Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecturer: Rainer Mautz

Geodetic Metrology and Engineering Geodesy

Institute of Geodesy & Photogrammetry, ETH Zurich

- HIL D43.2, Hönggerberg, Wolfgang-Pauli-Str. 15, CH-8093 Zurich
- +41 44 633 24 85
- http://www.geometh.ethz.ch/people/rmautz

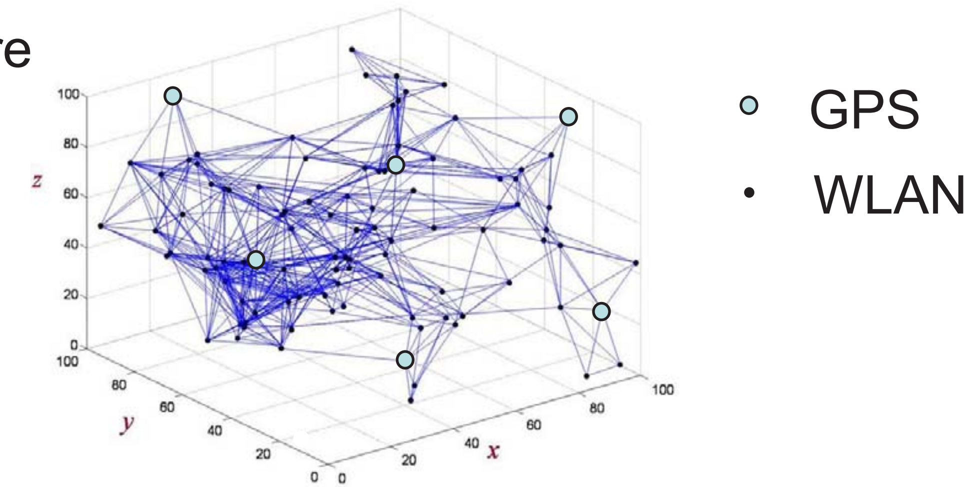
Application: Natural Hazards Monitoring (e.g. Volcanos)

Stratovolcano Sakurajima,
- island 77 km^2 1117 m height
- extremely active, densely populated
- monitored with levelling, EDM, GPS

Landsat image, created by NASA

Volcanoes experience pre-eruption surface deformation
Coverage: cm – dm over 10 km^2
Spatially distributed monitoring for early warning system

WLAN positioning system with densely deployed location aware nodes



Rating

- Area maturity

- Practical importance

- Theoretical importance

Sensor data without position information are normally worthless

Overview

- Sensor Types
- Positioning Systems
- Methods for Positioning

User Requirements:

