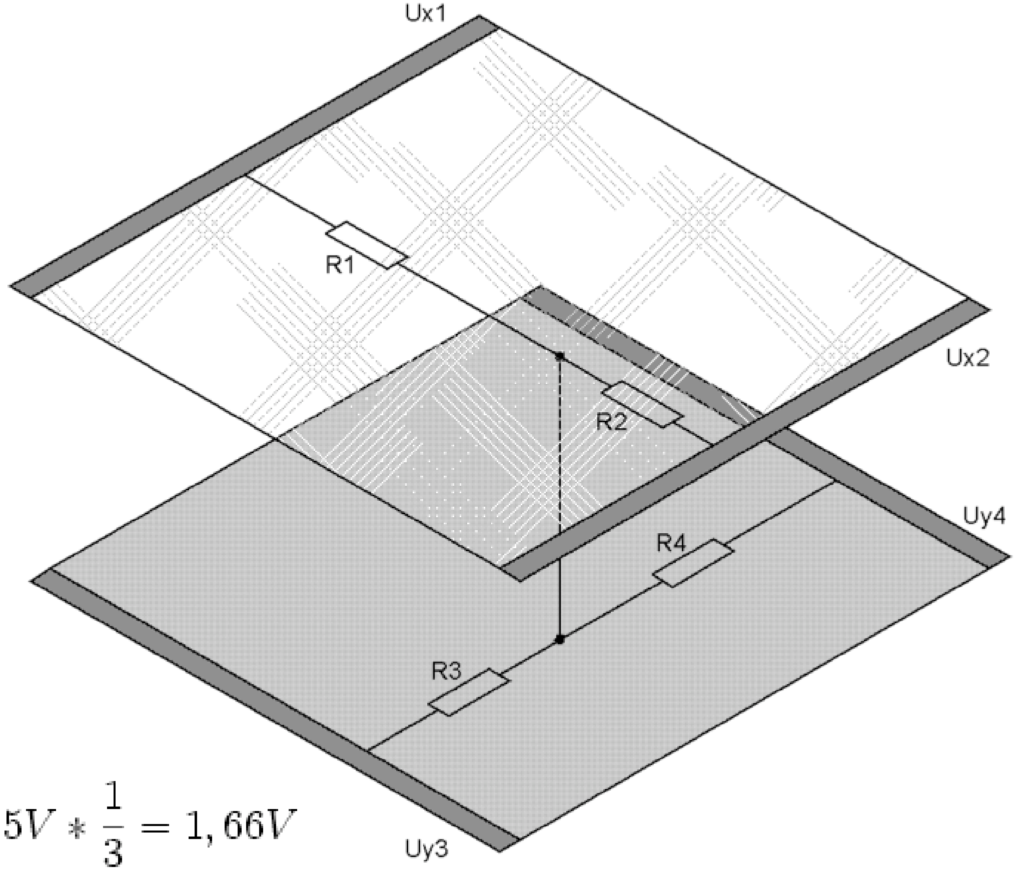
- Sensing
  - Touch screens, interactive surfaces
  - Cameras, microphones, RFID
- Tracking
  - Cell-based, signal strength, runtime
  - Radio, optical, acoustic
  - Load sensing
  - Meta-techniques

Sensing

Classical touch screen

[http://de.wikipedia.org/wiki/Touchscreen]

- Two sheets of conductive, transparent material
- Connected by finger or pen pressure
- Resistance measurements
  - Between X electrodes
  - Between Y electrodes

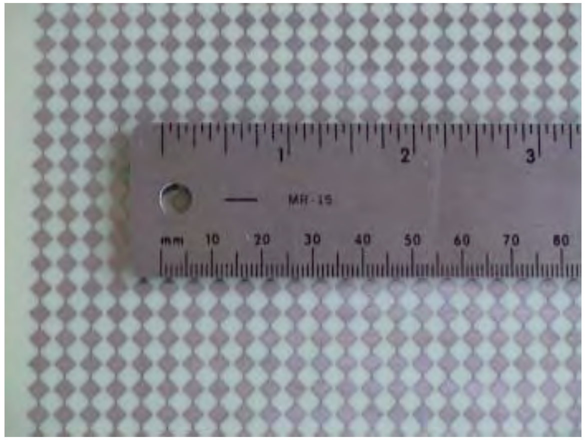


$$Uy_3 = Uy_4 = Ux_2 + \frac{(Ux_1 - Ux_2) * R_2}{R_1 + R_2} = 0V + 5V * \frac{1}{3} = 1,66V$$

Mitsubishi DiamondTouch

[P. Dietz, D. Leigh, UIST 2002]

http://www.merl.com/projects/DiamondTouch/



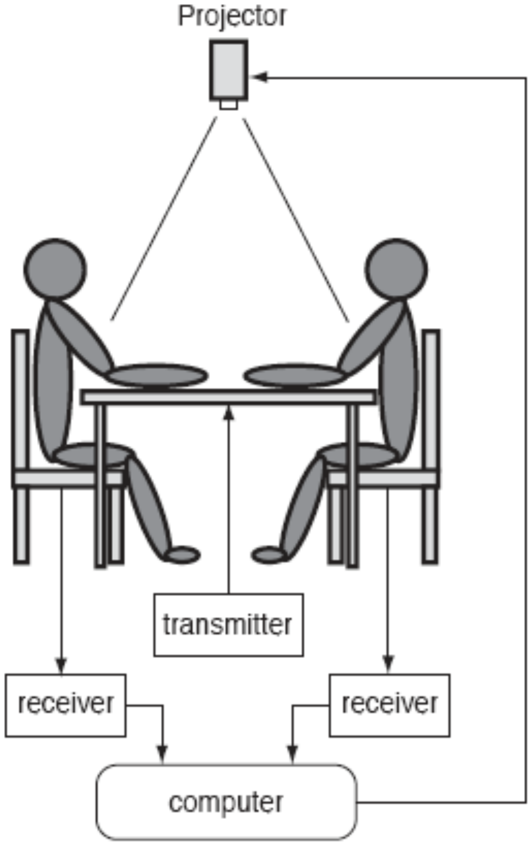


Figure 2: DiamondTouch works by transmitting signals through antennas in the table. These signals are capacitively coupled through the users and chairs to receivers, which identify the parts of the table each user is touching. This information can then be used by a computer in the same way as mouse or tablet data.

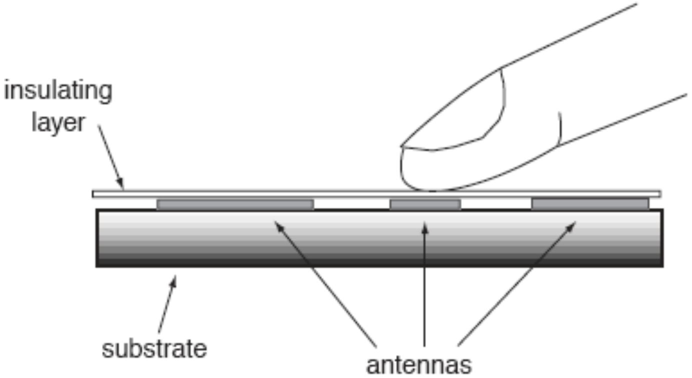
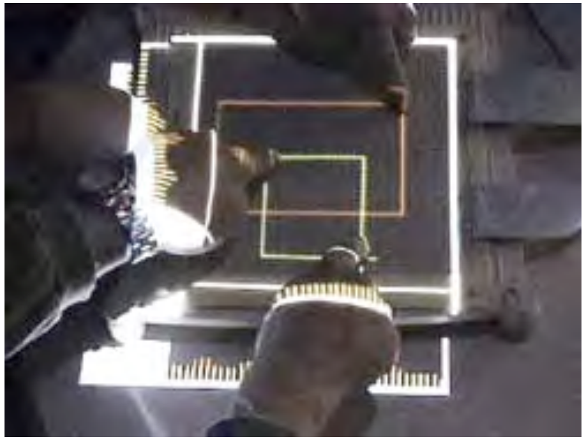


Figure 3: A set of antennas is embedded in the table-top. The antennas are insulated from each other and from the users.



Sony SmartSkin

[Jun Rekimoto, CHI 2002]

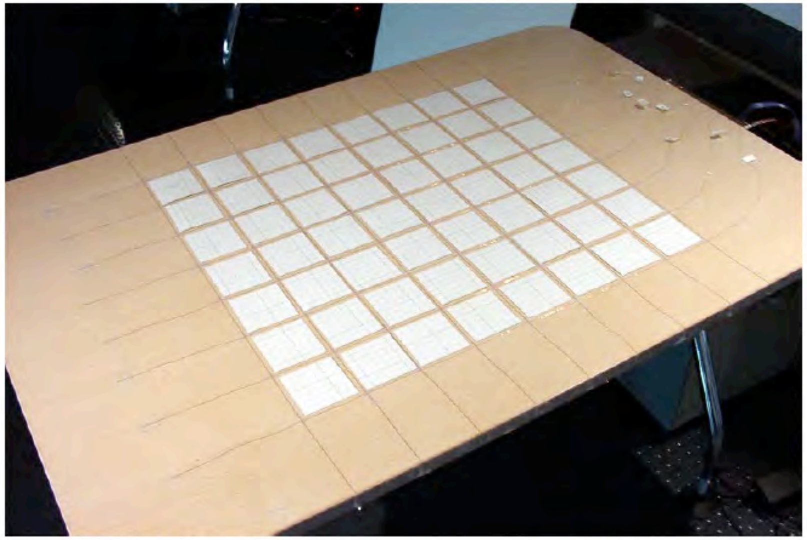
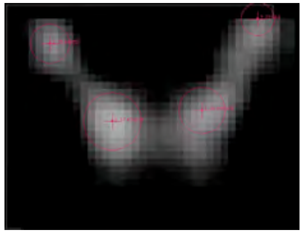


Figure 3: Interactive table with an 8 × 9 SmartSkin sensor: A sheet of plywood covers the antennas. The white squares are spacers to protect the wires from the weight of the plywood cover.



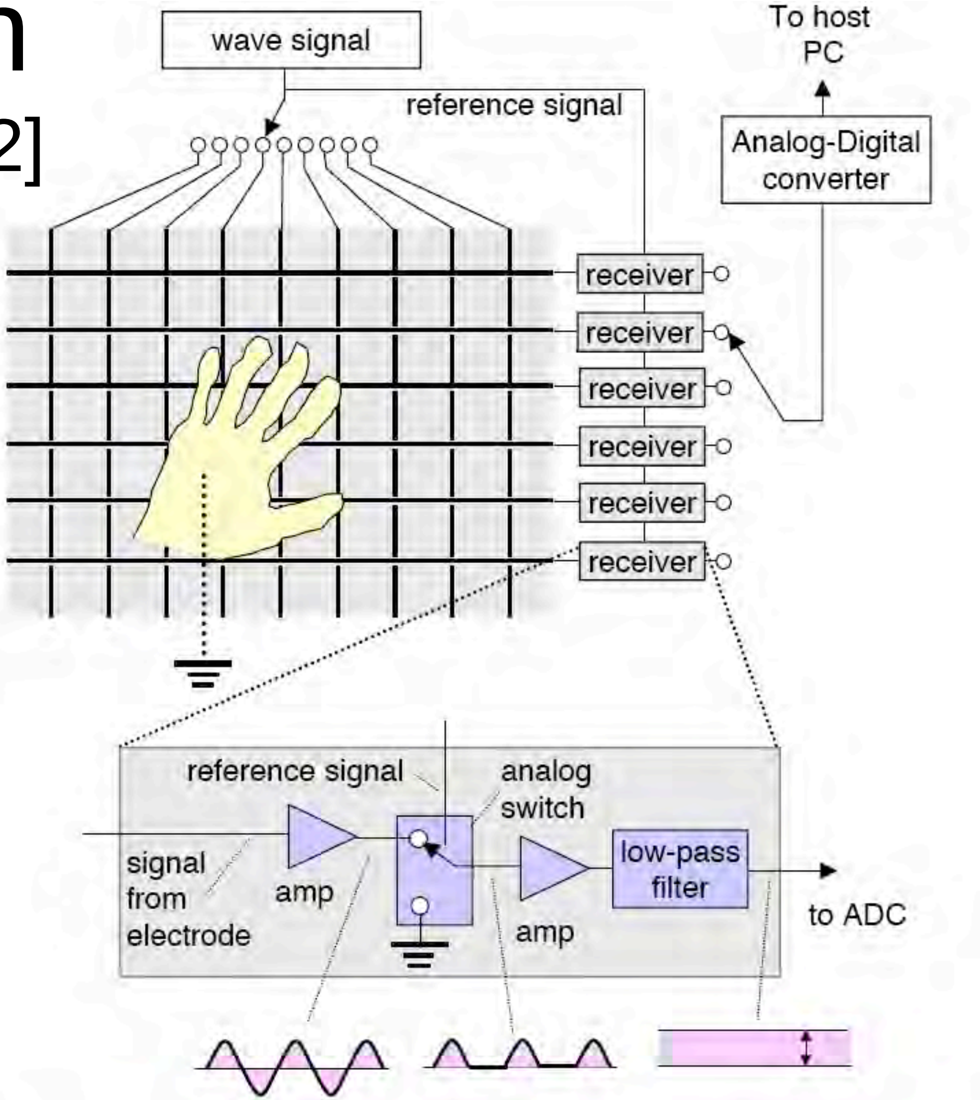


Figure 2: The SmartSkin sensor configuration: A mesh-shaped sensor grid is used to determine the hand's position and shape.

