Location Sensing

Mobile Computing and the IoT
Wireless and Mobile Computing

George Roussos

g.roussos@dcs.bbk.ac.uk

Birkbeck
UNIVERSITY OF LONDON

Session Overview

- What is location sensing
- How do we use location
- Location sensing system properties
- Location sensing techniques
  - Triangulation
  - Proximity
  - Scene analysis
- System examples

Location sensing

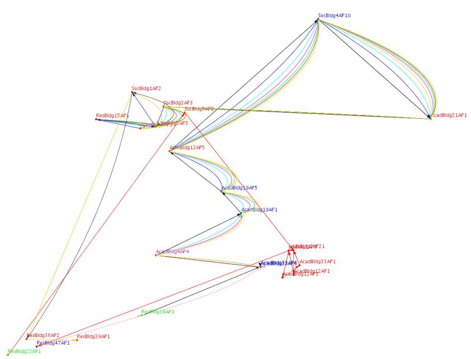
- Use computing and digital communications to find location
- How did we do it before?
  - visually using landmarks in the environment
  - tactile to recognize objects
  - used the positions of starts
  - somebody else told us where we are
- Why do we need location?
  - to navigate
  - to know how to behave (c.f. place)

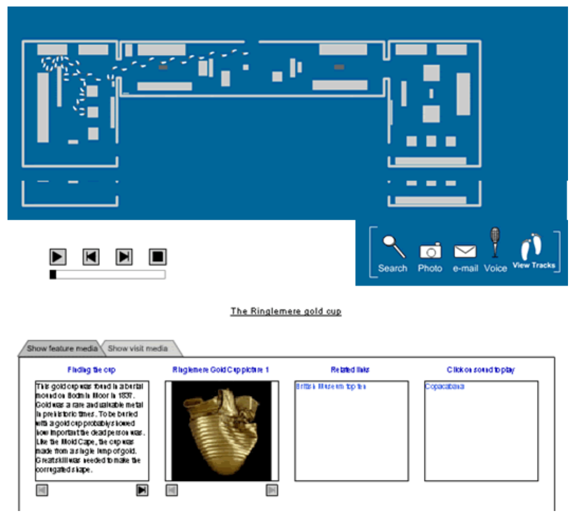
Uses of location

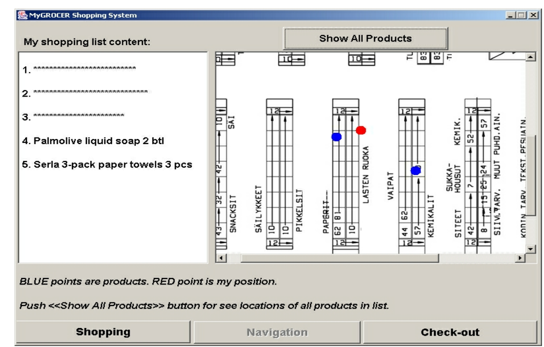
- Mapping and navigation systems
- Tracking people and objects
- Wireless routing (geo-casting)
- Gaming and robots
- Health and wellness (e.g. self quantification)
- Supporting smart spaces and location-based applications
  - Adapt to current user context

Example (research) applications

- Car navigation systems
- Tourist guides
- Indoor guides
- Tracking
- Context







Location System Properties

- Physical position and symbolic location information
- Absolute versus relative locations
- Localized location computation capability
- Accuracy and Precision
- Scale
- Recognition capability
- Cost
- Limitations

Physical Position and Symbolic Location

- Location information can be
  - Physical (47º39’17’’ N by 122 º18’23” W)
  - Symbolic (in the kitchen, next to a mailbox)
- Symbolic location information can be derived by physical position with additional information.
- Using only symbolic location information can yield very coarse-grained physical positions

Absolute vs. Relative

- Absolute location system
  - Shared reference grid for all objects
  - Can be transformed into a relative location
- Relative location system
  - Each object may have own frame of reference
  - Can transform into absolute location from relative location readings
    - Must know absolute position of reference points

Localized Location Computation

- Location computation can happen in:
  - The object being located
    - Ensures privacy
  - The external infrastructure
    - Lower computational and power demands on objects
    - Many more applications possible

Accuracy and Precision

- Accuracy
  - Grain size (e.g. “within 10 meters”)
- Precision
  - Probability of achieving a particular accuracy
- Sensor Fusion
  - Tries to improve accuracy and precision through integration of location systems to form hierarchical and overlapping levels of resolution
- Adaptive Fidelity
  - Ability to adjust precision in response to dynamic events like partial failures.

Scale

- Scale assessed by:
  - Coverage area per unit of infrastructure (e.g "1 base station per 10 square meters")
  - Number of objects the system can locate per unit of infrastructure per time interval (e.g. "25 computations per room per second")
- Larger scale achieved by increasing infrastructure

Recognition

- Necessary for applications that take specific actions based on location of object (e.g. airport baggage handling system)
- GUID (Globally Unique ID)
  - Used to provide recognition capability
  - Combined with other contextual information allows for different object interpretations in different settings. (e.g retrieving museum information in a particular language)

Cost

- Time
  - Installation process length
  - System administration needs
- Space
  - Amount of installed infrastructure
  - Hardware size
- Capital
  - Price per mobile unit or infrastructure element
  - Support personnel salaries

Limitations

- Improper functionality in certain environments:
  - Signal strength indoors
  - Exceeding request limits
  - Frequency interference

Location Sensing Techniques

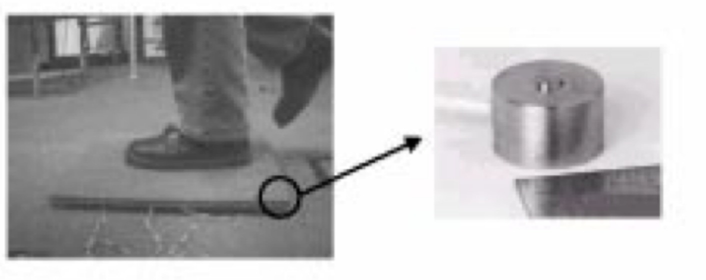
- Proximity
- Triangulation
- Scene analysis
- Other options
- Improving performance

