LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Praktikum Mobile und Verteilte Systeme

Indoor Positioning Systems

WLAN Positioning

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Wintersemster 16/17

Indoor Positioning

Today:

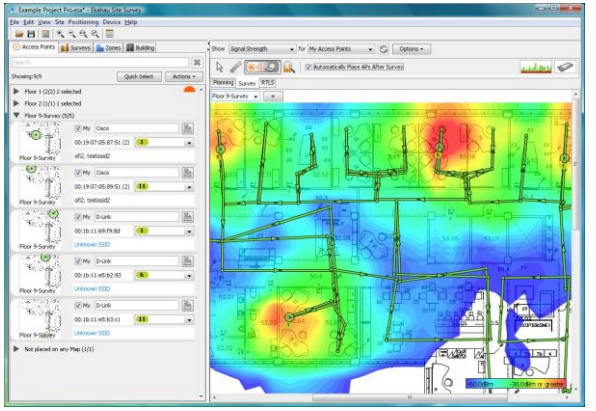
- Motivation
- Overview of different indoor positioning technologies/methods
- WLAN Positioning
- Sensor Fusion

Why Indoor Positioning?

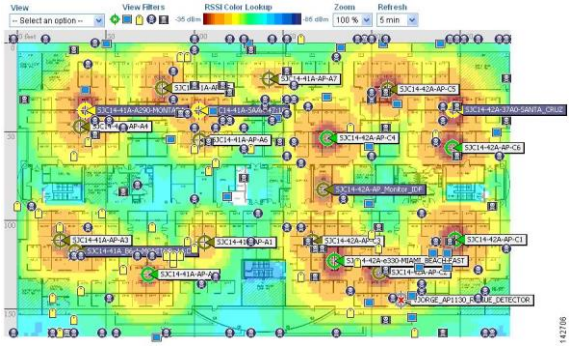
- Development of Location-based Services
  Value-added services that consider the position of a mobile target
  - Navigation Systems
  - Information Systems
  - Emergency
  - Advertising
  - …
- Location-based Services require a positioning method
  - GPS / Galileo / GLONASS / Beidou
  - GSM Cell-ID
  - Indoor…?

Indoor Positioning Systems

- Application examples
  - Object & asset tracking
  - Workflow optimization & maintenance
  - Information services
  - Healthcare & ambient assisted living
  - Security & safety



Ekahau (www.ekahau.com)



Cisco (www.cisco.com)





Positioning Fundamentals

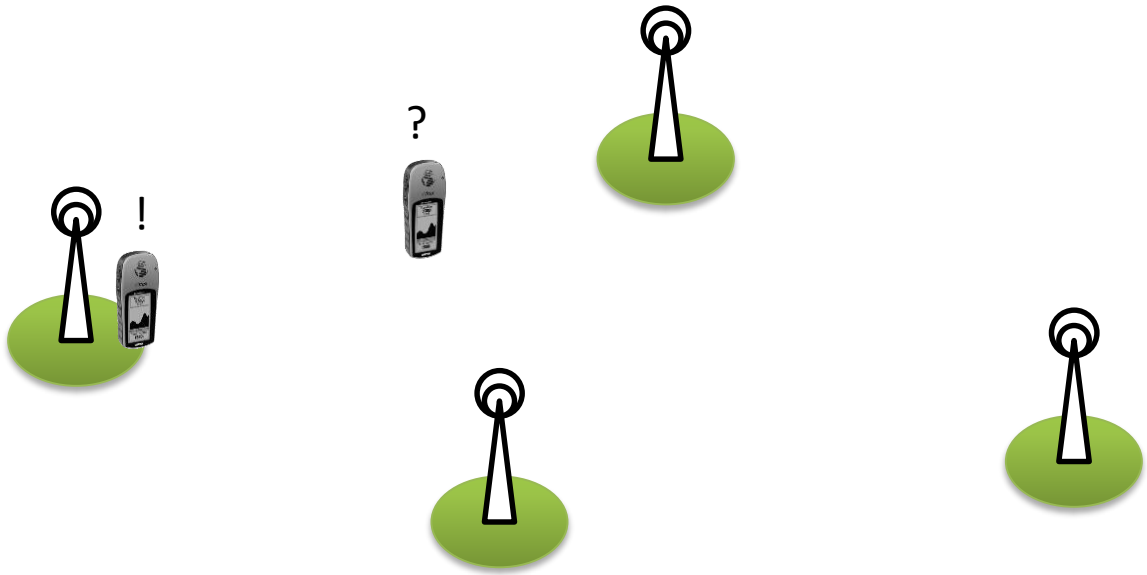
- Positioning is determined by
  - one or several parameters observed by measurement methods
  - a positioning method for position calculation
  - a descriptive or spatial reference system
  - an infrastructure
  - protocols and messages for coordinating positioning