SmartTech SmartBoard DViT

(digital vision touch)

Figure 1: DViT Technology Camera

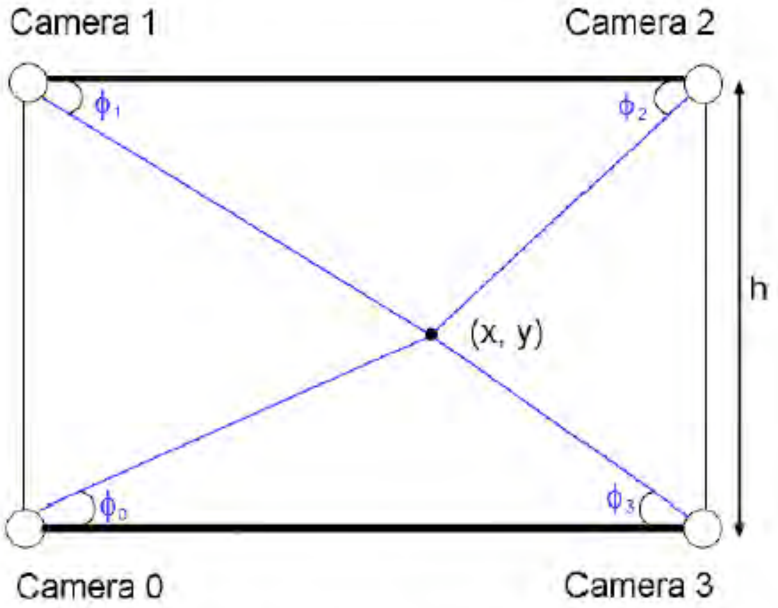


Figure 2: Camera Identification of a Contact Point

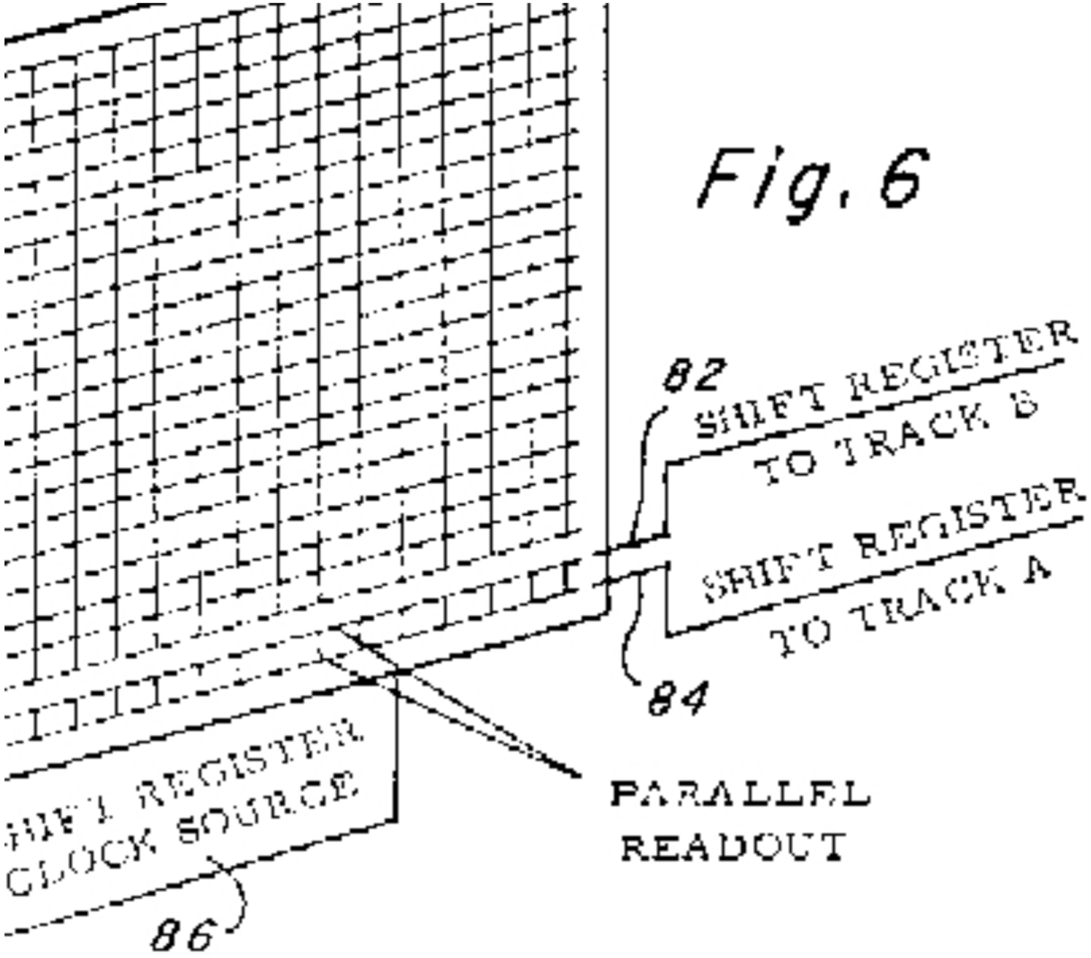
- Vision based, 4 cameras, 100FPS
- Nearly on any surface
- More than one pointers
- http://www.smarttech.com/dvit/index.asp

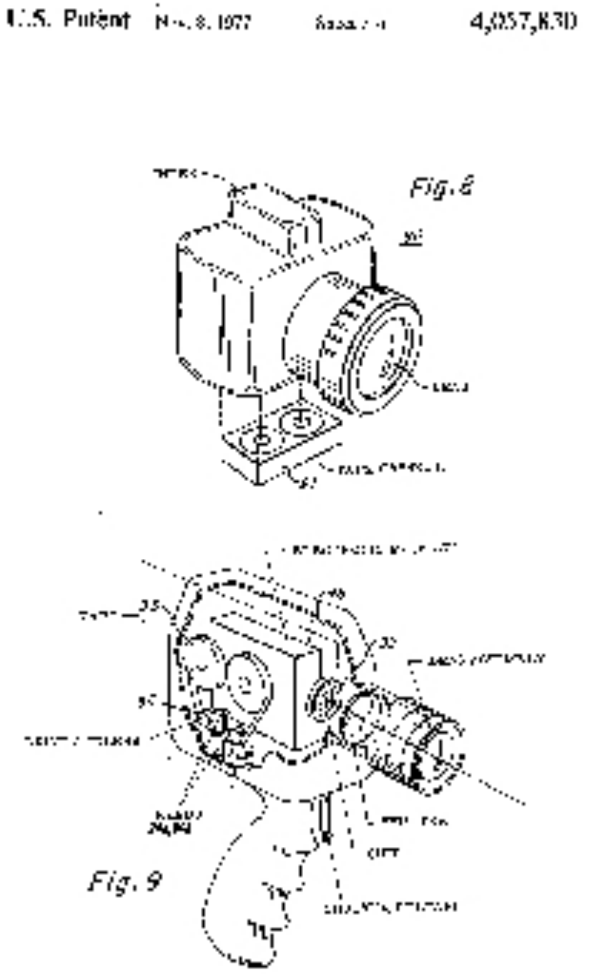
Cameras



- Key Criteria
  - Resolution, frame rate
  - BW, color, IR
  - Sensitivity
  - Image noise
  - Lens view angle
  - USB/FireWire/video

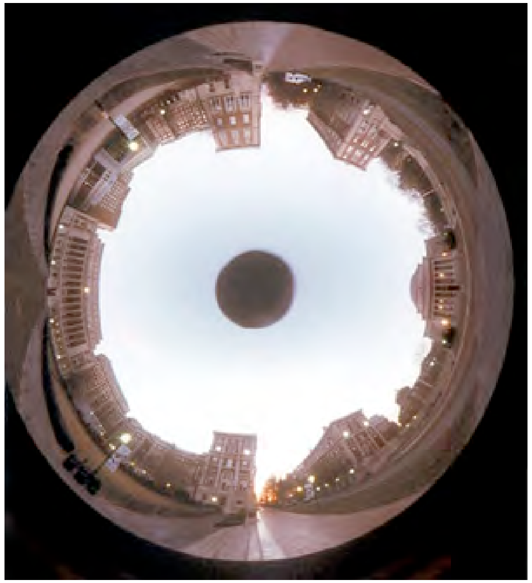

Digital camera patent (1972)

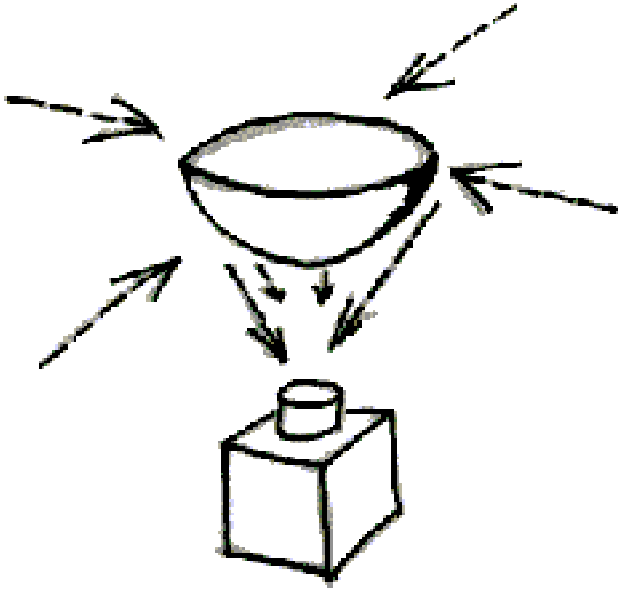




Quelle: http://www.digicamhistory.com/

Omnicam



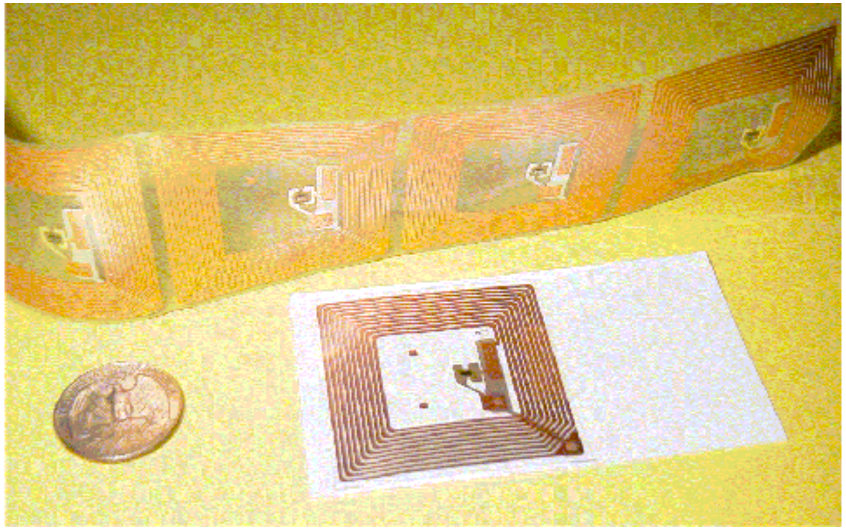


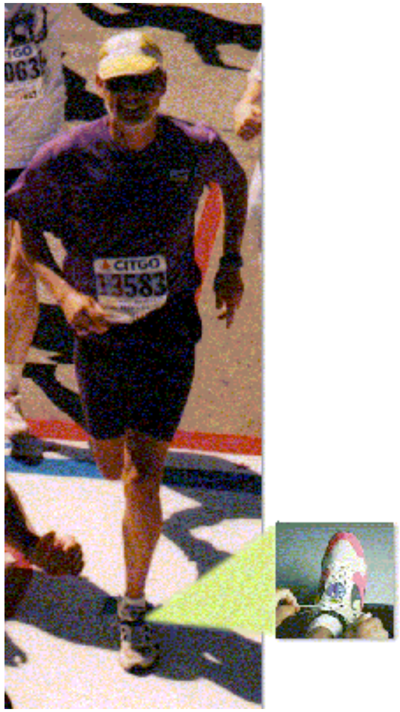
Microphones

- Different principles:
  - Dynamic, Piezo, condenser
- Different sizes and forms
  - Regular (sound from the air)
  - Contact microphone: records acoustic vibrations from solid objects
- Criteria:
  - Sensitivity
  - Frequency range
  - Electrical specifications
  - Active/passive