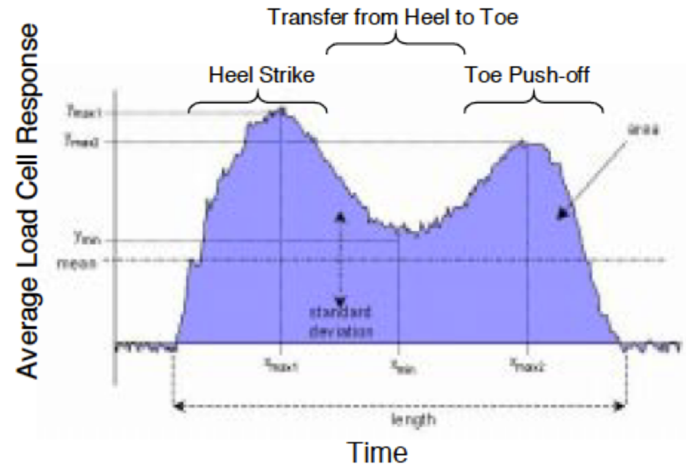
Proximity

- Identify location as near known landmark or other feature
- Physical contact
  - pressure, touch sensors or capacitive detectors
  - computer login
  - credit card or ATM transaction

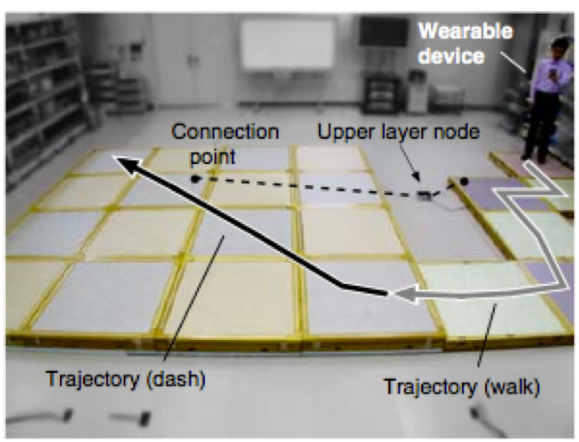
Sensing Floors

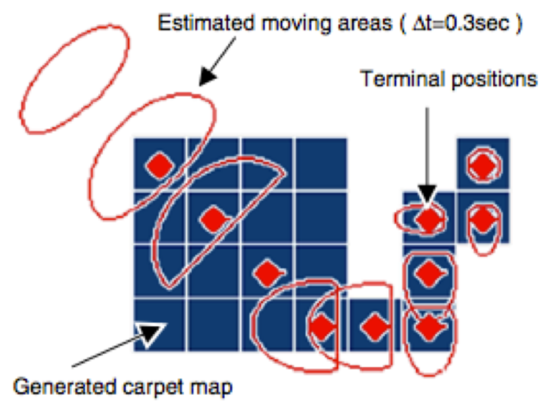
Orr and Abowd, The Smart Floor: A Mechanism for Natural User Identification and Tracking





Fukumoto and Mitsuru Shinagawa, CarpetLAN: A Novel Indoor Wireless(-like) Networking and Positioning System





Gravity Space video http://www.youtube.com/watch?v=9o7r3FVYvoI

Visual Markers

- Barcode encoding location information
  - Varied types of location
  - QR codes increasingly popular
- More advanced visual markers
  - Include orientation and rotation
  - Commonly referred to as fiducials
  - Used in augmented reality

BBC Mobile Location Tag

Fiducial marker

Mobile augmented reality

Using fiducials to overlay information e.g. 3D object models, on images captured via the mobile phone camera. Fiducials are used to provide the location where information will be superimposed.

Source: http://www.cs.columbia.edu/~ohan/

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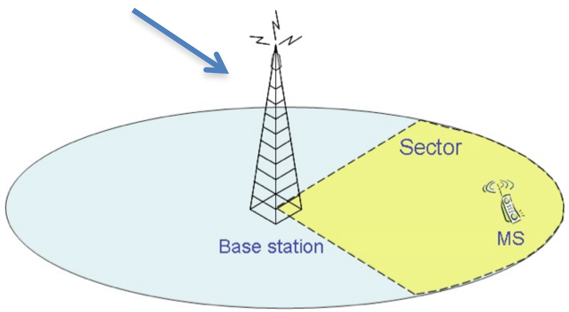
Proximity via wireless

- Device is located within range of an access point
  - GSM or other cellular a.k.a Cell-ID
  - Wi-Fi
  - Bluetooth or other low power wireless
  - RFID

Cell ID

Each BTS has unique ID
(within operator domain)




```
{
  "cellId": 42,
  "locationAreaCode": 415,
  "mobileCountryCode": 310,
  "mobileNetworkCode": 410,
  "age": 0,
  "signalStrength": -60,
  "timingAdvance": 5555
}
```

- BTS has unique ID within operator network
- MCC mobile country code
- MNC mobile network code
- LAC Location area code
- Also possible to identify the sector where MS is located
- Geolocate e.g. via Google API

RFID Location tags

- Affix tags at locations
- Tags transmit location identifiers thus allowing locations sensing
- Extensive installation at Shinjuku in Tokyo (ucode)
- Same idea can be employed indoors

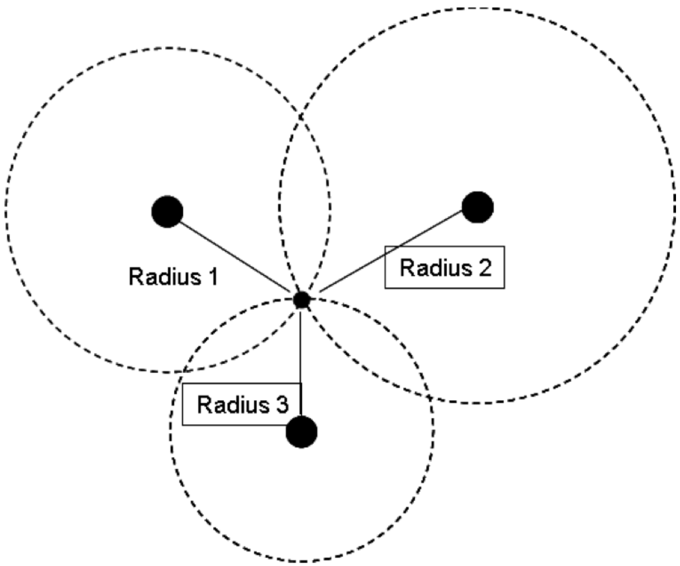
Proximity tags in museum exhibits

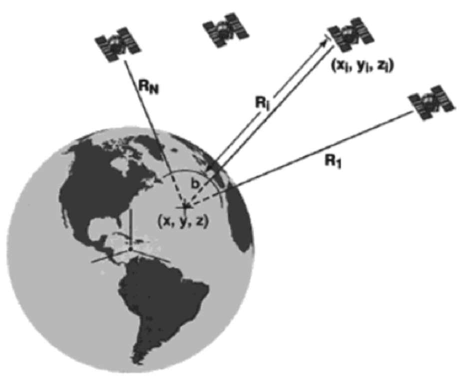
- Tags in the floor read by displays on wheels at the Okayama City Digital Museum
- PDA recognizes specific exhibits at Granite State MetalWorks
- San Francisco MOMA installation than displays live social networking information