availability: 100% of the time

timeliness: realtime

reliability: no failures

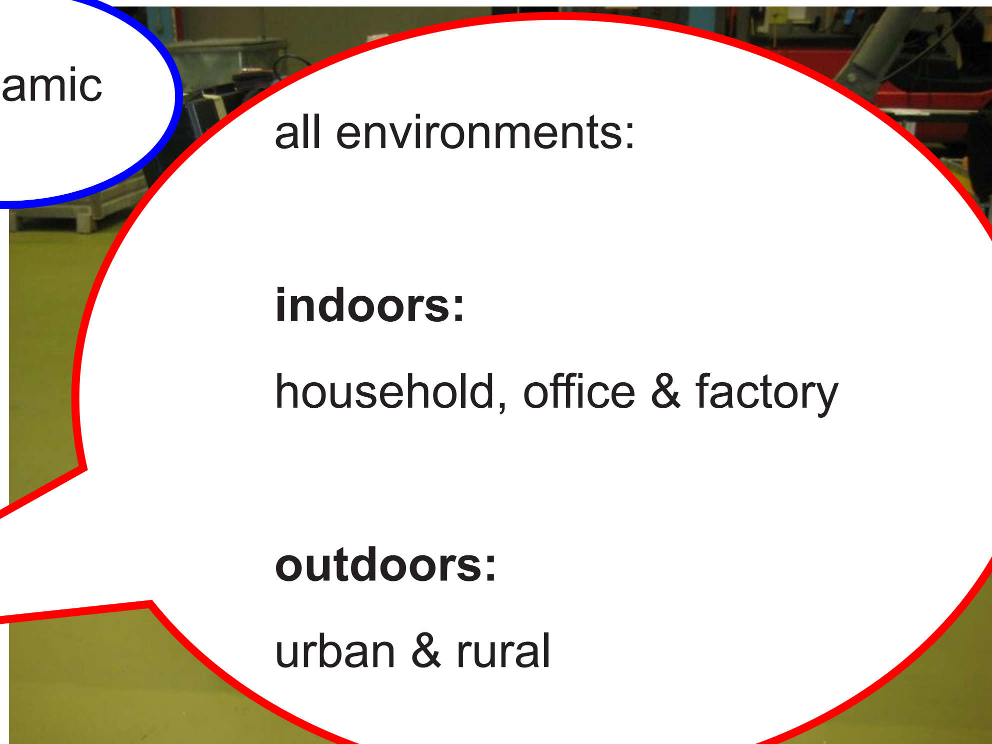
hybrid systems: to be avoided

local installations: none