RFID Tags (orig. TI + Philips)

- Transponder, external energy supply
  - Small memory, 39bit-ID
- small range (depends on antenna type)
  - from 0.1m to 2m
- Problem of collision detection





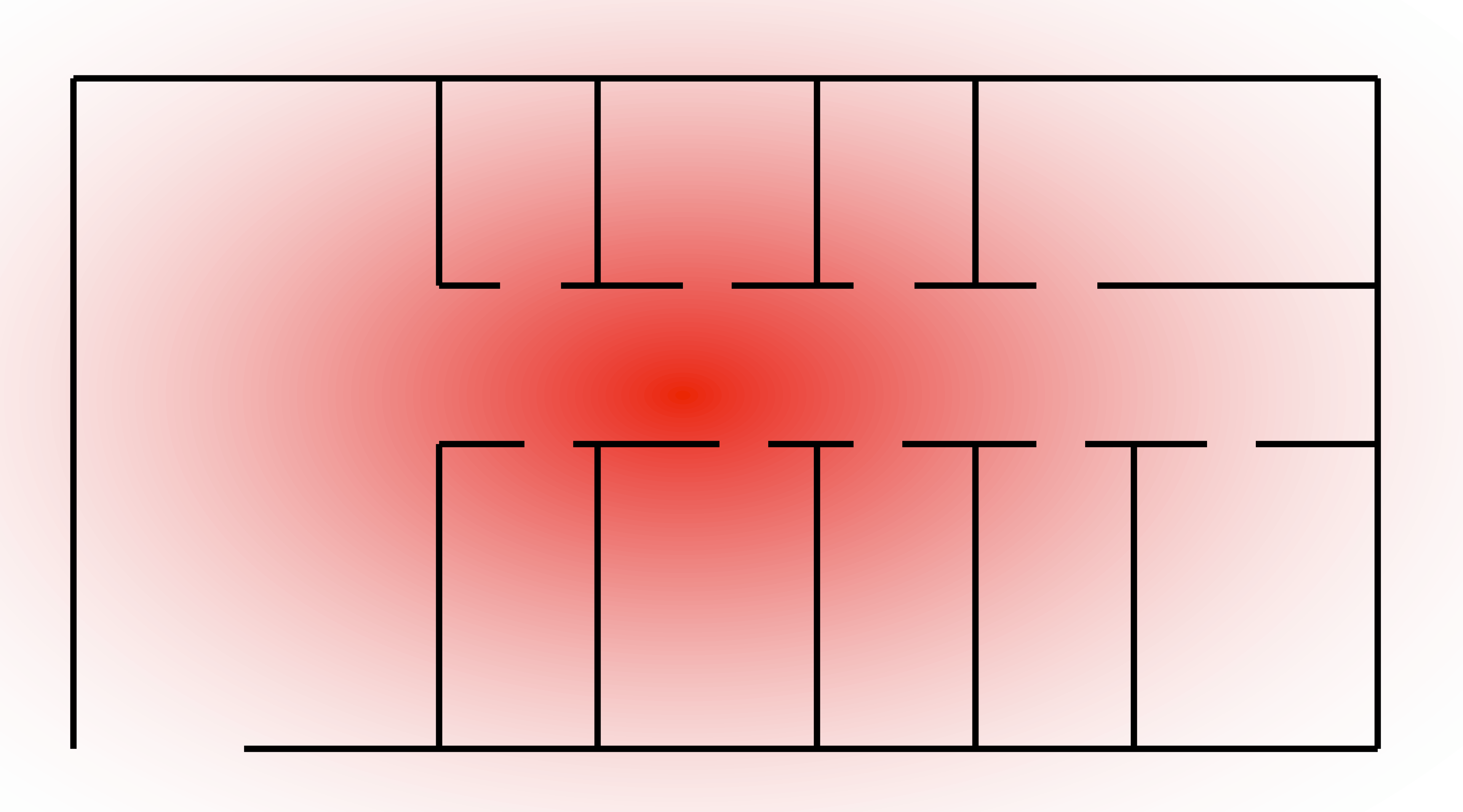
RFID example: smart store

Tracking

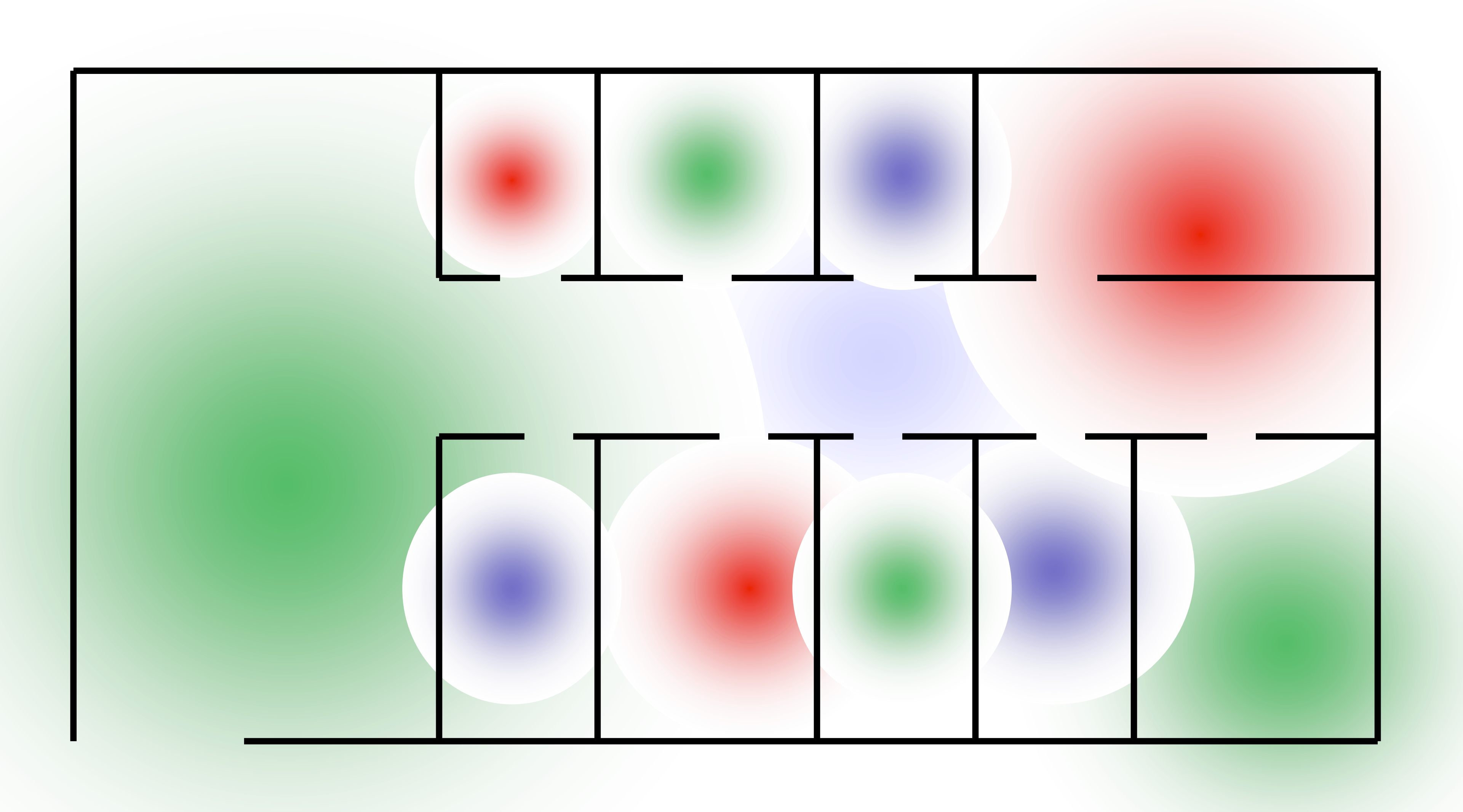
Cell-based Tracking

- Each sender has a unique Id, which can be identified

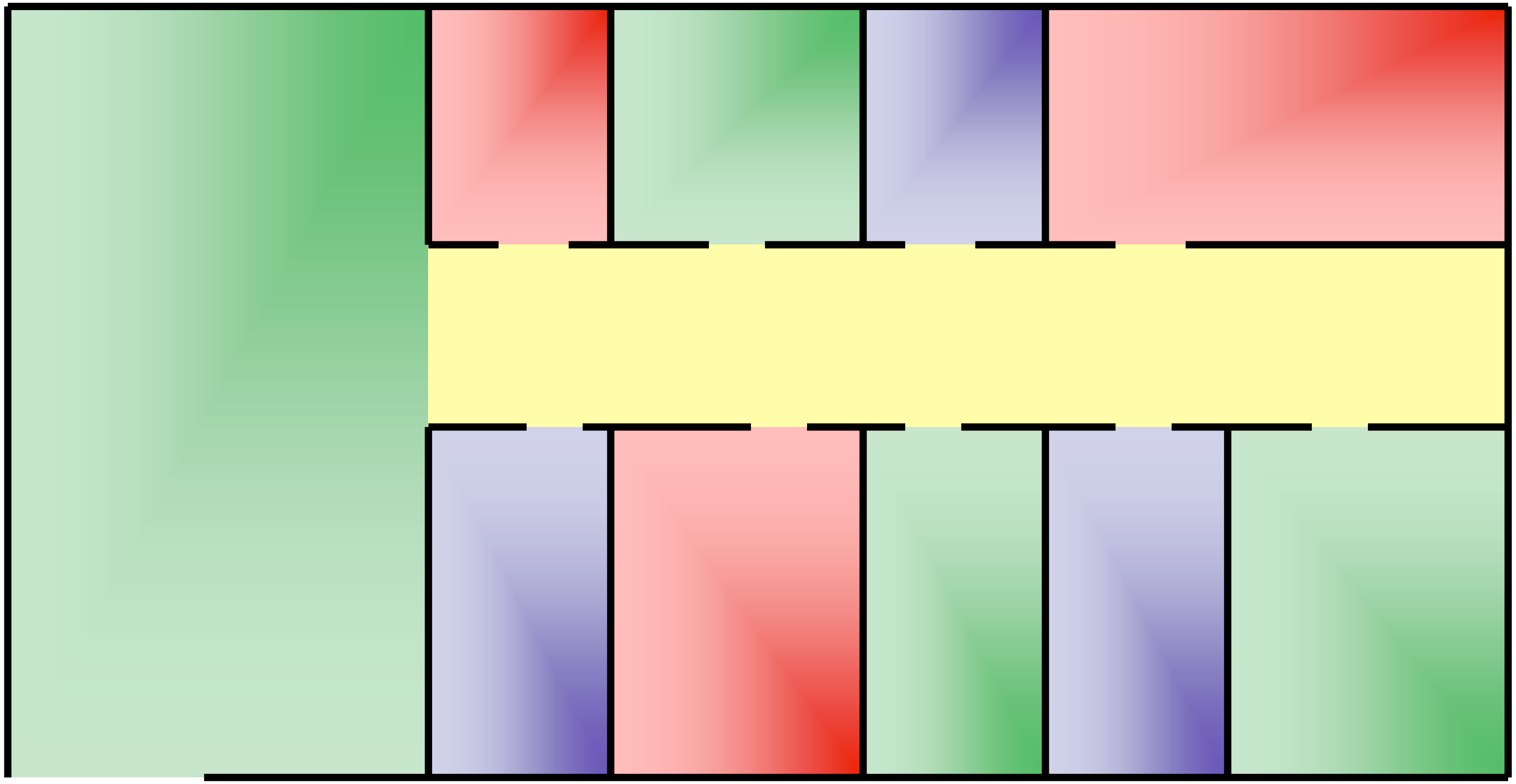
WLAN cells



Bluetooth cells



Infrared cells



Measuring signal strength

- Radio:
  - Triangulation: approximate the distance by measuring the signal strength from several senders
  - Signal strength is heavily dependent on the environment (radio)
- Infrared:
  - With IrDA no measurement of signal strength possible
- Acoustic:
  - problems with noise
  - Precision highly variable