Positioning method	Observable	Measured by
Proximity sensing	Cell-ID, coordinates	Sensing for pilot signals
Multilateration	Range or Range difference	Traveling time of pilot signals Path loss of pilot signals Traveling time difference of pilot signals Path loss difference of pilot signals
Angulation	Angle	Antenna arrays
Dead reckoning	Position and Direction of motion and Velocity and Distance	Any other positioning method Gyroscope Accelerometer Odometer
Pattern matching	Visual images or Signal Fingerprint	Camera Received signal strength

Proximity Sensing

Proximity is sensed by a station using (short) range pilot signals:

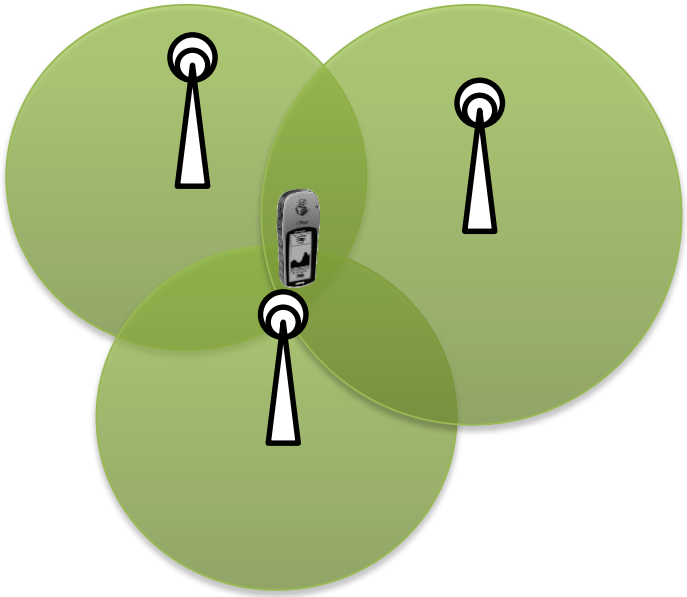
- Cell-ID or coordinates

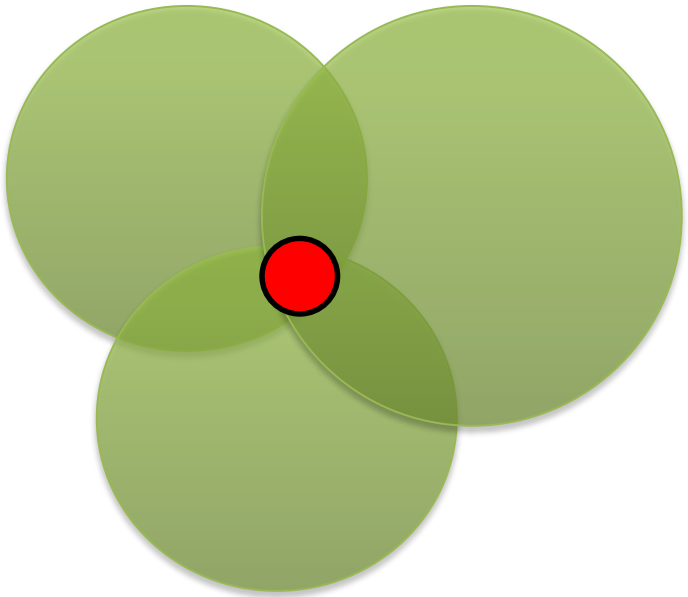


Multilateration

Position is computed by a number of range measurements to known fix-points:

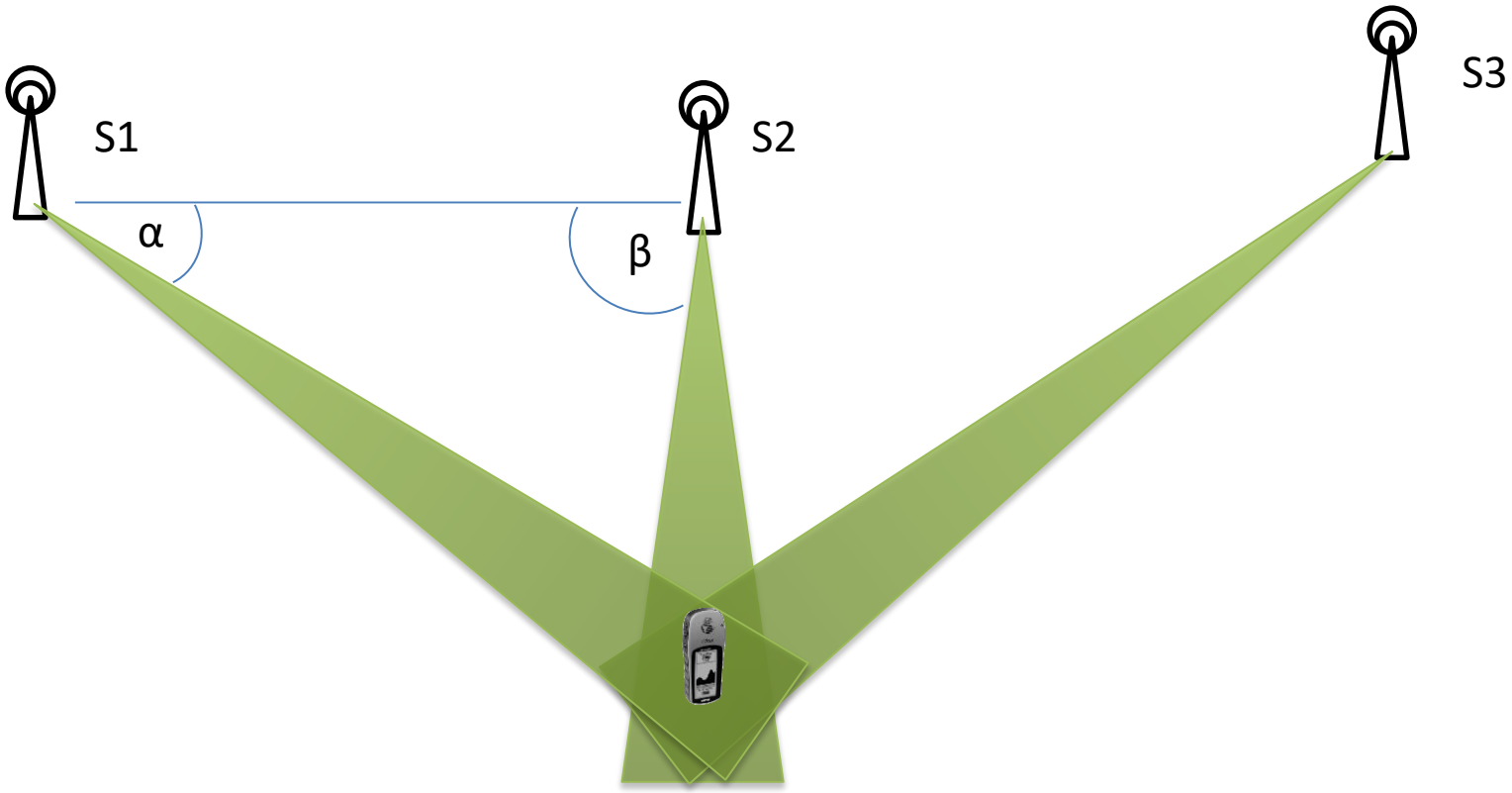
- 1 fix-point: Position is on a spherical shell
- 2 fix-points: Position is on a circular line
- 3 fix-points: 2 symmetric intersections