accuracy: mm - cm

coverage: global

dynamic



all environments:

indoors:

household, office & factory

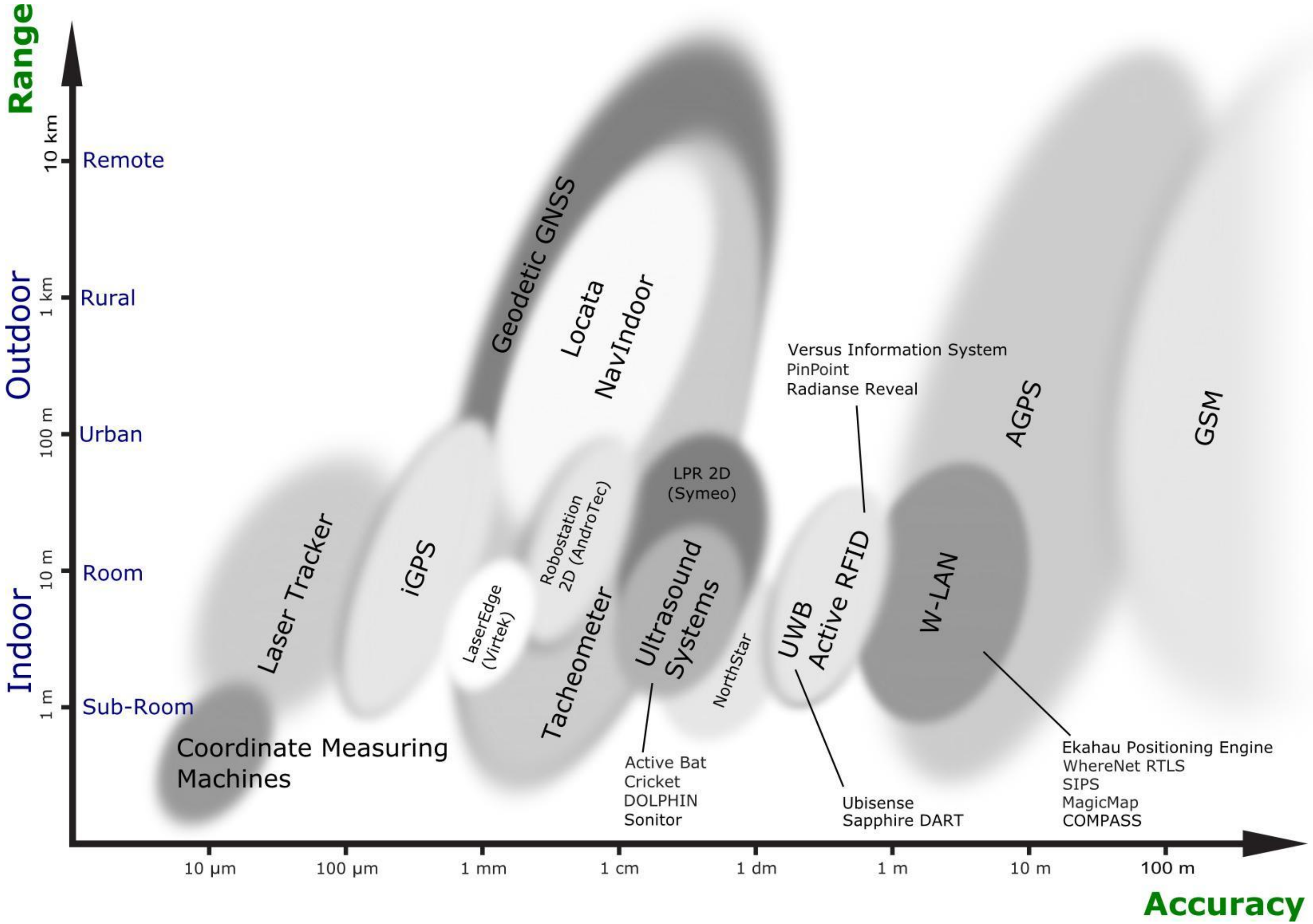
outdoors:

urban & rural

Classification of Positioning Systems:

- Principle (trilateration, triangulation, signal strength)
- Signal (Radio Frequencies, Light Waves, Ultrasound, RFID, Terahertz)
- Environment (indoor, outdoor, urban, rural, remote)
- Active / passive sensors
- Accuracy (μm – km)
- Application (industry, surveying, navigation)

Positioning Systems



Sensors used in Geodetic Networks

1. optical sensors (motorised total station, digital level)
2. GNSS sensors (that allow phase measurements)
3. geotechnical sensors (relative measurements using extensometer, inclinometer, plumbing, DMS, hydrostatic levelling)
4. meteo sensors (thermometer, pressure sensor, air moisture sensor)

key aspects & issues:

- physical dimensions of the sensor (size, weight)
- additional devices for data collection
- format of generated data
- measurement rate
- connection to computer network
- electrical power consumption and voltage
- price

Positioning Sensors

1. optical sensors – motorised total stations

Leica TPS1200	Leica TPS1100	Leica TPS2000	Trimble S6/8
			

not yet specialised for that purpose (still can be used manually)
problems: sensitive electronic, optical sight (fog), price, need for prisms

Totalstation Network

automatic **total station**: a 1-node monitoring network

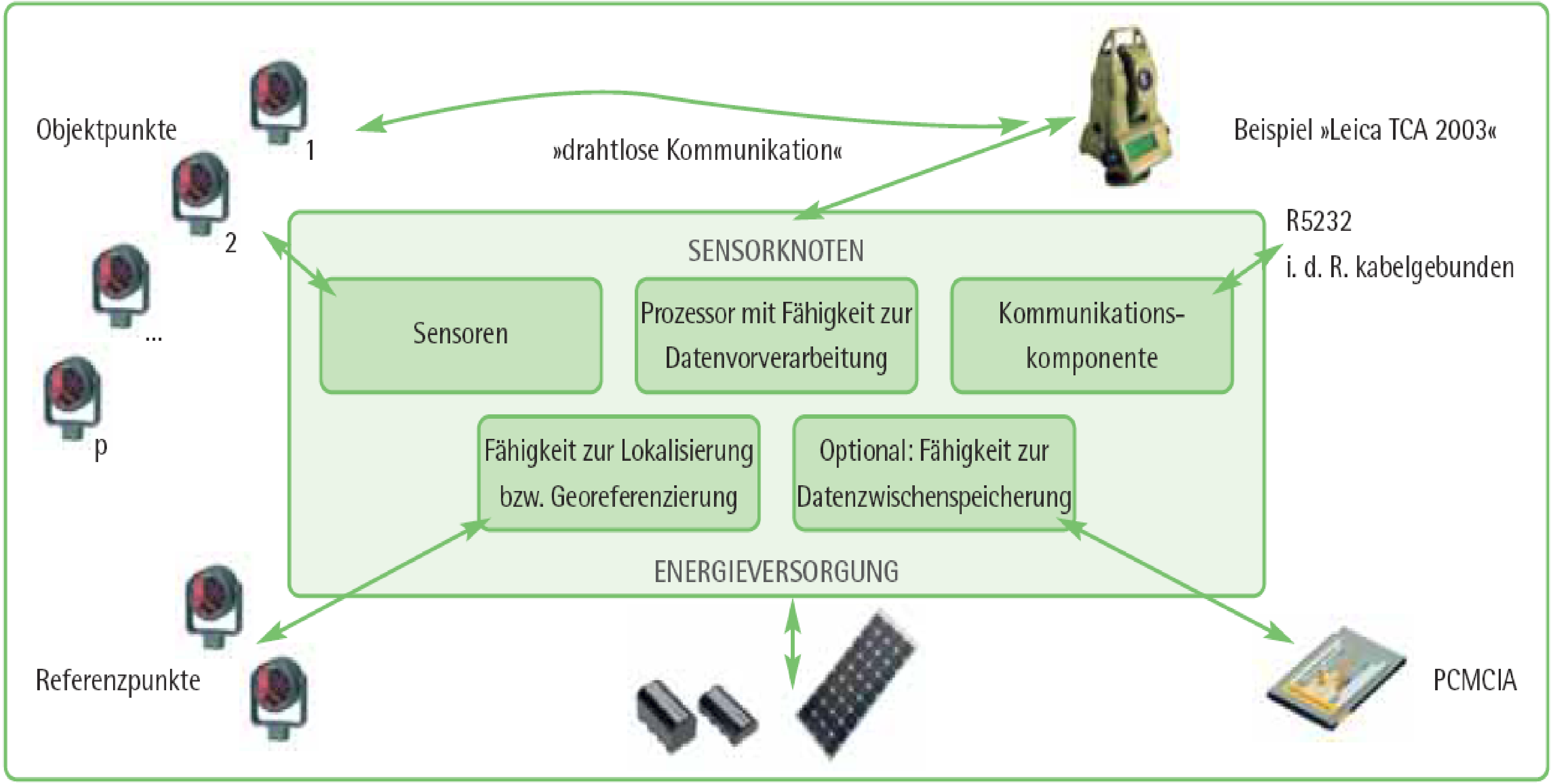


Abb. 3: Motorisiertes Tachymeter als Sensorknoten bei Überwachungsaufgaben

from: Heunecke, Geosensornetze im Umfeld der Ingenieurvermessung

Positioning Sensors

1. optical sensors – motorised total stations

Mt.Terri Felslabor - Messeinsatz – Stephan Schütz

Sensors used in Engineering Geodesy Networks

1. optical sensors – digital levels

Leica DNA03	Leica NA3000	Trimble DiNi12	Zeiss DiNi10 in Sonderausführung der Firma SOLEXPERTS
			