- ==> Machine Learning approach, Fingerprinting

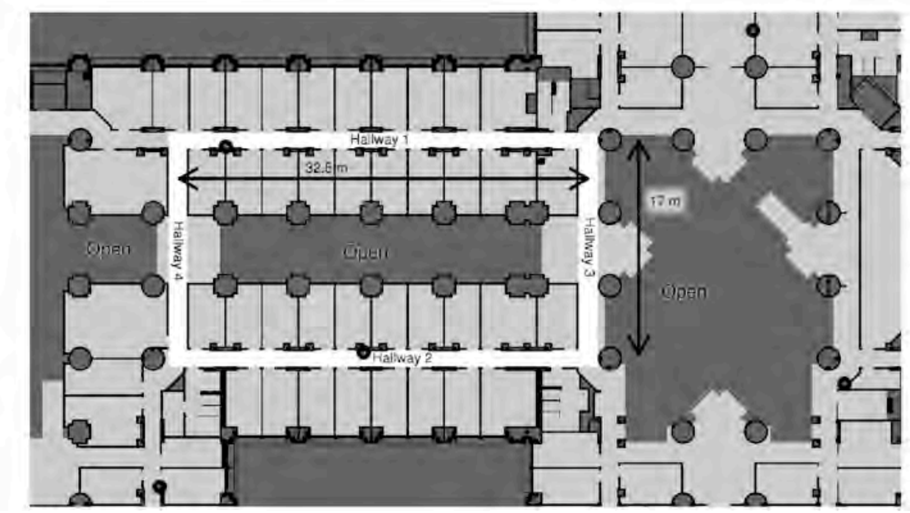
Idea: WLAN Fingerprints

- Use already existing WLAN infrastructure for positioning
- Measuring signal strength is very inexact with people and walls around
- Instead: learn the “fingerprint” at defined locations (vector of signal strengths)
- Try to identify the “closest match” at other locations

WLAN Fingerprints

[Ladd et al. 2002+2004]

- Sampling in the hallway every 10 feet (>1300 meas.)
- Simple Probabilistic Algorithm (Bayes-rule)
  - Error within 1.5 meters with P=0.77
- Filtering and Sensor Fusion
  - Error within 1.5 meter with P=0.83
- Offline-Processing with Hidden-Markov-Model
  - Error within 1.5. meter with P=0.91



WLAN Fingerprints

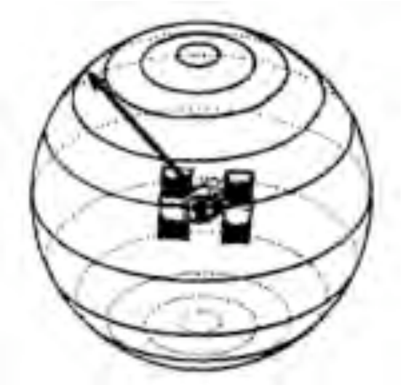
- Problems:
  - Access points may move or (dis)appear
  - The 2.4 Ghz band is absorbed by water
    - Humans (problem with orientation)
    - Weather conditions (rain)
  - Practical precision around 10m
  - Requires complicated training phase

- Commercially available: www.ekahau.com

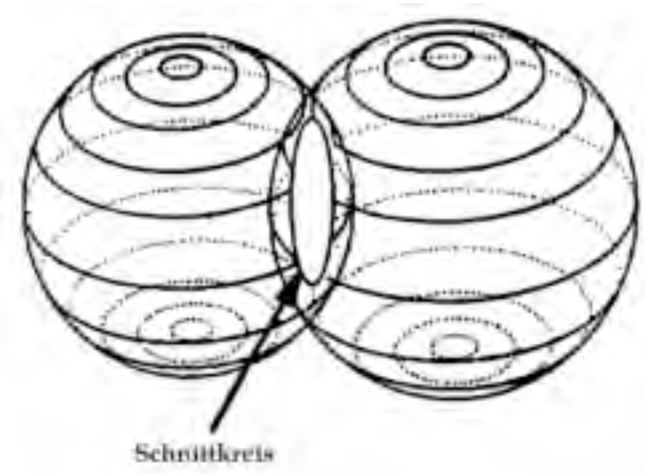
Positioning by signal runtime

- Measuring signal runtime from known senders
- More accurate than signal strength measurement but also more difficult
- Problems
  - Radio: Multi-path, atmospheric distortions
  - Good placement of senders necessary
- Enhance results by introducing reference points

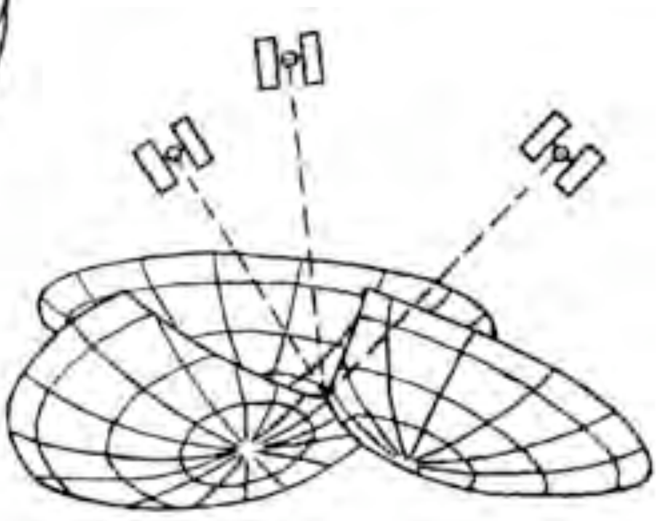
Global Positioning System (GPS)



one satellite



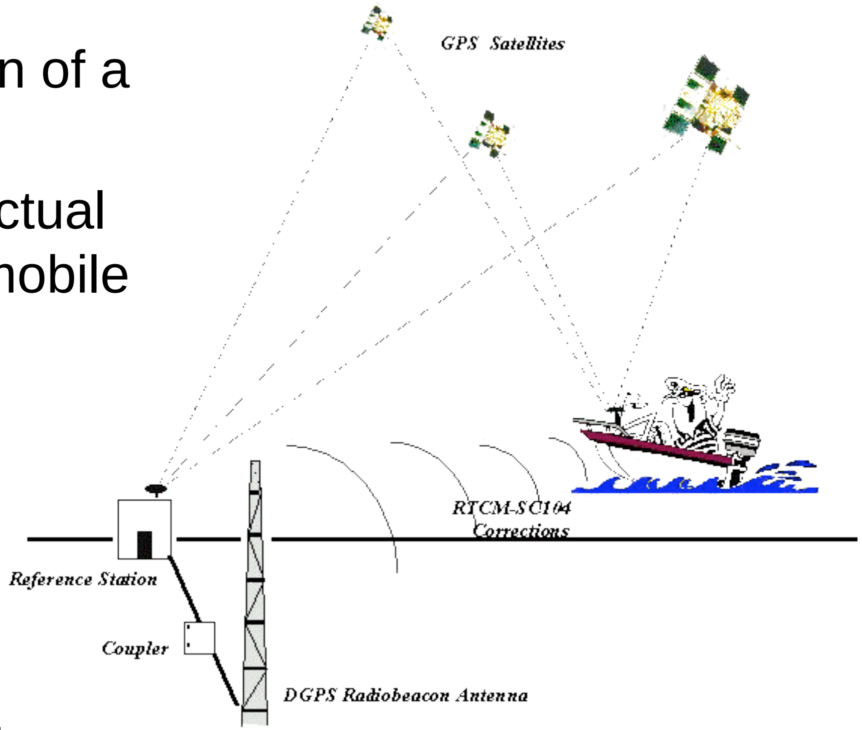
two satellites



three satellites

Differential GPS

- Increase the precision by using a correct reference signal
    - Need to know the exact position of a receiver
    - Send the difference between actual and measured position to the mobile device
- Problem: Delay of correction signal
- Used to be very important because of errors (300m) induced into GPS by US military

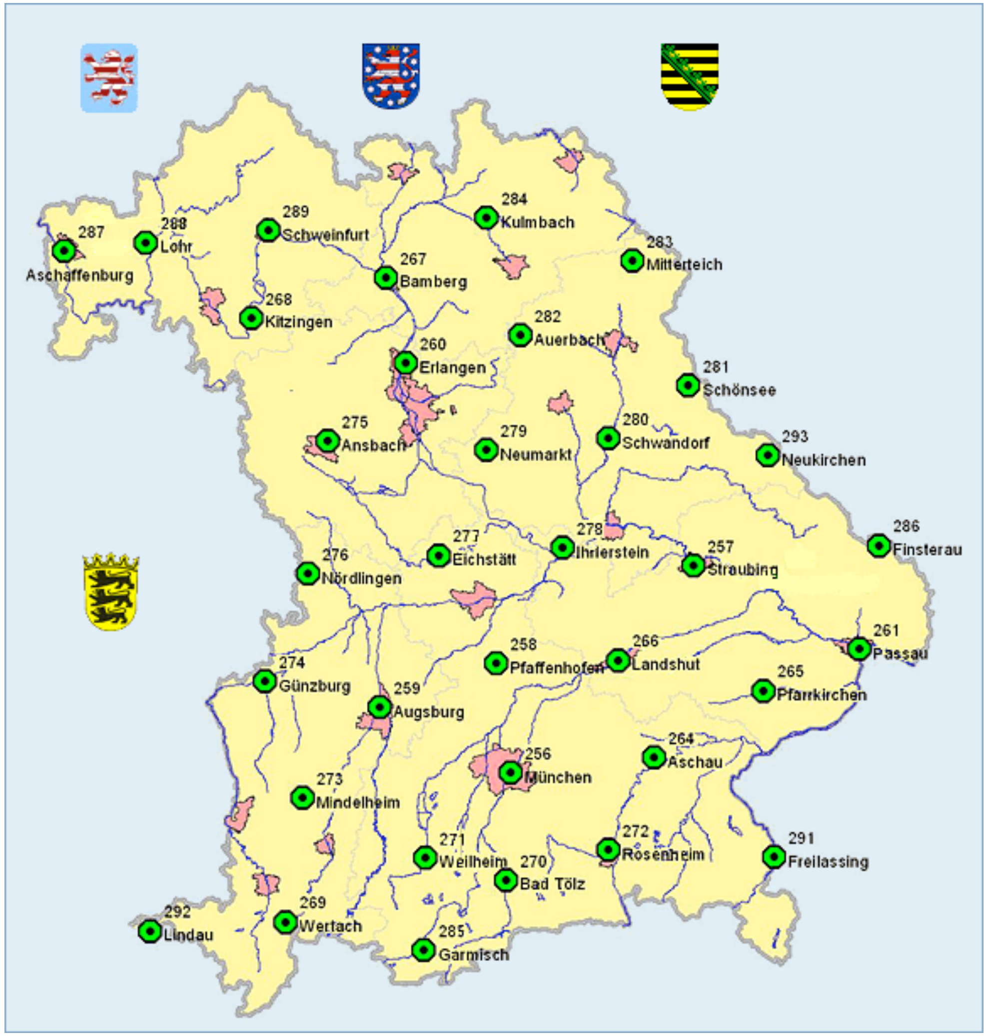


Differential GPS Broadcast Site

Landesvermessungsamt: SAPOS

- In Bavaria: 36 reference stations
- Networked with reference stations of other states to increase precision and reduce the number of stations needed

http://www.sapos.de/



[LVA Bayern 2005]

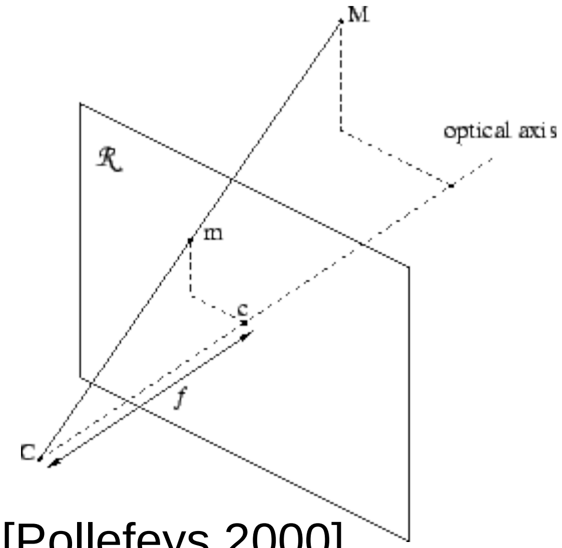
Camera-based Tracking

- Try to detect:
  - Objects directly (people, landmarks, features, textures)
  - Fiducials (e.g., 2D-Barcodes)

- Problems
  - Image processing is still hard
  - Mostly not very robust

Camera-based tracking: pinhole camera model

- Simple, but also applicable in practice
- Project 3D-Point (x,y,z) to 2D-Point (u,v)
- Can be refined by more complex geometry and by using actual intrinsic camera parameters (lens properties etc.)