Triangulation

- Compute object locations using the properties of triangles (e.g law of sines, Pythagorean theorem etc)
- Several combinations of distance/angle measurements would work
- Generalization into 3 dimensional objects
- E.g. 3 non-collinear points are needed in 2D and 4 non-collinear points are needed in 3D

Lateration





$$r_1^2 = x^2 + y^2 + z^2$$
$$r_2^2 = (x-d)^2 + y^2 + z^2,$$
$$r_3^2 = (x-i)^2 + (y-j)^2 + z^2$$

subtract the second from the first and solve for *x*

$$x = \frac{r_1^2 - r_2^2 + d^2}{2d}$$

substituting back into the formula for the first sphere produces the formula for a circle, the solution to the intersection of the first two spheres:

$$y^2 + z^2 = r_1^2 - \frac{(r_1^2 - r_2^2 + d^2)^2}{4d^2}$$

setting this formula equal to the formula for the third sphere finds

$$y = \frac{r_1^2 - r_3^2 + (x-i)^2}{2j} + \frac{j}{2} - \frac{(r_1^2 - r_2^2 + d^2)^2}{8d^2 j}$$

we can simply rearrange the formula for the first sphere to find the z-coordinate

$$z = \sqrt{r_1^2 - x^2 - y^2}$$

Lateration Measurements

Types of measurements

- Direct touch
  - Measure distance directly
- Time-of-flight of the radio signal between transmitter and receiver
  - Measure time and then calculate the distance using the speed of the signal
- Signal attenuation ie. drop in the strength of a signal as it propagates in space
  - Measure the signal at the receiving end and then calculate the distance as the drop to what the signal was at the source

Lateration Measurements

- Time-of-flight example
  - sound waves
  - speed 344m/s at 21^{o}C
  - distance = time x speed
  - speed depends on environmental conditions
  - depends on accurate timings
- Signal attenuation
  - calculate based on send and receive strength
    - Absorption, scattering, interference
    - Free space loss = 32.4 + 20xLog F(MHz) + 20xLog R(Km)
  - attenuation varies based on environment

Time-of-Flight Problems

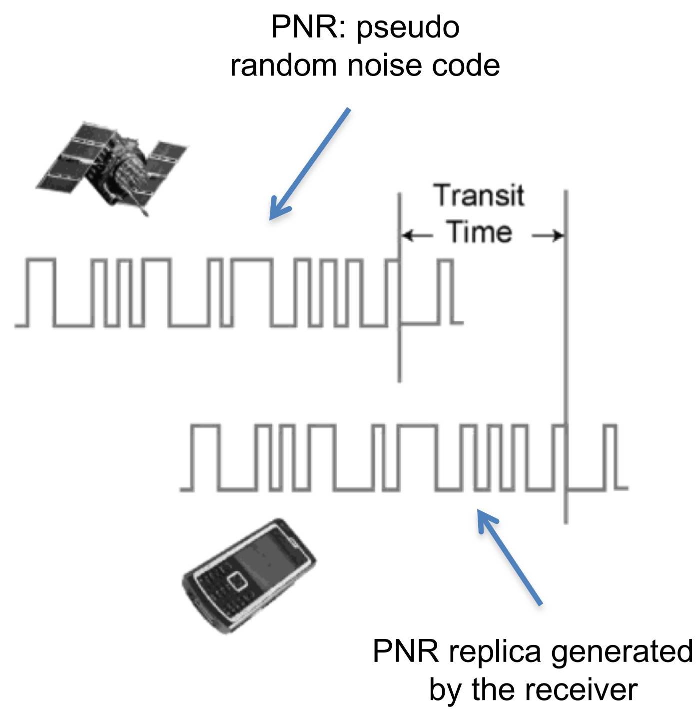
- Often requires high time resolution (for accurate light or radio propagation measurements)
  - a light pulse which travels at 299,792,458m/s will cover 5m in 16.7ns
  - a 0.001 sec error leads to 200 miles error!
- Clock synchronization critical
  - Accurate synchronization between reference beacons and receivers
  - Beacons could use atomic clocks (100k cost)
  - Could improve using extra measurements

Global Positioning System

- 31 satellite constellation
- 24 required for global coverage
- More than 50 launched since 1978
- Powered by solar energy
- Each carries a 4 rubidium atomic clocks
  - locally averaged to maintain accuracy
  - updated daily by US Air Force Ground control
- Satellites are precisely synchronized with each other
- 400 M USD operating costs per year

Global Positioning System

- Receiver is not synchronized with the satellite transmitter
- Satellites transmit their local time in the signal
- Satellites transit their location in the signal
- Receivers compute their difference in time-of-arrival
- Receivers not synchronised