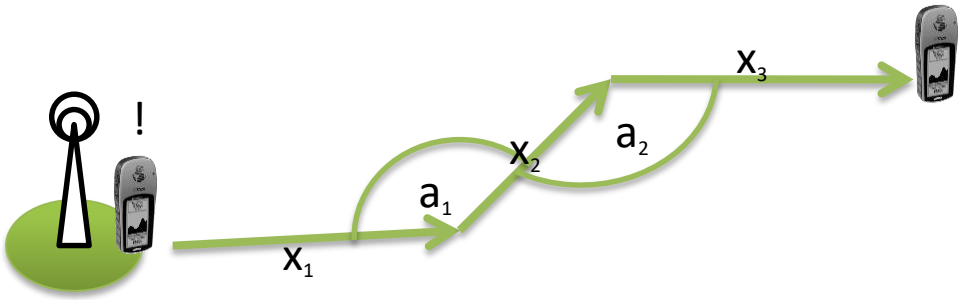
Triangulation

- Position is derived by measuring the angle of an arriving signal by multiple stations at known fix-points:



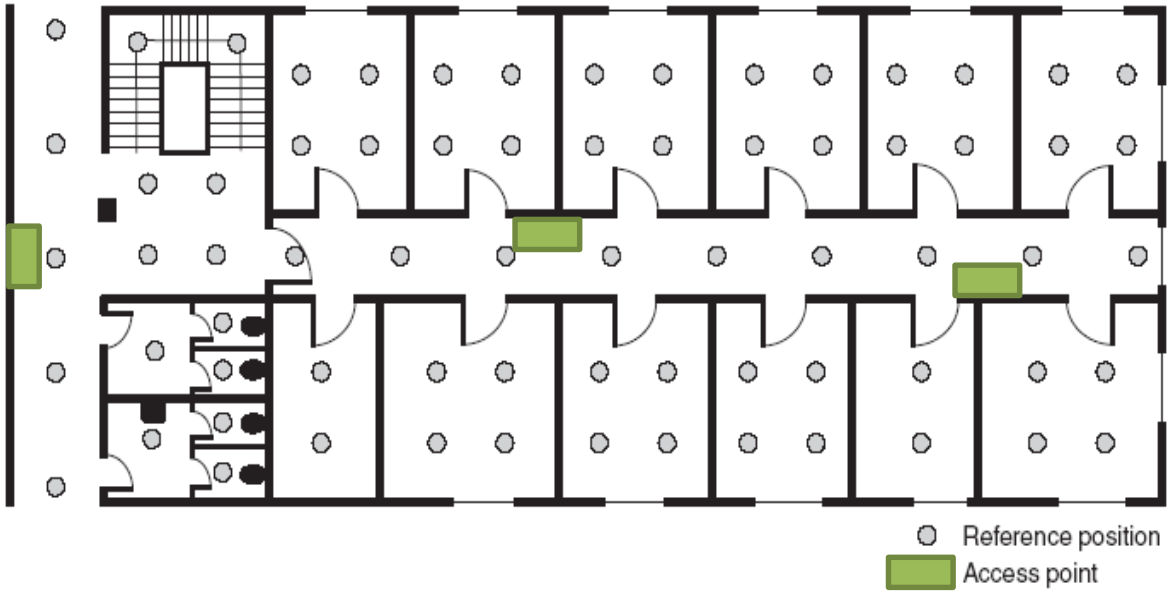
Dead Reckoning

- From a fixed starting position, the movement of the mobile device is estimated (e.g., using velocity and direction of movement):



Fingerprinting

- Position is derived by the comparison of location dependent online measurements with previously recorded data:



Positioning systems and their accuracy

Name	Signals	Observable	TB, NB, TA	Accuracy
Active Badge	Infrared	CoO	NB	Cell (Room)
ActiveBat	Ultrasonic, Radio	TDoA	NB	10cm
AeroScout	RFID & WLAN	TDoA & RSS	NB	3 - 5m
Cisco WLA	WLAN	RSS	NB	~ 3m
Cricket	Ultrasonic, Radio	Proximity sensing	TB	few cm
EasyLiving (Microsoft Research)	misc.	misc.	NB	30cm
Ekahau	WLAN	RSS	TB	~2m
GPS	Satellite	ToA	TB	~2m
Horus (University of Maryland)	WLAN	RSS		1m
MagicMap	WLAN	RSS	TB, P2P	<10m
MetroGroup Future Store	RFID	TDoA & AoA	NB	30cm
PARCTAB (Xerox Research Center)	Infrared	CoO	NB	Cell (Room)
PlaceLab	WLAN, Bluetooth, GSM	RSS	TB	~10m
PinPoint (Universität Maryland)	RFID	TDoA		1 - 3m
RADAR	WLAN	RSS	TA NB	2 - 3m
Rosum: TV-GPS	GPS & TV-Signale	RSS	TA	?
Rover (Universität Maryland)	WLAN & Bluetooth	RSS		2m
SmartFloor (Georgia Inst. of Techn.)		Footprint profile		90%
SpotOn (Predecessor of PlaceLab)	Radio	RSS	NB	3m
Tadlys: Topaz	Bluetooth	CoO	TA	2 - 3m
UbiSense	Ultra Wide Band	TDoA & AoA	NB	30cm
WhereNet	WLAN	TDoA	NB	2 - 3m
WIPS	Infrarot, WLAN	CoO	TA NB	Cell (Room)

AoA = angle of arrival
CoO = cell of origin
RSS = received signal strength
TDoA = time difference of arrival

TB = terminal based
TA = terminal assisted
NB = network based

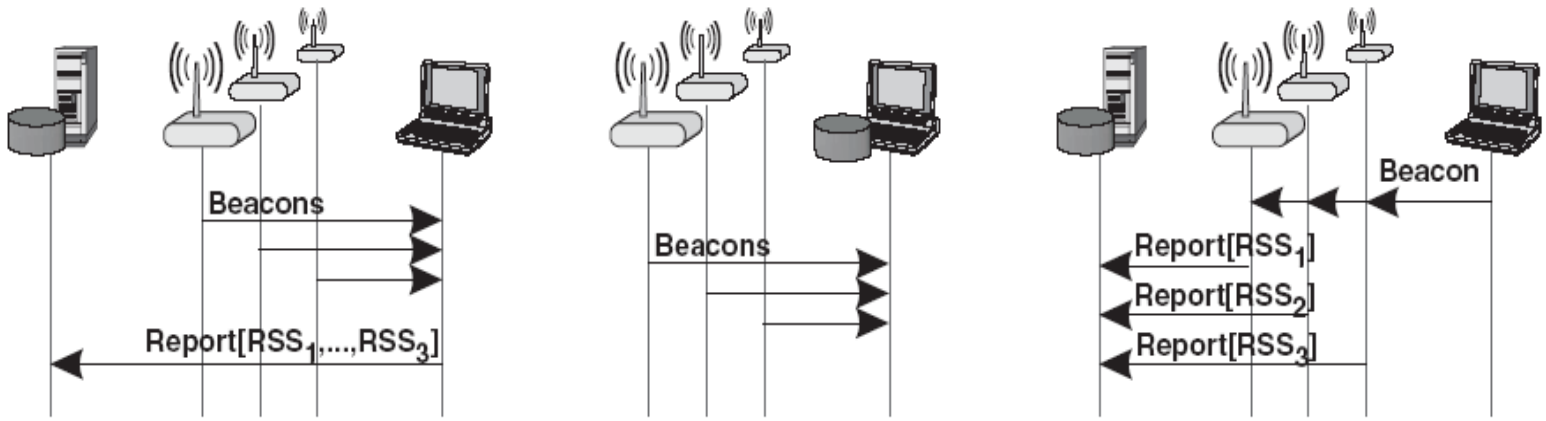
(without engagement)

WLAN Positioning

Why use IEEE 802.11 components for indoor positioning?