[Pollefeys 2000]

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} f_x \dfrac{x}{z} \\ f_y \dfrac{y}{z} \end{pmatrix}$$

Camera-based tracking: 2D-3D-reconstruction

- Image analysis yields 2D-position of 3D points
  - Specific markers: simple and robust
  - Object features: between difficult and impossible
- Goal: determine 3D position and orientation of objects relative to the camera
- Problem: often not really possible with one camera
- Several solutions:
  - Use two or more cameras
  - Make assumptions about objects (e.g., marker size)

CyberCodes (Rekimoto2000)

- Idea: use camera to identify 2D-barcodes
- Get orientation, position and id of tags
- Use low-res camera with small form factor
- Cybercodes can be printed on any ordinary laser printer

www.csl.sony.co.jp/person/rekimoto.html

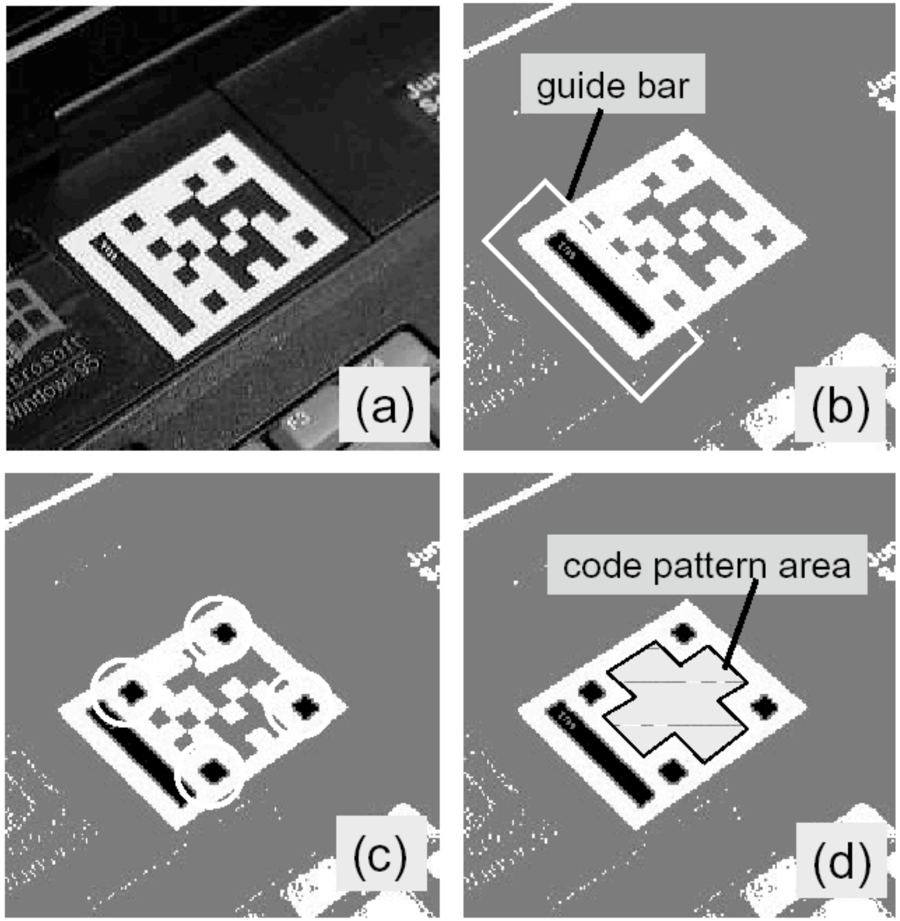
Identification Procedure

(a) CyberCode

(b) Identify guide bar

(c) Identify corners

(d) Identify pattern area



CyberCode enabled devices

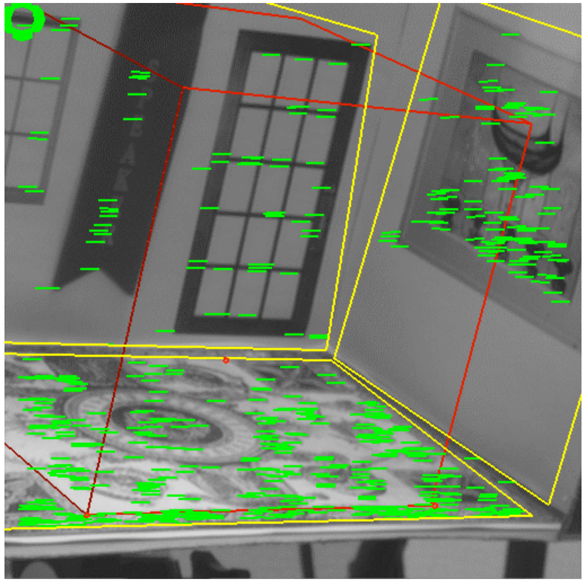
AR Toolkit

- Originally by Mark Billinghurst
- Design your own markers:
  - Black fringe with black symbol on white background
  - Edge length depending on camera resolution and distance
- From a video stream determine:
  - X/Y coordinates of markers in the picture
  - IDs of markers
  - Matrix describing the position and orientation of the marker relative to the camera in 3D
- Example application: Magic Book

http://www.hitl.washington.edu/research/shared_space/download/
http://www.ims.tuwien.ac.at/~thomas/artoolkit.php

Markerless (Feature) tracking

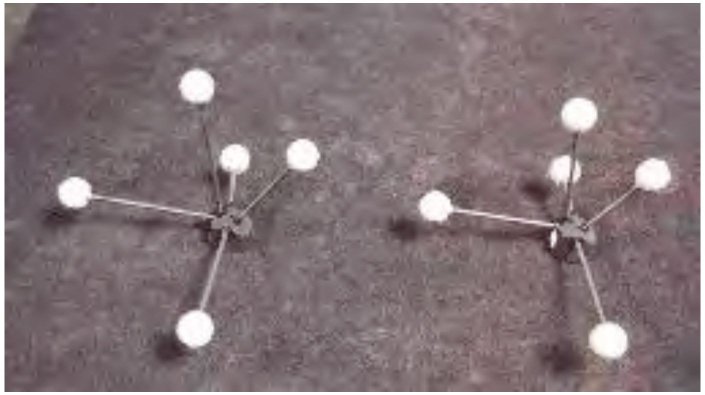
- Very active research topic today
  - Edge tracking
  - Key or feature points (Harris & Stephen, SIFT...)



Film: [Gordon & Lowe: Scene Modelling, Recognition and Tracking with Invariant Image Features, ISMAR 2004]

Infrared Camera Tracking

- Camera-based technique (e.g. ART GmbH)
  - Passive markers
  - Active markers
- Image processing relatively simple
  - High speed processing, high resolution.



Infrared Hiball-Tracker

(www.3rdtech.com/HiBall.htm)

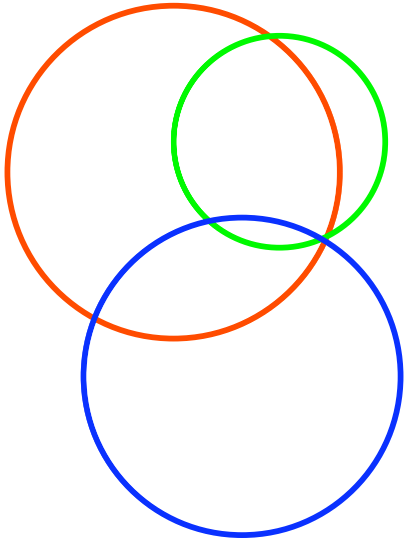
- LED-Array is sensed by multiple receivers
- High precision (1 mm, 0.3 degree)
- Needs cable-based infrastructure

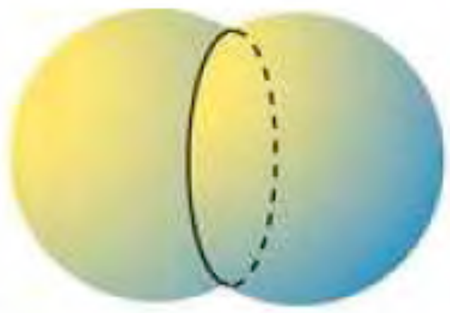
- Sensors detect flash pattern
- 2000 Hz readings

Ultrasonic tracking (e.g., www.isense.com)

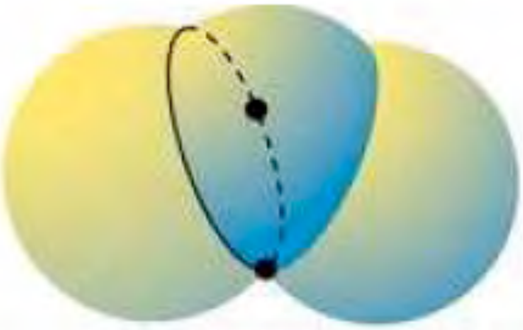
- High precision: 1 mm, 0.05 degrees
- Working area: 0.6-2 m²
- High price
- Very robust
- Application areas:
  - VR, Virtual Studio
  - Medical applications (preparation for surgery)
  - architecture, rapid prototyping

Ultrasonic tracking: Principle





[Bishop et al. 2001]



[Bishop et al. 2001]

2D:
3 circles determine a point

3D:
2 spheres determine a circle

3D:
3 spheres determine 2 alternative points

→ Exclude one by geometrical constraints

Ultrasonic tracking: reconstruction

- 3 spheres with radius r_i and center (x_i, y_i, z_i)

$$(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 = r_0^2$$
$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = r_1^2$$
$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = r_2^2$$

- Trick: move coordinate system
  - Sphere 0 to origin (0,0,0)
  - Sphere 1 at position (1,0,0)
  - Sphere 2 at position (0,1,0)

→ Can be transformed back to real world coordinates

Ultrasonic tracking: reconstruction

- Simplified equations:

$$x^2 + y^2 + z^2 = r_0^2$$

$$(x-1)^2 + y^2 + z^2 = r_1^2$$

$$x^2 + (y-1)^2 + z^2 = r_2^2$$

- Solution:

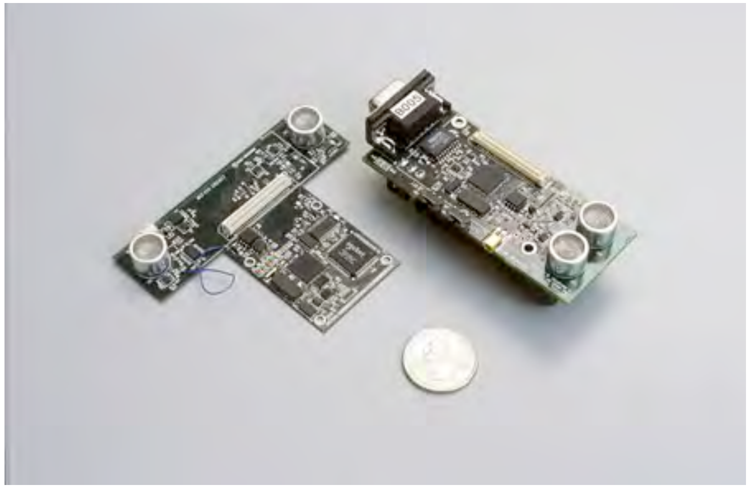
$$x = \frac{r_0^2 - r_1^2 + 1}{2}$$

$$y = \frac{r_0^2 - r_2^2 + 1}{2}$$

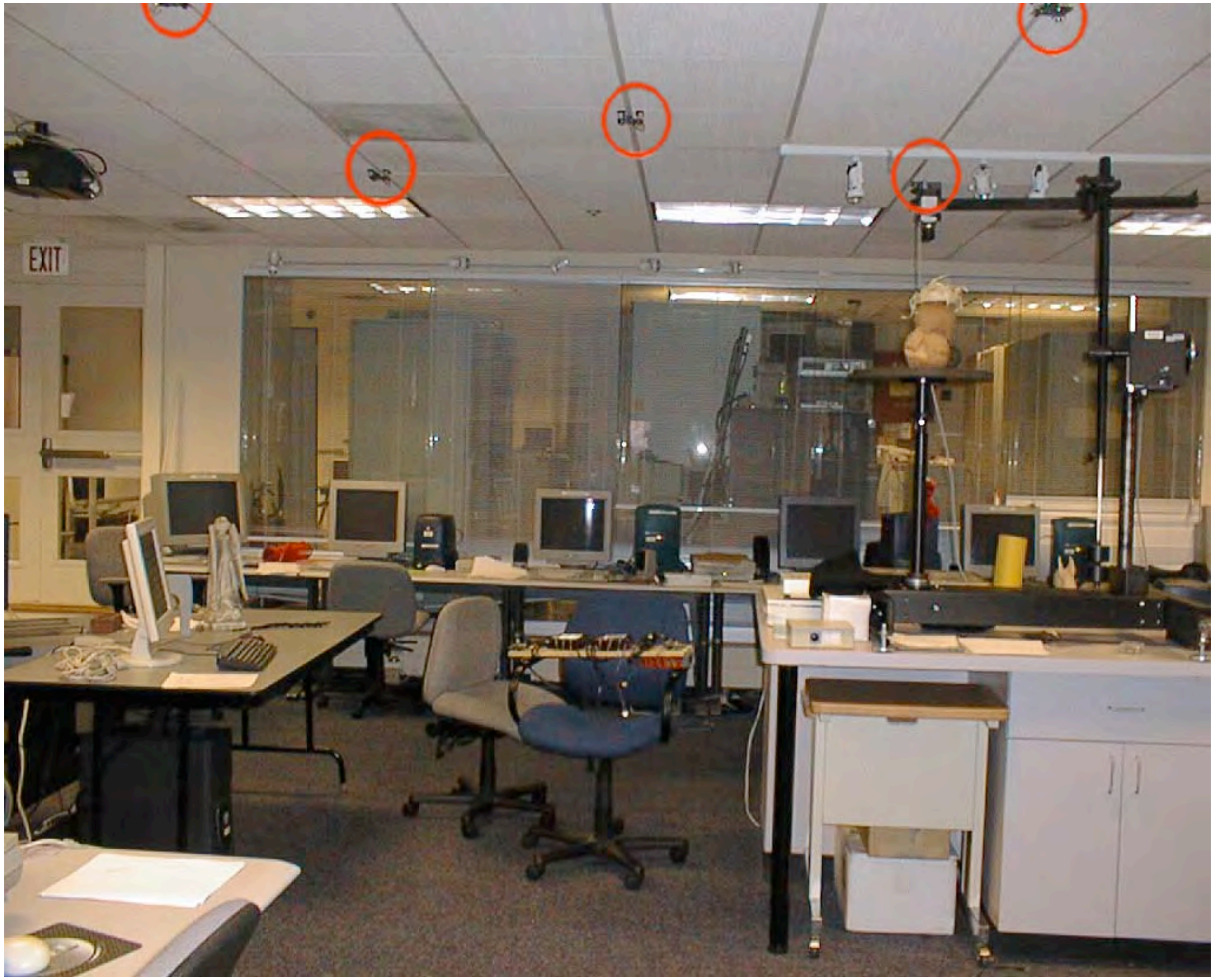
$$z = \pm\sqrt{r_0^2 - x^2 - y^2}$$

Combined techniques: Cricket (nms.lcs.mit.edu/projects/cricket/)

- Combination of radio and ultrasonic beacons
- Receiver and transmitter on the device
- Small size
- Available right now: Position
- Experimental: Position and orientation
- Precision: 1-3 cm, 5 degrees
- Problems: Multipath, ultrasonic to distinguish



Cricket Installation



Magnetic Tracking

(e.g., www.ascension-tech.com)

- Ascension Technologies: Flock of Birds
- Create reference magnetic field (using a big electrical magnet)
- Range up to 3m, updates up to 144 Hz
- Accuracy 1,8mm 0,5 degrees
- Use magnetic sensors as targets
  - Cables needed!
  - 6DOF: Position and Orientation
- Problems:
  - Field is warped by metal structures
  - CRT monitors unusable in the field

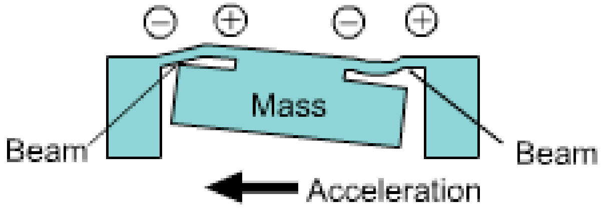
Inertial tracking: Basics

- Main principle: mass inertia
- Fast, Independent of infrastructure
- But: only relative measurements
- Problem: drift
  - Values change slowly
  - Over time, measurements are increasingly wrong
- Solution: combine with other techniques

Accelleration sensor

- Built from piezo elements and weights
- Integrated circuit

■Detection of acceleration in the X-axis (Y-axis) direction



■Detection of acceleration in the Z-axis direction

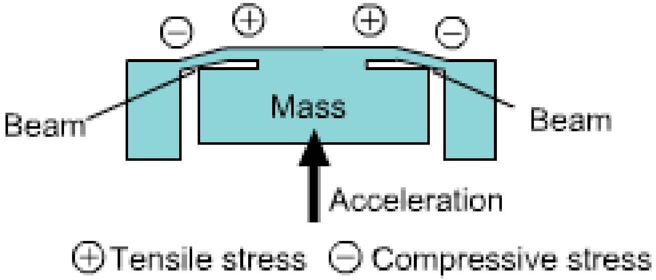
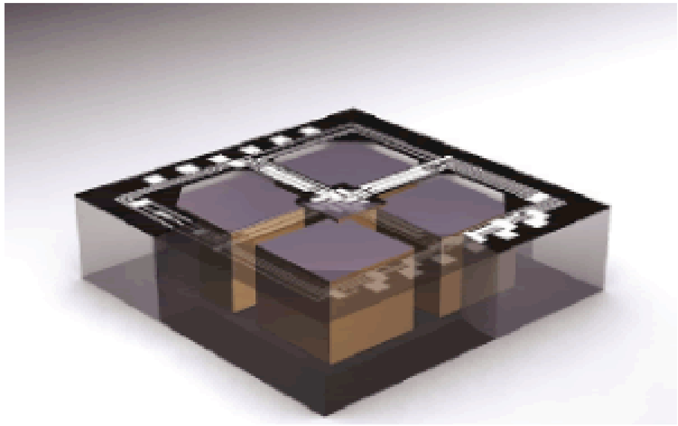
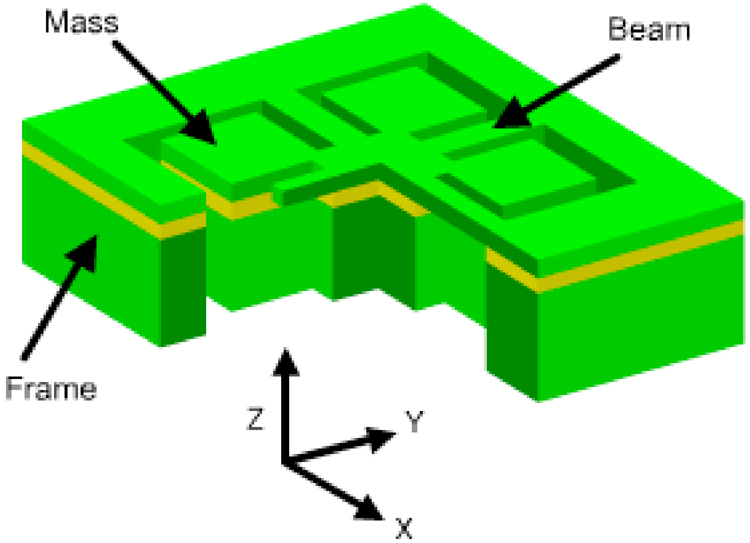
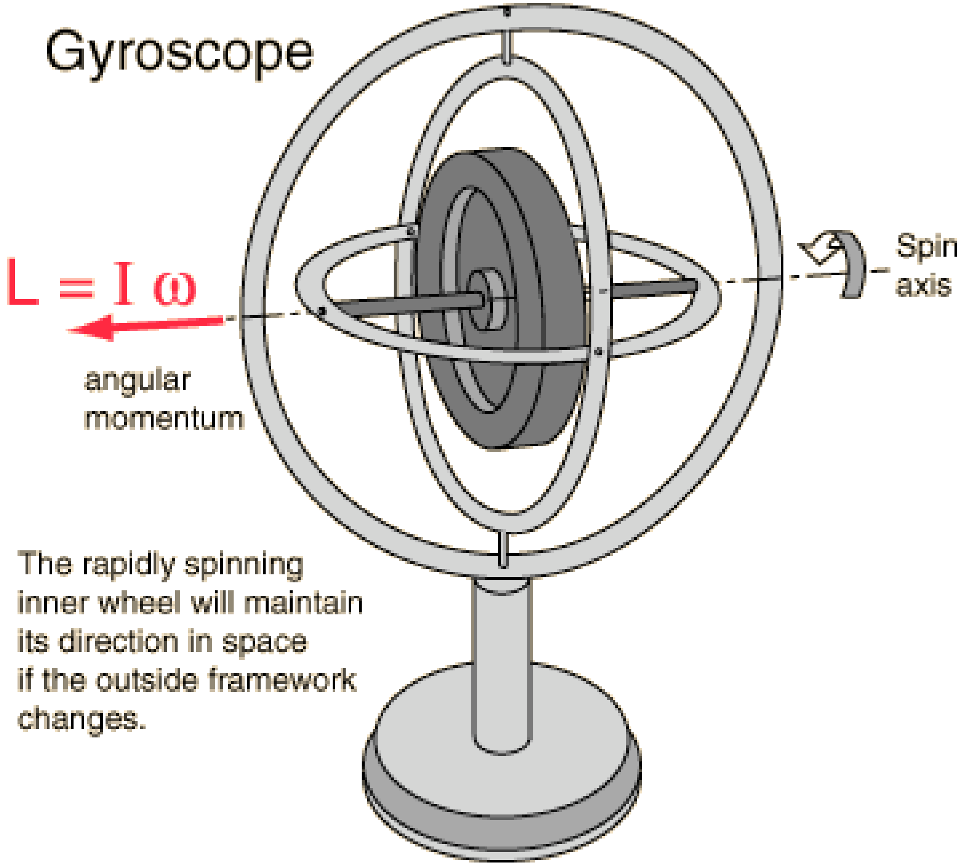