- restricted to 40 m and horizontal views
- restricted to monitor a single staff

Sensors used in Engineering Geodesy Networks

2. GNSS sensors – handheld & geodetic receivers

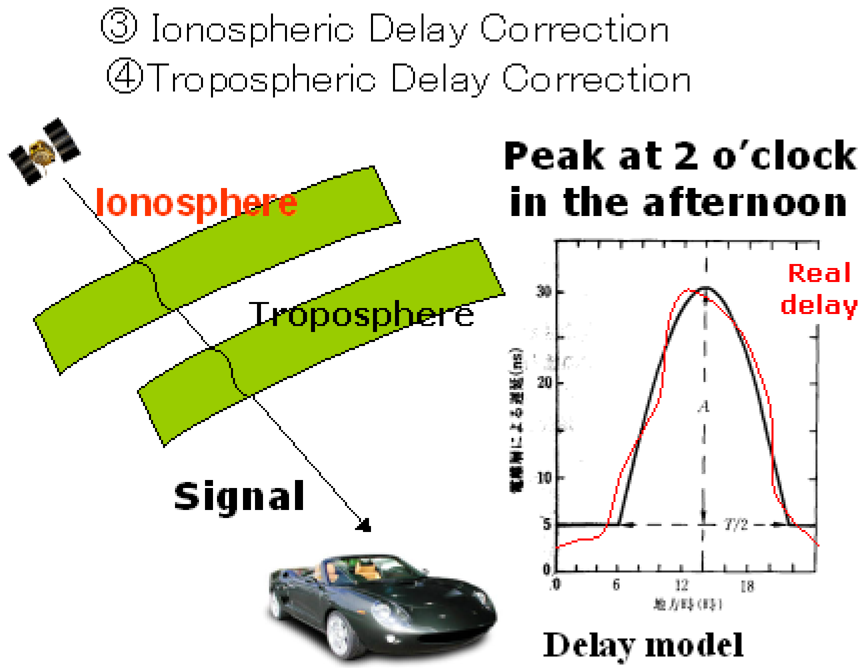
Garmin etrex	Rockwell DAGR	Leica System 1200	Trimble 5600
			

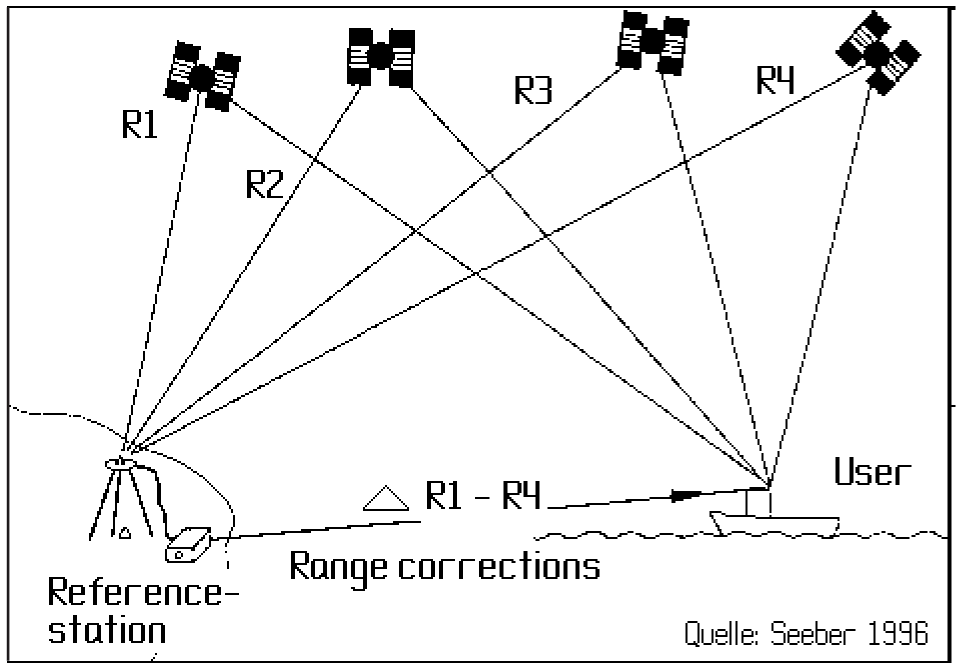
Why do geodetic receivers reach mm-accuracy?

Sensors used in Engineering Geodesy Networks

1. Use of both frequencies L1& L2
2. Phase measurements
3. DGPS (relative measurements)

→ elimination of ionospheric delays





from: WIDE University (School of Internet)
http://www.soi.wide.ad.jp/class/20050026/slides/01

GNSS Attenuation of building materials (L1 = 1500 MHz)

Material	[dB]	Factor [-]
Glass	1 - 4	0.8 – 0.4
Painted Glass	10	0.1
Wood	2 - 9	0.6 – 0.1
Roofing Tiles / Bricks	5 - 31	0.3 – 0.001
Concrete	12 - 43	0.06 – 0.00005
Ferro-Concrete	29 - 33	0.001 – 0.0005

Stone (1997)