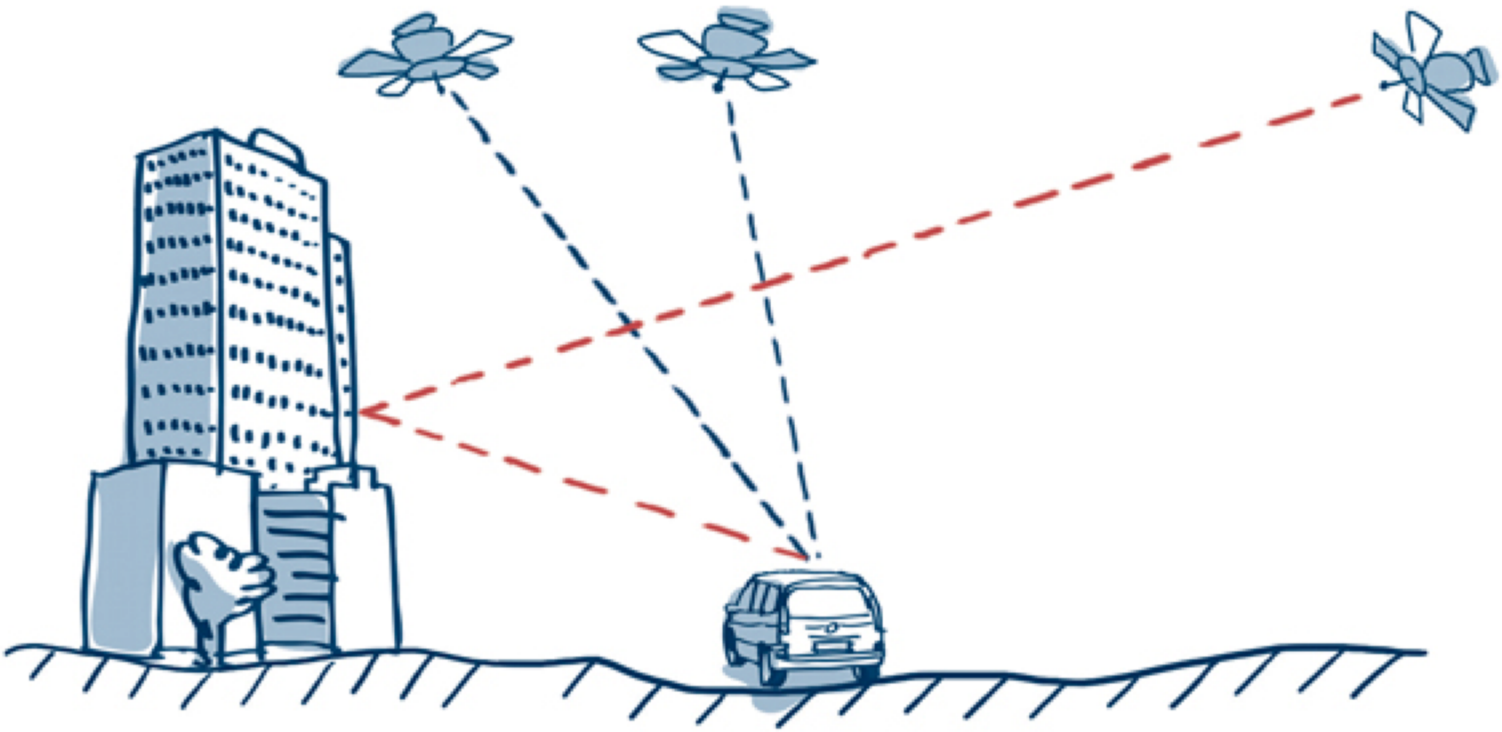


Errors in GPS

- Receivers estimate their position (longitude, latitude, elevation) using (at least) 4 satellites
- Accuracy is about 5 meters
  - 20 meters until recently when random error was introduced
  - called selective availability this was a military feature

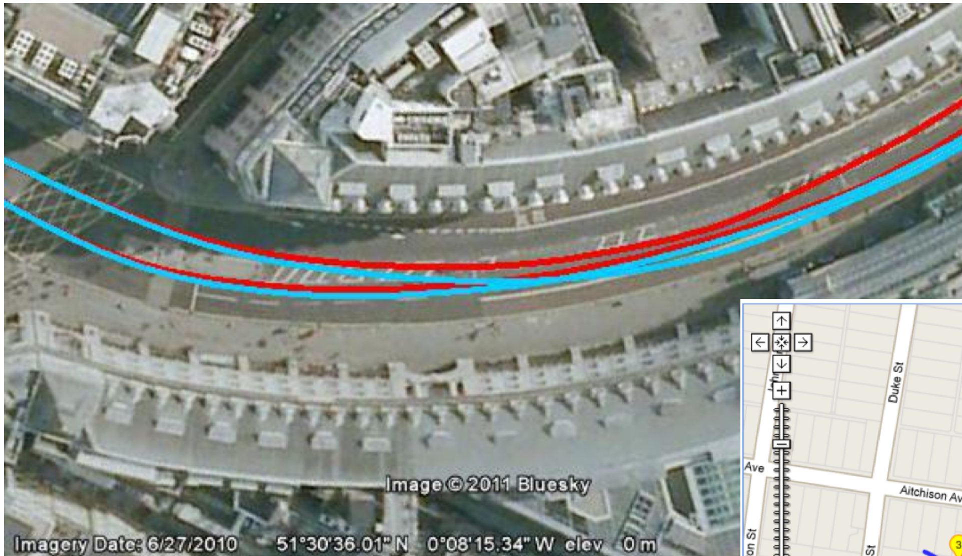
Error Source	One-sigma error (m)
Ionosphere	4.0
Troposphere	0.7
Satellite position data	2.1
Satellite clock	2.1
Multipath	1.4
Average error	*5.3*