Figure 1 MEMS sensor chip in the GS3

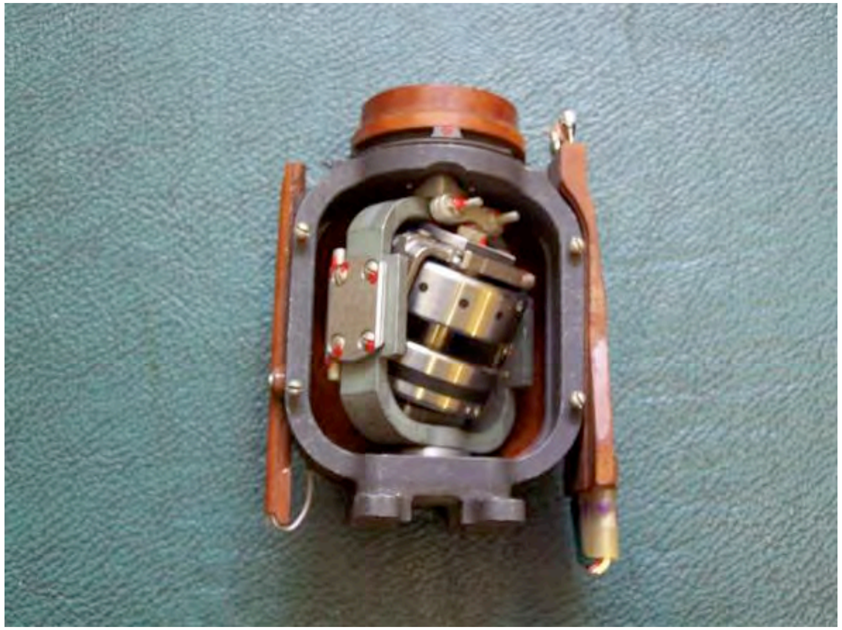




Gyroscope

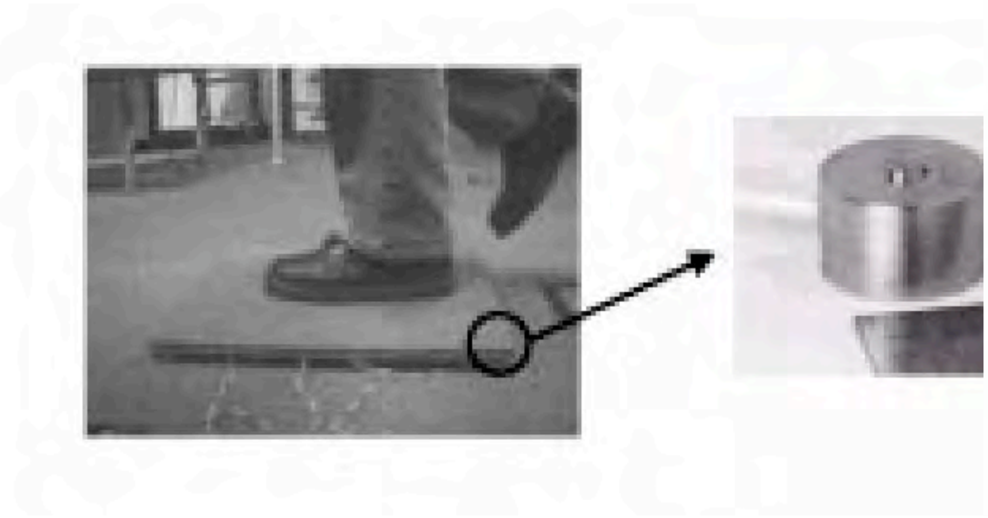

Gyroscope
$L = I\omega$
angular momentum
Spin axis
The rapidly spinning inner wheel will maintain its direction in space if the outside framework changes.

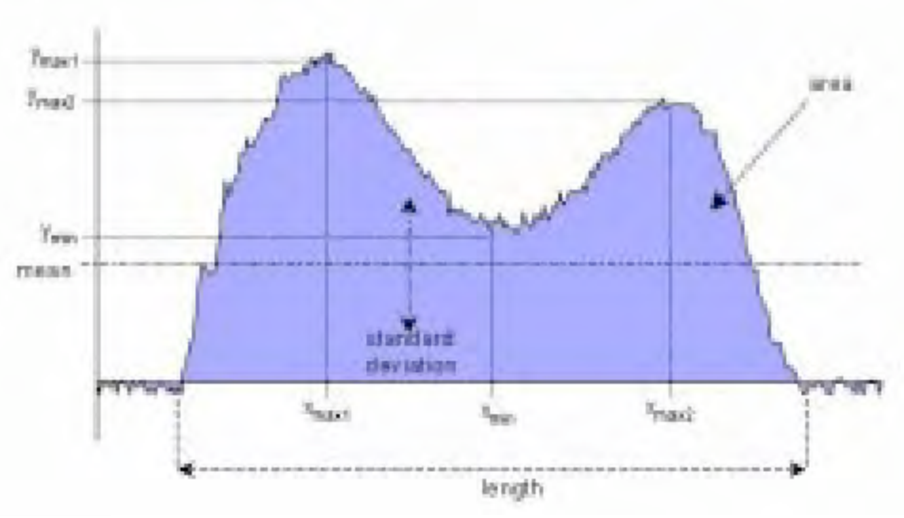

InterSense Wireless InertiaCube3™ Receiver
InterSense Wireless InertiaCube3™



Floor Sensors

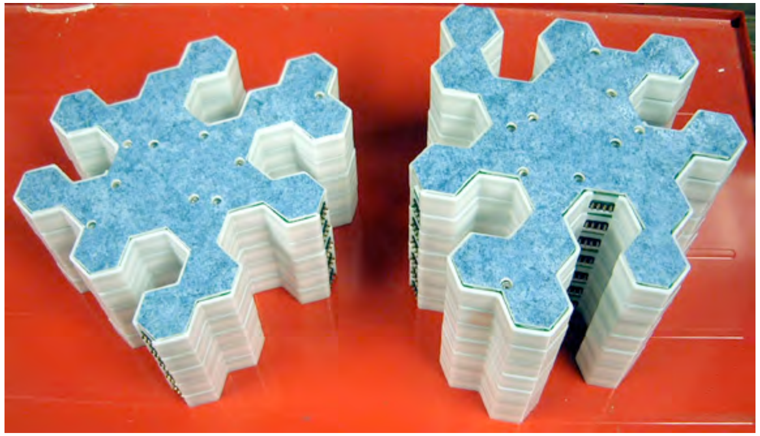
- Weight sensors integrated into the floor
- Measure steps and can even identify individuals
- Problems
  - Multiple users
  - High instrumentation of the environment
- www.cc.gatech.edu/fce/smartfloor/





Floor sensors (ztiles)

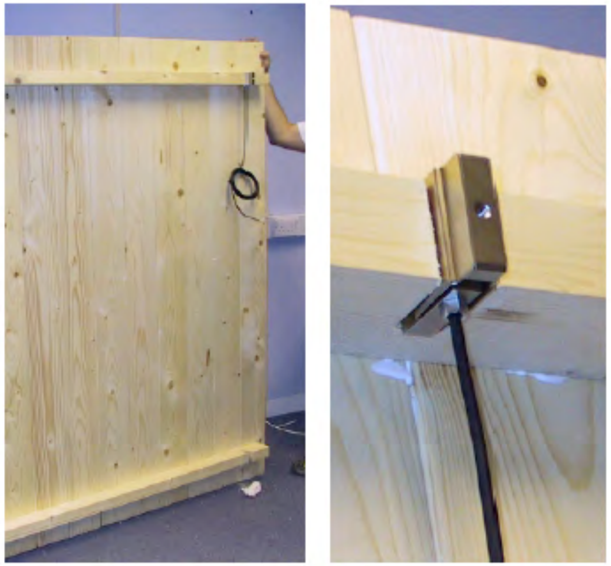
- Development towards pre-fabricated tiles (*McElligot et al. Ubicomp 2002*)
- Ad-hoc networking capabilities
- Easy to install
- Robust against failure of single elements
- www.media.mit.edu/resenv/ZTiles/
- www.idc.ul.ie/ztiles/



Load sensor areas

Schmidt et al. 2002, Strohbach, Lancaster Univ.
www.comp.lancs.ac.uk/~strohbach
Use load sensors to detect usage patterns

- on the floor
- on the tables
- on the shelves



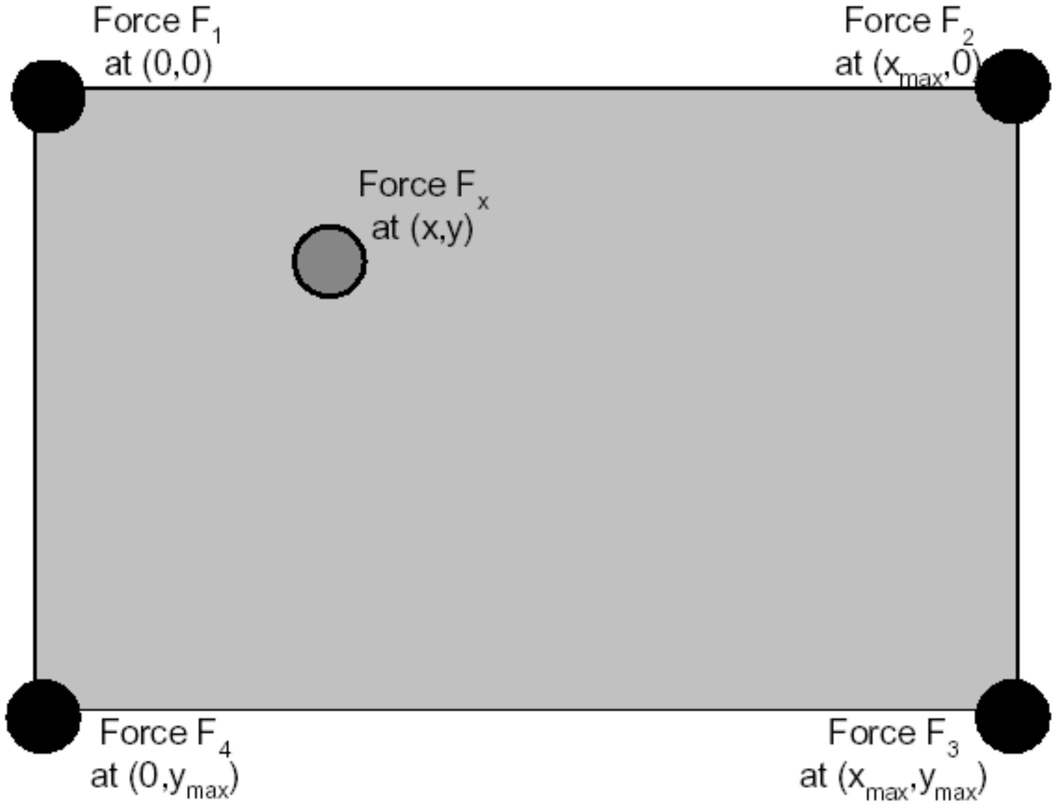
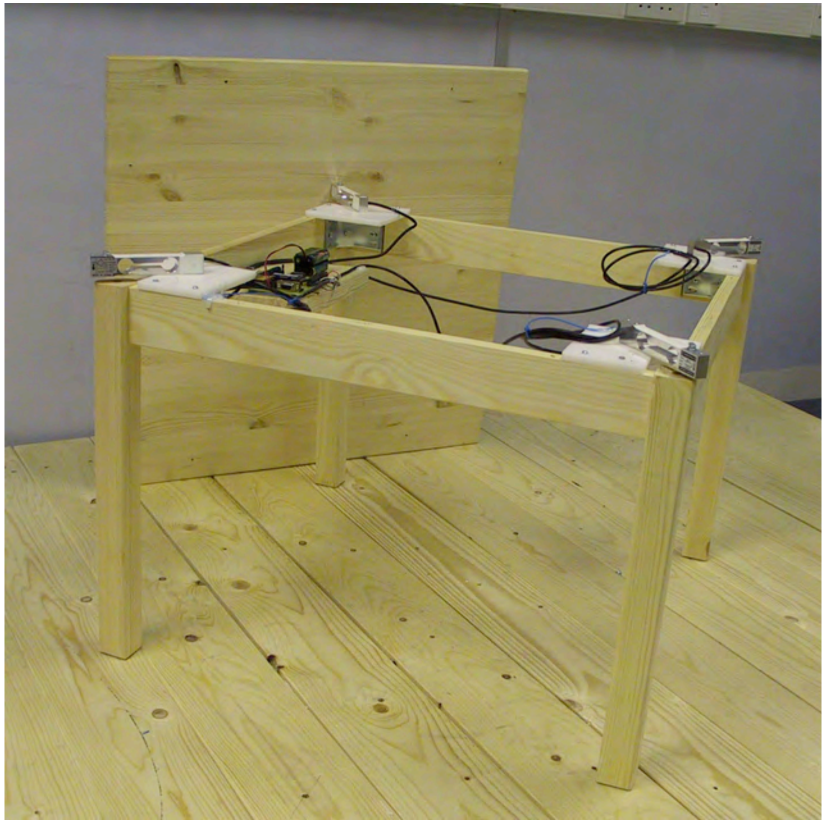
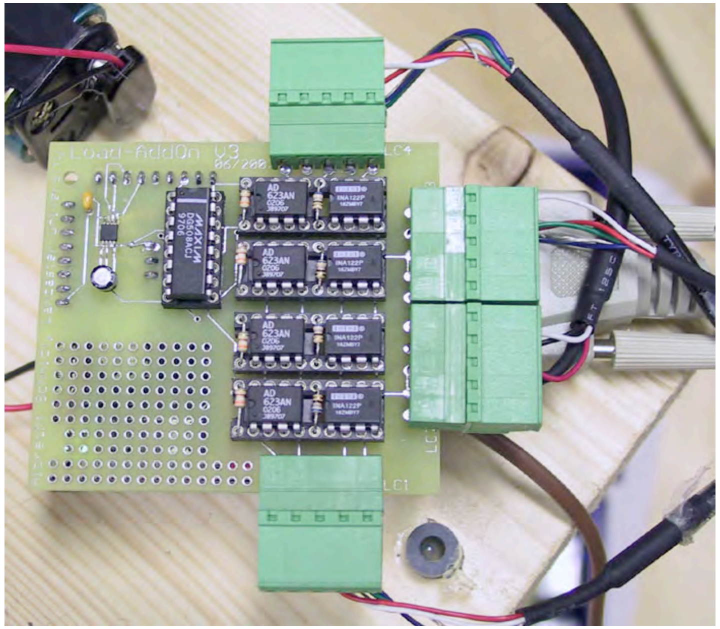
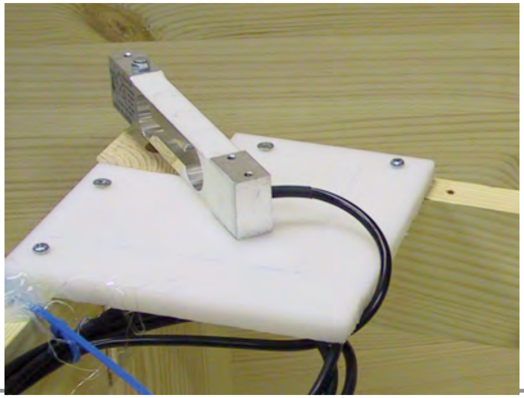