- Widely deployed infrastructure
- Available on many mobile platforms
- 2,4 GHz → signal penetrates walls → no line-of-sight necessary
- A standard WLAN access point deployment is often already sufficient to achieve room-level accuracy

WLAN Positioning – TA, TB, NB



(a) Terminal-assisted mode (b) Terminal-based mode (c) Network-based mode

Terminal assisted (TA)

- Measurements are made at the terminal
- Position calculation happens at the server

Terminal based (TB)

- Measurements and position calculation are made at the terminal

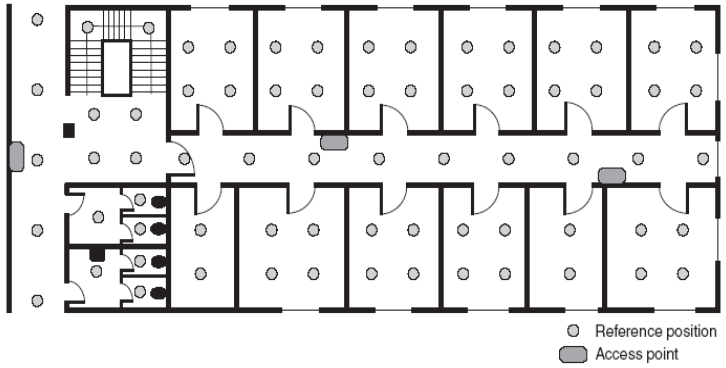
Network based (NB)

- Beacons are emitted by terminal
- Measurements and calculation are done at the server

WLAN Fingerprinting – Idea

WLAN Fingerprinting

- Derive position from **patterns of signals** received from/at several WLAN access points
- Observable: **received signal strength** (RSS)
- **Offline phase (Sample Creation)**
  - Record **well-defined RSS patterns for well-defined reference positions** and store them in a radio map
  - Due to **line-of-sight conditions** on the spot, it might be necessary to observe RSS patterns from **several directions** for each position
- **Online phase (Positioning)**
  - RSS patterns related to the target are recorded and compared with the RSS fields of the entries stored in the radio map
  - Position of the target is extracted from the reference position with the closest match



WLAN Fingerprinting – Example of a Radio Map

Position	Direction	RSS / [dBm] from 00:02:2D:51:BD:1F	RSS / [dBm] from 00:02:2D:51:BC:78	RSS / [dBm] from 00:02:2D:65:96:92
Pos. 1	0°	-59	-75	-71
	90°	-54	-73	-67
	180°	-49	-72	-69
	270°	-55	-73	-65
Pos. 2	0°	-35	-64	-50
	90°	-27	-64	-43
	180°	-40	-65	-52
	270°	-30	-60	-64
Pos. 3	0°	-69	-66	-73
	90°	-65	-60	-68
	180°	-63	-66	-70
	270°	-68	-62	-76

$$m = \begin{pmatrix} -65 \\ -57 \\ -71 \end{pmatrix} \; ? \longrightarrow \text{Position 3 bei } 0° \qquad \arg\min_i \left(\left| m - f_i \right| \right)$$

WLAN Fingerprinting – Empirical vs. Modeling Approach

Empirical approach

- Create radio maps from measurements
- Disadvantages
  - Time consuming
  - Measurements must be repeated whenever the configuration of access points changes
  - Influenced by surroundings / obstacles (furniture positions, etc.)

Modeling approach

- Create radio maps from a mathematical model
  - Calculate the radio propagation conditions taking into account the positions of access points, transmitted signal strengths, free-space path loss, obstacles reflecting or scattering signals, …
- Disadvantages
  - Complexity and accuracy of mathematical models

WLAN Fingerprinting – Deterministic vs. Probabilistic Approach

Deterministic Approach

- Record several RSS samples for each reference position and direction
- Create radio map from mean values of these samples
- Online phase: match observed and recorded sample according to Euclidian distance and adopt the reference position with the smallest distance as the current position of the terminal