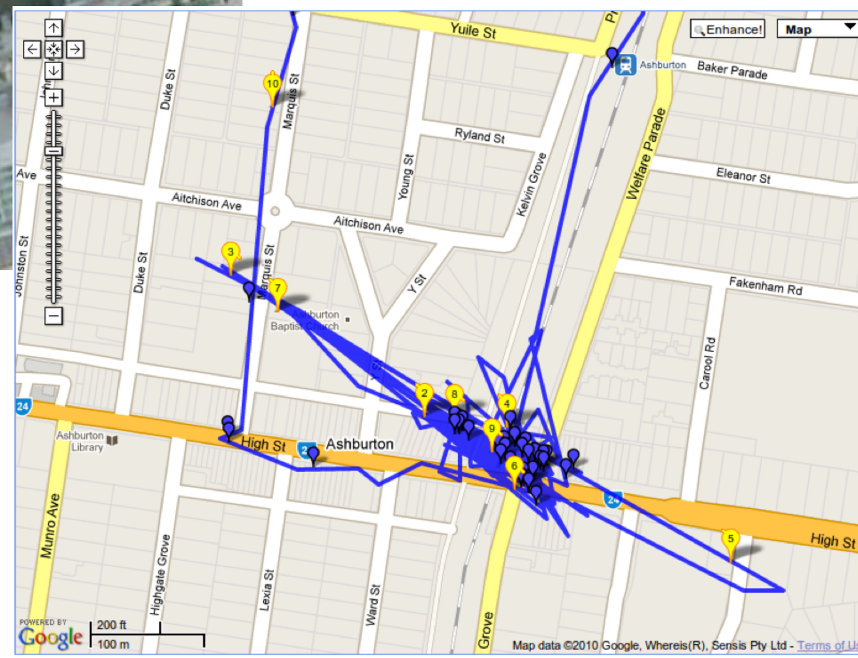
Multipath



Source: Bosch Sensortec

Observable error





Source: Oxford Technical Solutions oxts.com

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Urban Canyons

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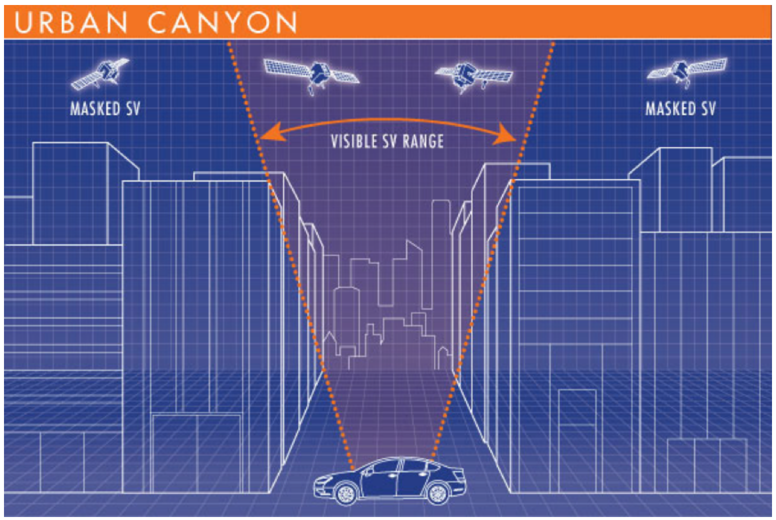
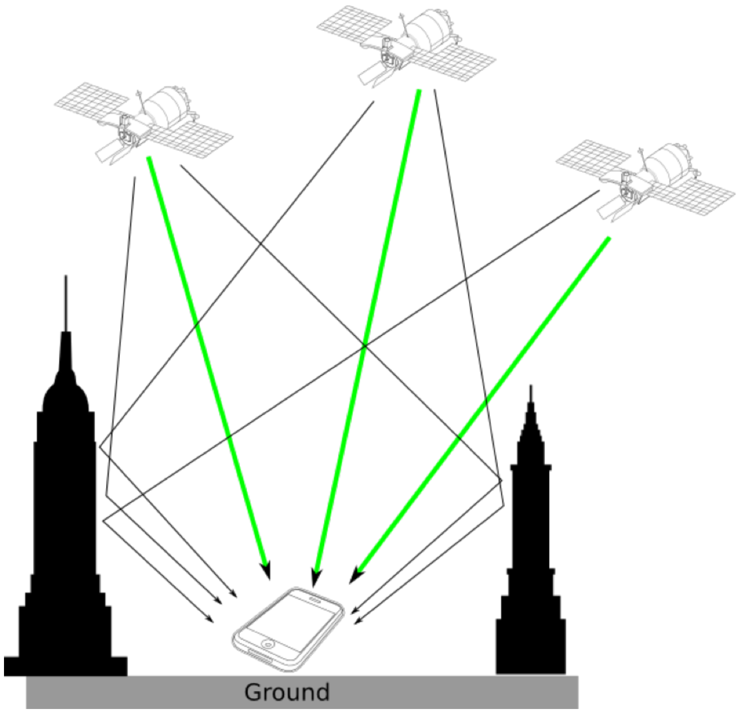
GPS in Urban Canyons

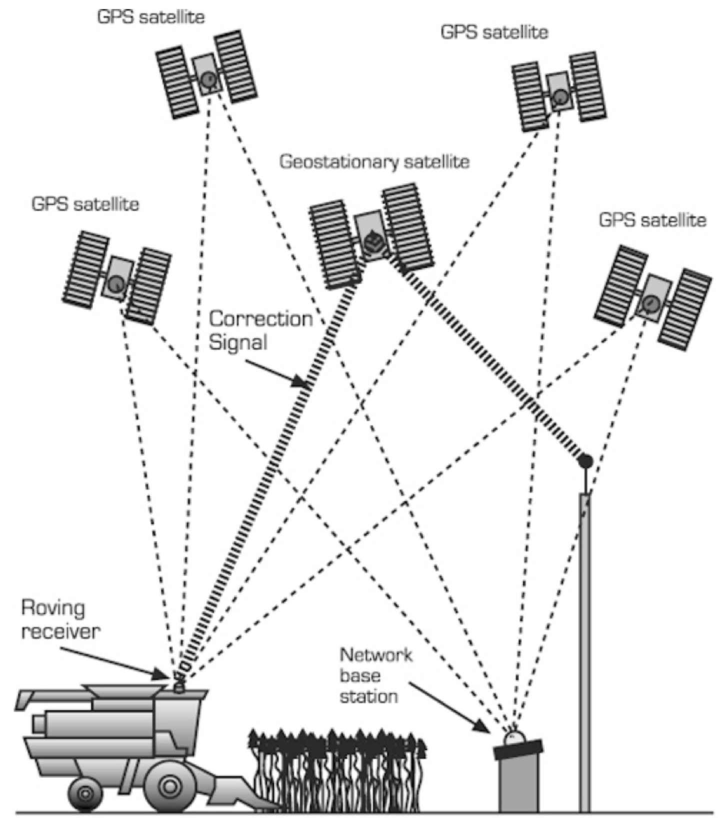




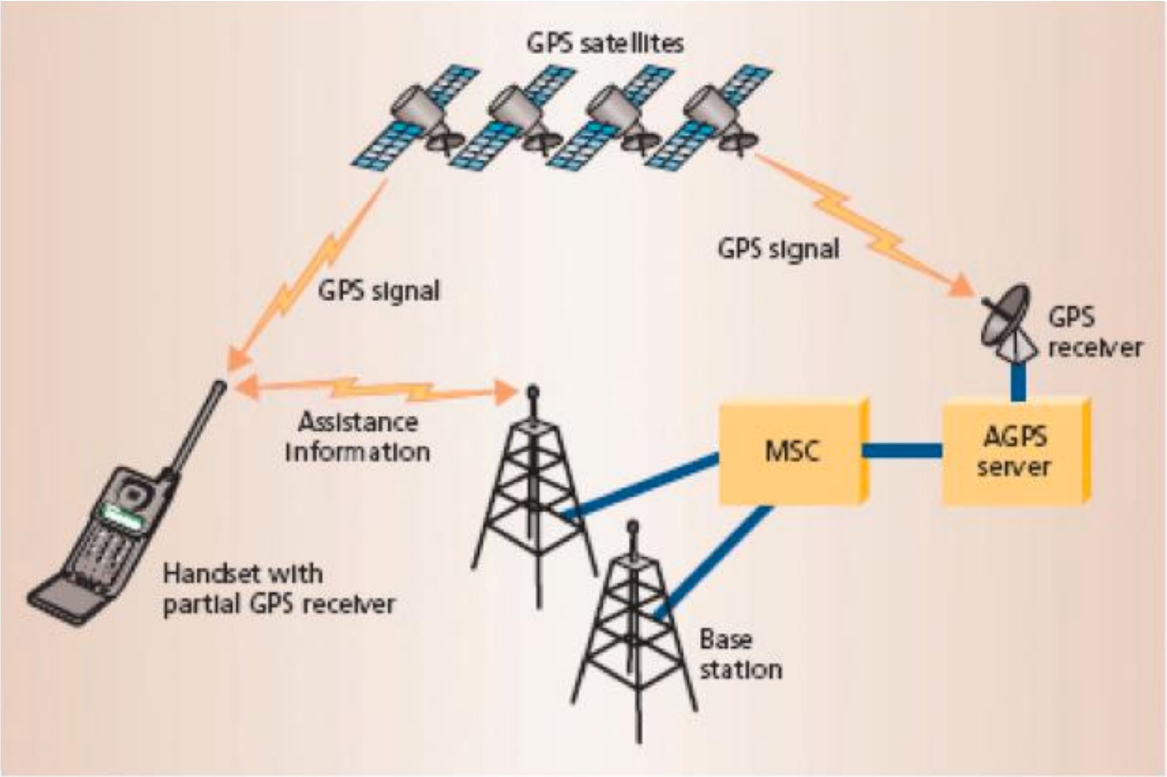
Source: fmcsmart.forumotion.com/

Improving accuracy

- WAAS system
- Geostationary satellites used to correct GPS
- 1-2m median accuracy