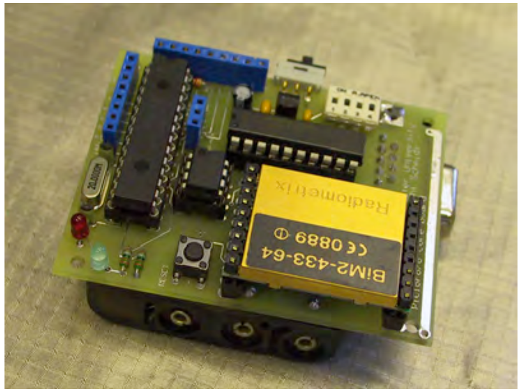
Table as a sensor area



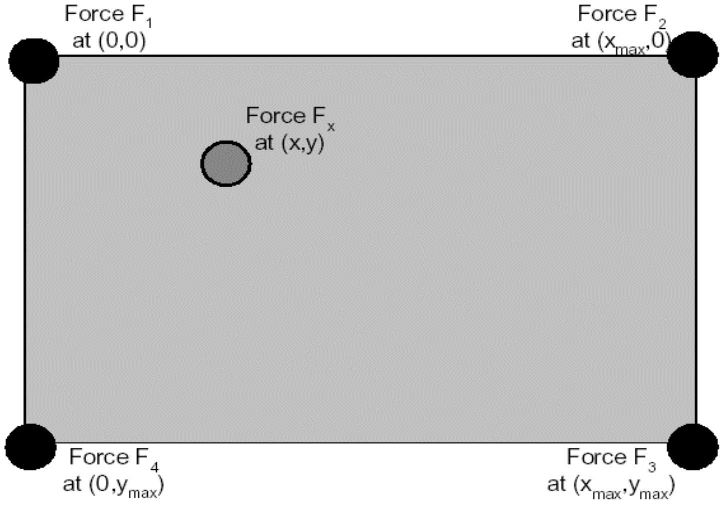


- Smart-Its sensor AddOn board
- 16 Bit DA
- Instrumentation Amps





Calculating the position



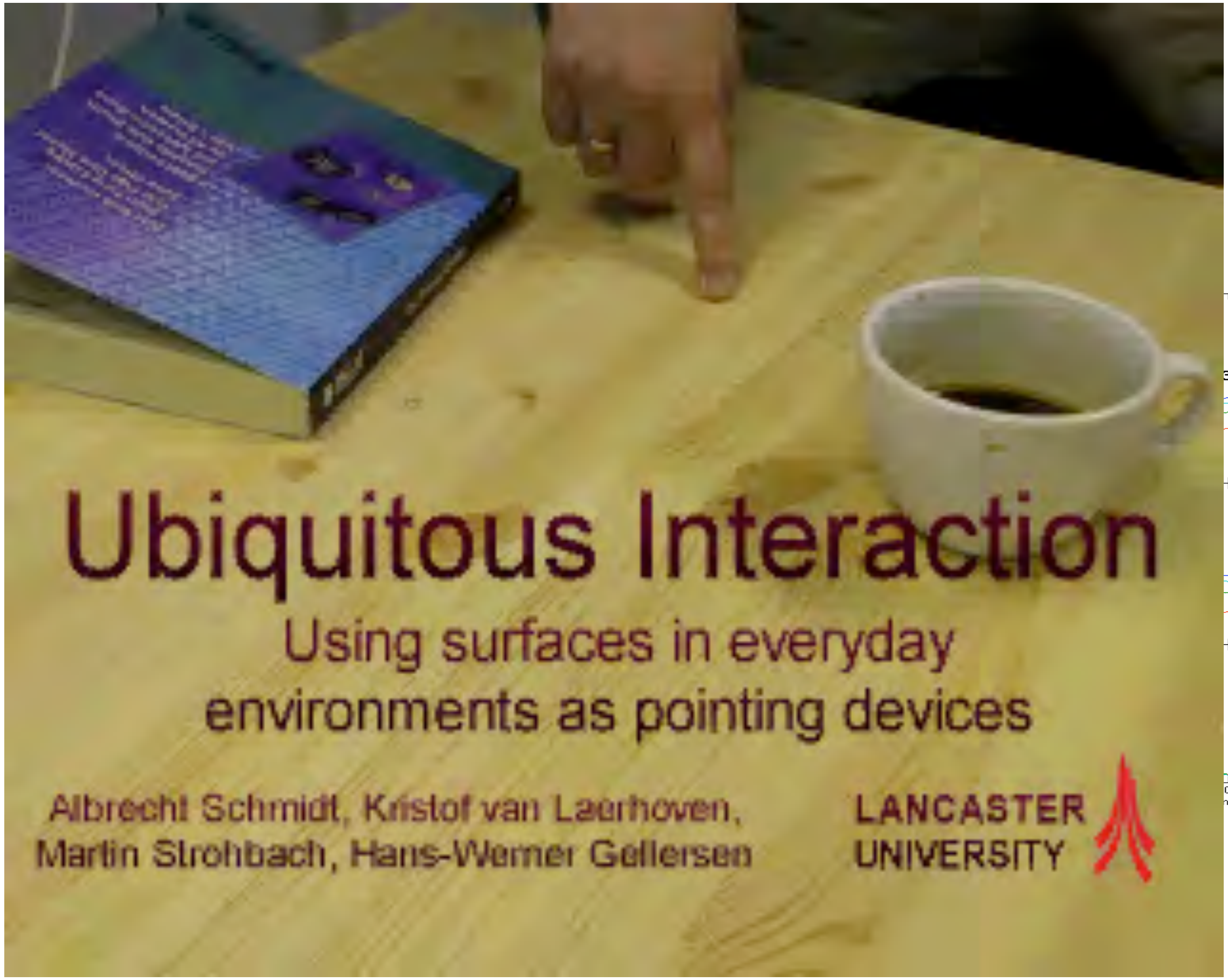
$$F_x = F_1 + F_2 + F_3 + F_4 \qquad (1)$$

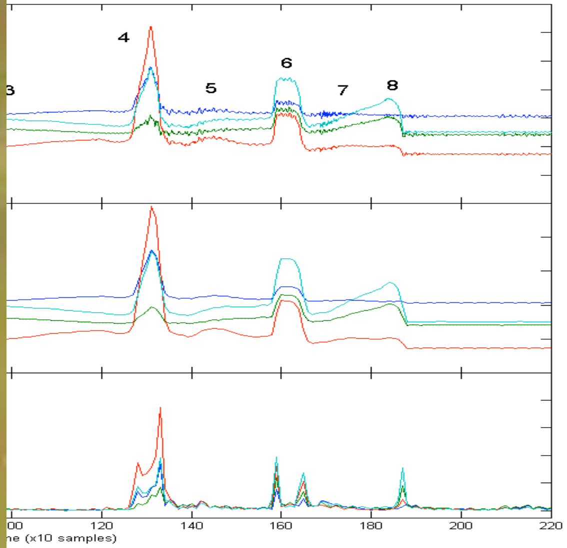
$$F0_x = F0_1 + F0_2 + F0_3 + F0_4 \qquad (2)$$

$$x = x_{\max} \frac{(F_2 - F0_2) + (F_3 - F0_3)}{(F_x - F0_x)} \qquad (3)$$

$$y = y_{\max} \frac{(F_3 - F0_3) + (F_4 - F0_4)}{(F_x - F0_x)} \qquad (4)$$

Video: Load-Sensing Table





Tracking: general considerations and meta-techniques

Inside-out tracking

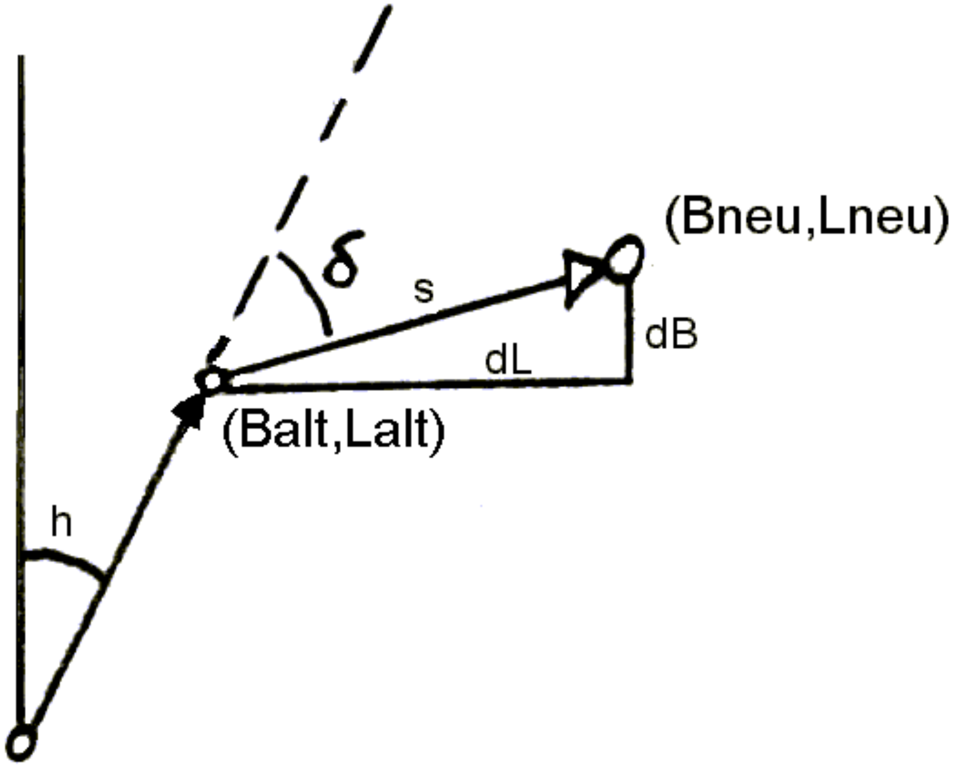
- Process of positioning is done locally
- Observe external cues
  - Examples: PDA with camera, GPS
- Active localization by processing perceived signals

Outside-in tracking

- Infrastructure observes user
  - Radio, IR, acoustics,
- Environment knows all user positions
- Processing in the environment of signals perceived from mobile unit

Dead Reckoning

- Oldest navigation technique for sailors
- Starts with one known position (e.g. the harbor)
- Determine new position from measured speed and direction
- For indoor purpose
    - Try to detect steps
    - Use gyro/compass to determine orientation



Sensor fusion

Problem:

there is no perfect tracker.

Idea:

combine several sensors to make up for specific weaknesses

Variations:

- Integrate several sensors in 1 device
- Combine several devices by additional software

Types of sensor fusion

complementary:

- Sensors don‘t depend on each other
- Example: GPS + compass&altimeter

concurrent:

- Several sensors determine same relation
- Used to minimize errors

cooperative:

- Each sensor provides only partial information
- Example: (human) stereo vision