Probabilistic Approach

- Describe variations of signal strengths experienced during the offline phase by probability distribution
- Probability distributions of various access points are applied to the observed RSS pattern to find the most probable position
- Accuracy can be significantly refined compared to the deterministic approach

WLAN Fingerprinting – Overview Systems

System	Observable	Accuracy	Mode			Radio Map		Matching	
			ta	tb	nb	Emp.	Mod.	Det.	Prob.
RADAR	RSS	2.1m / 50%			X	X		X	
Ekahau	RSS	3.1-4.6m / 90%	X			X			X
Horus	RSS	2.1m / 90%		X		X			X
Nibble	SNR	10m /80%	X			X			X
WhereMaps	RSS	1.5m / 50% 6.0m / 95%		X			X		X
Cisco WLA	RSS	-			X	X	X		X

Sensor Fusion

Idea:

- Refine the WLAN positioning with additional measurements from other sensor sources
  - Accelerometer
  - Gyroscope
  - Compass

How to combine several sensors (Sensor Fusion):

- Probability distributions
  - Kalman Filter
  - Particle Filter

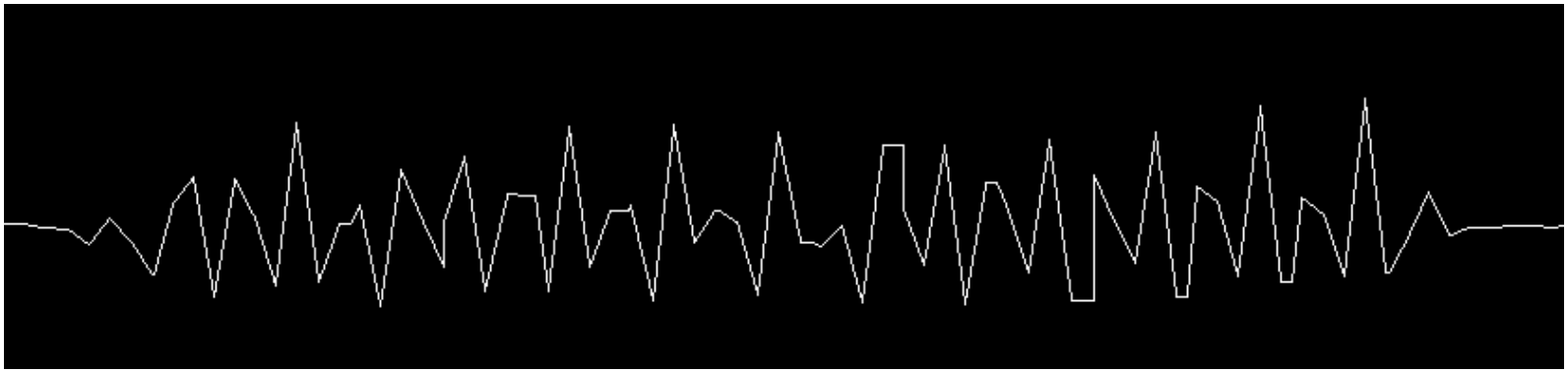
Sensor Fusion: Step Detection

Recognition of steps with the help of the accelerometer.

Example: Recognition of a large drop in vertical acceleration.

Computation *(similar to FootPath – IPIN 2011)*:

- Ringbuffer with 5 entries ($\approx$ 1 second by a sampling speed of 5Hz)
- If drop in vertical acceleration > -2ms^2
  - step detected
  - empty buffer
- Else write current vertical acceleration to the buffer



Links & Videos

- **Multi-Sensor Pedestrian Indoor/Outdoor Navigation 2.5 D (DLR)**
  - http://www.youtube.com/watch?v=2NfSHNurOAc
- **Pedestrian Inertial Navigation and Map-Matching (DLR)**
  - http://www.youtube.com/watch?v=4ZdBtZdNEzg
- **Particle filters in action (University of Washington)**
  - http://www.cs.washington.edu/ai/Mobile_Robotics/mcl/

Practical Course

- A simple WLAN positioning system
  - Deterministic
  - Empirical
- Android classes
  - Broadcast Receiver
  - WifiManager (active scanning)
  - ScanResult