Assisted-GPS



Use the network to improve GPS estimation

Network employs well-known locations of fixed stations

Does not require delay for first fix

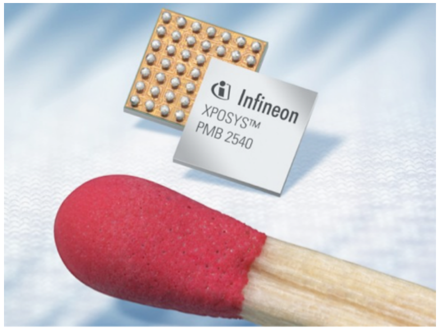
GPS data with NMEA

```
$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47
```

GGA	Global Positioning System Fix Data
123519	Fix taken at 12:35:19 UTC
4807.038,N	Latitude 48 deg 07.038' N
01131.000,E	Longitude 11 deg 31.000' E
1	Fix quality: 0 = invalid 1 = GPS fix (SPS) 2 = DGPS fix 3 = PPS fix 4 = Real Time Kinematic 5 = Float RTK 6 = estimated (dead reckoning) (2.3 feature) 7 = Manual input mode 8 = Simulation mode
08	Number of satellites being tracked
0.9	Horizontal dilution of position
545.4,M	Altitude, Meters, above mean sea level
46.9,M	Height of geoid (mean sea level) above WGS84 ellipsoid
(empty field)	time in seconds since last DGPS update
(empty field)	DGPS station ID number
*47	the checksum data, always begins with *

Using GPS

- GPS terminals require significant battery resource and computational power
- Signal strength measurements are low cost
- Computation can be unloaded to a more powerful device on the network e.g. assisted GPS



Other satellite systems

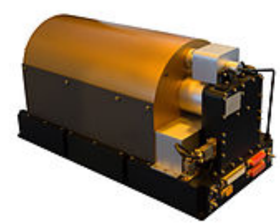
- GLONASS: Russia, India
  - In operation since 1982
  - 24 satellites
  - Lost control after collapse of Soviet Union
  - Often used together with GPS

- BAIDU: China
  - 23 satellites
  - Open to public use since December 2012

Galileo

- 15 fully operational satellites
- Improved clock performance to improve accuracy
  - 2 PHM and 2 rubidium clocks
- Fucino and Oberpfaffhofen Galileo Control Centers
- Timing accuracy is 28 billionths of a second
- Clock controversy in 2017

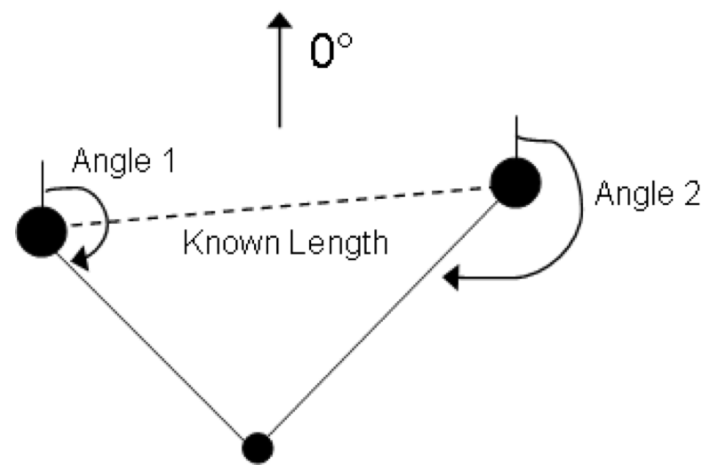
Galileo rubidium clock



passive hydrogen maser clock

Angulation

- Location sensing in 2D requires
  - 2 angle measurements from known location
  - 1 distance measurement (between the 2 locations above
- Example system: phased antenna array

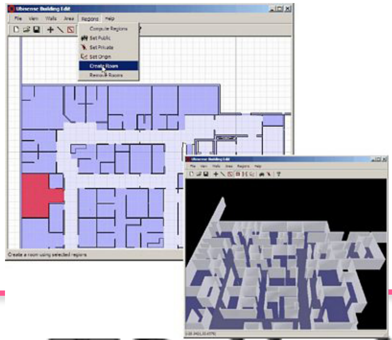


Phased Antenna Array

- Multiple antennas with known separation (i.e. distance) – the military is very fond of this!
- Each measures time-of-flight of signal
- Using the difference in times and the (known) geometry of the receiving array, we can calculate the required angle
- If there are enough elements in the array and large separation, angulation can be performed accurately

Ubisense

- Uses phased array antennas on the tag
- Tags relay location back to the network
- Real time tracking
- Uses ultra wide band technology



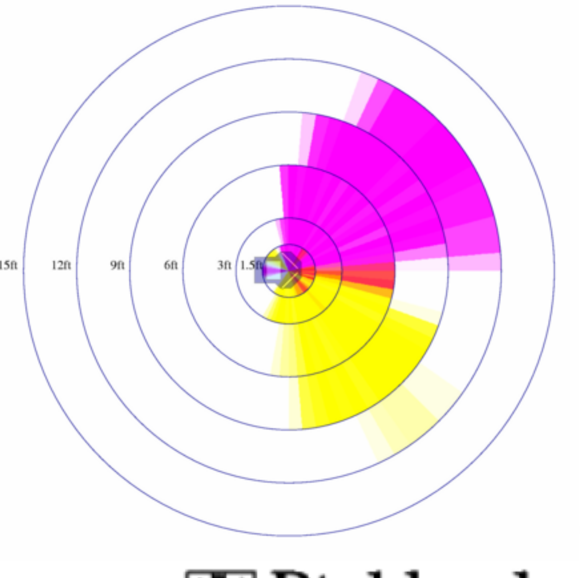
Scene Analysis

- Compares scenes to reference scenes
  - Image, electromagnetic spectrum
- Construct a signature of a position and apply pattern matching techniques with this signature
- Differential scene analysis
  - Tracks differences in scenes

RFID and vision

- Dumbo at Intel Labs Seattle
- Uses vision to navigate the environment
- Uses RFID reader to create a map of proximity to RFID
- Can subsequently use the model to sense location with RFID only

http://seattleweb.intel-research.net/projects/guide/projects/dumbo/



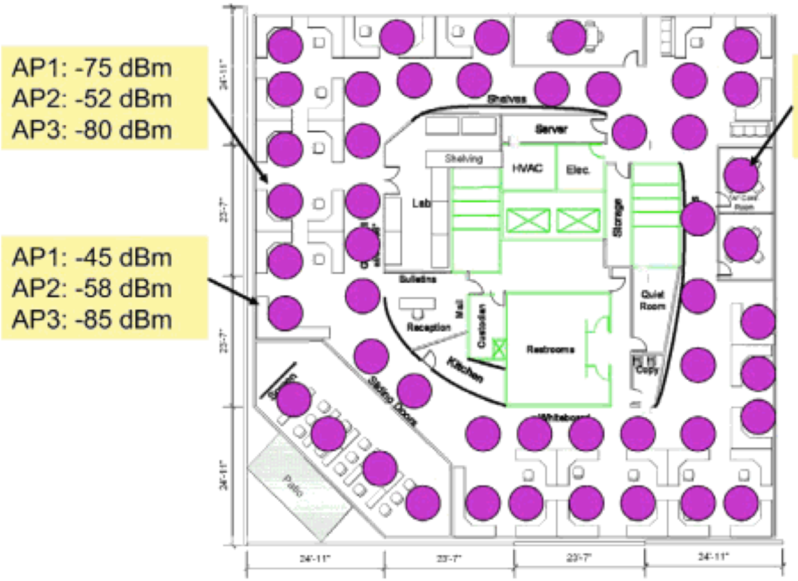
Wi-Fi fingerprinting

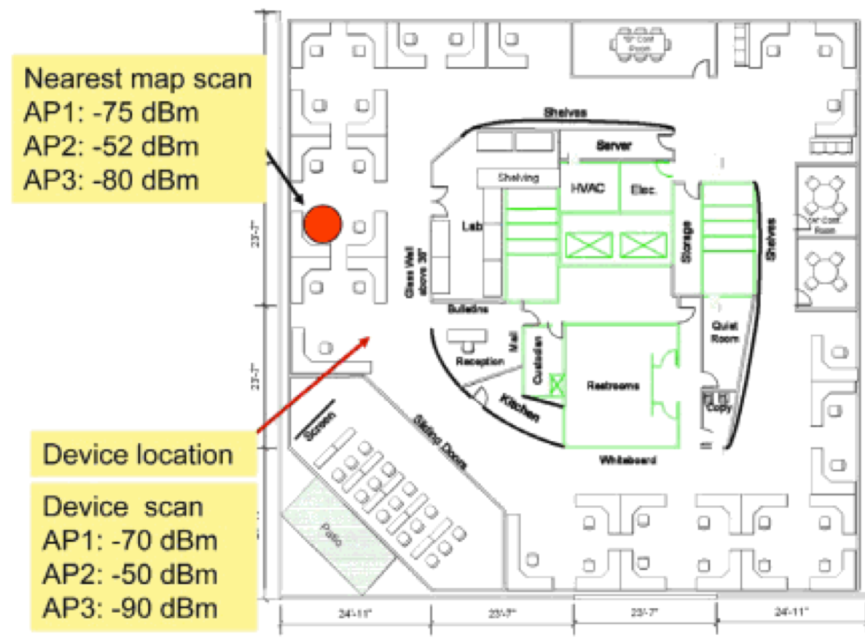
KisMAC 0.21a

Search For...

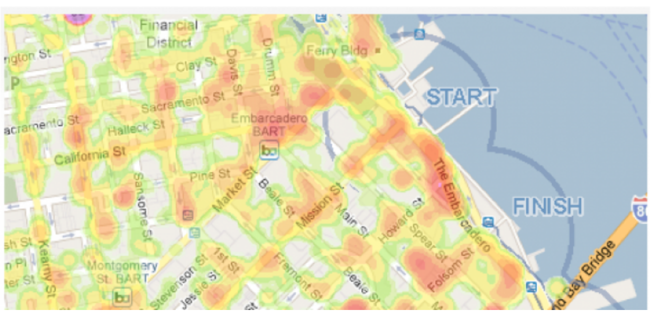
#	Ch	SSID	BSSID	Enc	Type	Signal	Avg	Max	Packets	Data	Last Seen
0	6	PorkChop	00:50:F2:75:4F:F0	WEP	managed	16	13	19	114	6.79KiB	2006-11-03 23:07:14 -0800
1	6	GrassRoots	00:13:10:3D:1E:50	WEP	managed	21	18	22	102	8.37KiB	2006-11-03 23:07:14 -0800
2	6	linksys	00:12:17:D0:B7:2F	NO	managed	16	14	18	123	10.09KiB	2006-11-03 23:07:14 -0800
3	6	default	00:13:46:A1:C0:3C	NO	managed	15	13	17	130	10.28KiB	2006-11-03 23:07:14 -0800
4	10	watchnu2	00:0F:EA:F4:F0:87	WEP	managed	50	51	54	69	8.15KiB	2006-11-03 23:07:14 -0800
5	10	huge living	00:11:24:9E:8E:D6	WPA	managed	16	15	20	78	11.35KiB	2006-11-03 23:07:14 -0800
6	2	UG	00:0D:88:F1:F4:6C	WEP	managed	0	10	19	81	6.01KiB	2006-11-03 23:07:14 -0800
7	6	<hidden ssid>	00:14:1B:63:2C:A0	WEP	managed	2	0	255	43	5.88KiB	2006-11-03 23:07:14 -0800
8	6	<hidden ssid>	00:14:1B:63:29:10	WEP	managed	5	6	9	52	7.11KiB	2006-11-03 23:07:14 -0800
9	6	<hidden ssid>	00:06:25:DD:A9:D5	NO	managed	7	7	11	60	3.57	
10	6	linksys	00:0C:41:D0:25:CD	NO	managed	9	11	14	70	5.67	
11	1	Belkin_Pre_N_95C	00:11:50:97:90:75	NO	managed	0	12	17	56	5.41	
12	1	<hidden ssid>	00:14:1B:63:2E:10	WEP	managed	0	10	16	68	9.30	
13	6	2WIRE457	00:12:88:E1:2D:F1	WEP	managed	0	5	5	1	8	
14	6	2WIRE204	00:12:88:01:F8:91	WEP	managed	0	3	5	3	24	
15	11	Chapman	00:16:B6:16:35:4E	WEP	managed	0	3	3	1	8	

Create map and match closer





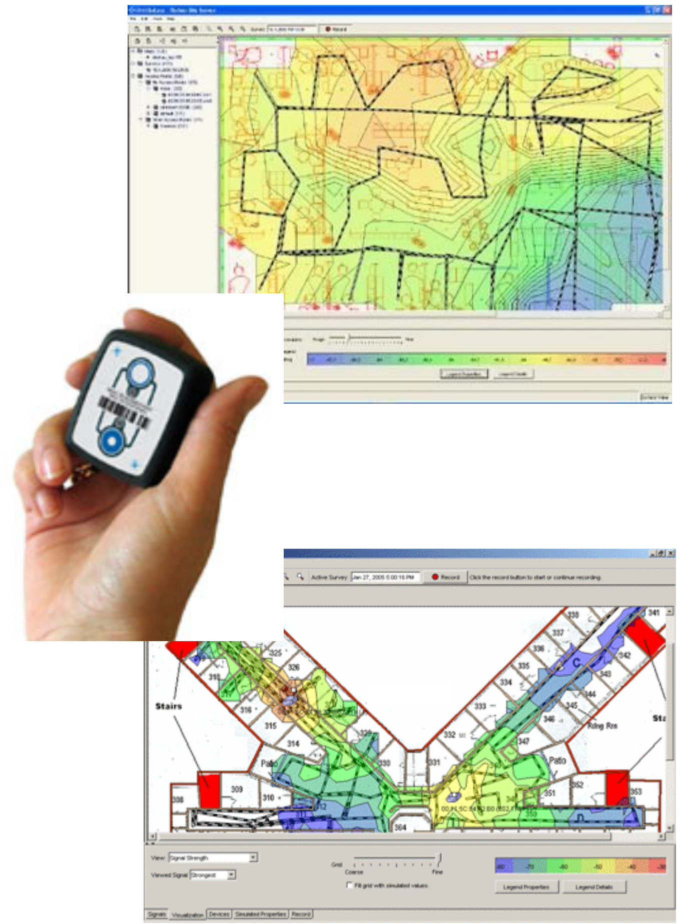
Creating AP DB



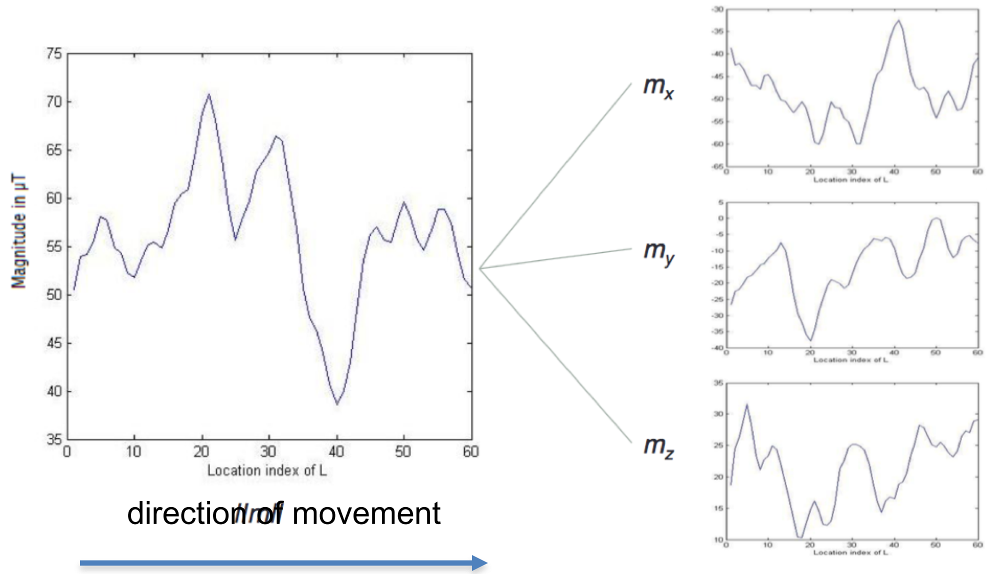
- Scanning expeditions
- Google, Apple and Skyhook
- Scan wi-fi and cellular
- Used by Android, iOS
- Devices feed back to the database updates

Ekahau

- Signal strength from wi-fi access points
- Has to do a site survey to build model
- Uses Bayesian statistics to improve prediction of location (e.g. models signal propagation)
- Real time data using tag



Geomagnetic fingerprinting

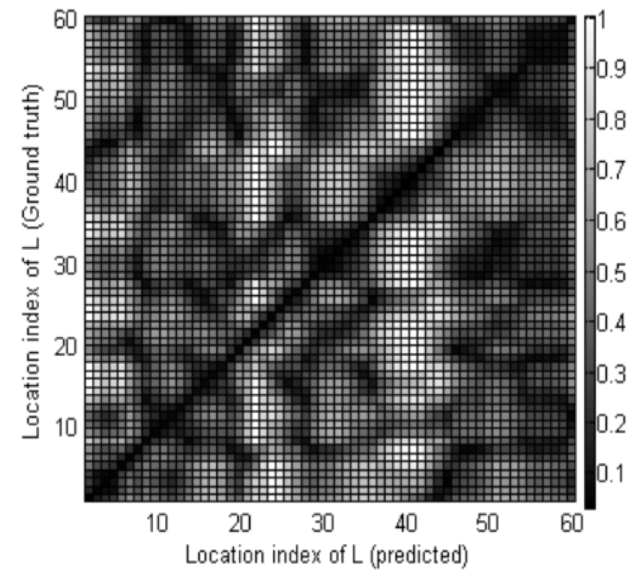


- Use distortions by material entities of the magnetic field generated by earth
  - buildings, furniture, machines etc

J. Chung, M. Donahoe, C. Schmandt, I-J Kim, P. Razavai and M. Wiseman, 2011, Indoor Location Sensing Using Geo-Magnetism, ACM Mobisys

Matching fingerprints

- Find nearest neighbor of the current measurement which minimizes the root mean square (RMS) error
- Additional corrections using the angle of the magnetism vector
- Magnetometer common in most modern smartphones



Scene Analysis Challenges

- Issues
  - the observer needs access to the features of the environment against which it will compare its observed scenes
  - changes of the environment that affects these features may require their reconstruction

Sensor Fusion

- Combine multiple sources of information
  - Identify floor from Bluetooth beacon
  - Estimate number of steps taken since entry to area using accelerometer
  - Check for wifi fingerprint match
  - Check for geomagnetic fingerprint match only close to the estimated vicinity
- Principle behind IndoorAtlas

Summary

- What is location sensing
- How do we use location
- Location sensing techniques
- System examples