Signal Strength in Decibel Watt of GNSS Satellites

Environment	[dBW]	
Satellite	+14	signal strength delivered from satellite
Outdoors	-155	unaided fixes OK for standard receivers
Indoors	-176	decode limit for high sensitive receivers
Underground	-191	decode limit for aided, ultra-high sensitive receivers

Sensors used in Engineering Geodesy Networks

3. Geotechnical Sensors

Gloetzl Loggingeinheit MFF2-12	Gloetzl Schlauchwaage GHD	Gloetzl Stangenextensometer GWW 30/40
		

- only one-dimensional, mostly local, relative measurements
- high effort for installation (cables, adaption to the object, e.g. plumbing shafts, inclinometer pipes)
- analogue signals → A/D converter, logging unit

Sensors used in Engineering Geodesy Networks

4. Meteorological Sensors

Meteo-Station WS-2308:

T, p, wind direction, wind speed,
participation,
time reference using DCF-77
Mainflingen

important for correction of other sensors

Sensors used in Engineering Geodesy Networks

5. Digital Cameras

IP-Camera NC 1000-W10:

- detection of movements,
- usable in the night
- WLAN capability
- detection of sounds

IP-camera has its own IP-address. It can be used as a webcam that does not require a direct connection to a computer

Cameras will play a more important role!

Positioning (Localization)

Task: Given distance or angle measurements or mere connectivity information, find the locations of the sensors

- Anchor-based
  - Some nodes know their locations, either by a GPS or as pre-specified.
- Anchor-free
  - Relative location only. Sometimes called virtual coordinates.
  - Theoretically cleaner model (less parameters, such as anchor density)

- Range-based
  - Use range information (distance or angle estimation).
- Range-free
  - No distance estimation, use connectivity information such as hop count.
  - It was shown that bad measurements don't help a lot anyway.

Measurement Methods for Positioning

Angle estimation

- Angle of Arrival (AoA)
  - Determining the direction of propagation of a radio-frequency wave incident on an antenna array.

Distance estimation

- Received Signal Strength Indicator (RSSI)
  - The further away, the weaker the received signal.

- Time of Arrival (ToA) or Time Difference of Arrival (TDoA)
  - Signal propagation time translates to distance.
  - RF, acoustic, infrared and ultrasound.

Positioning Based on Range Measurements

Lateration Methods

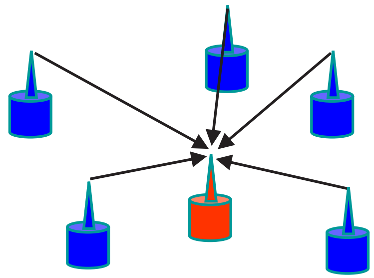
Initial anchor

Step 1: becomes anchor

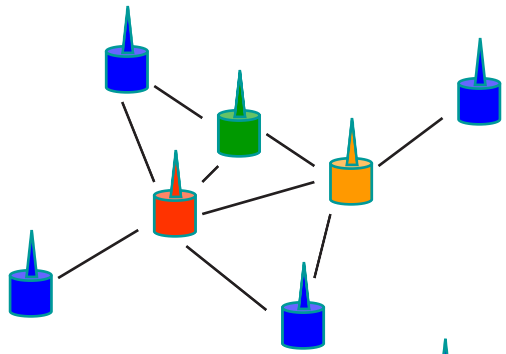
Step 2: becomes anchor

Step 3: becomes anchor

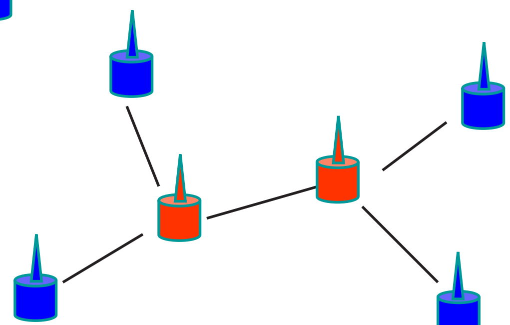
Multilateration:



Iterative Multilateration:

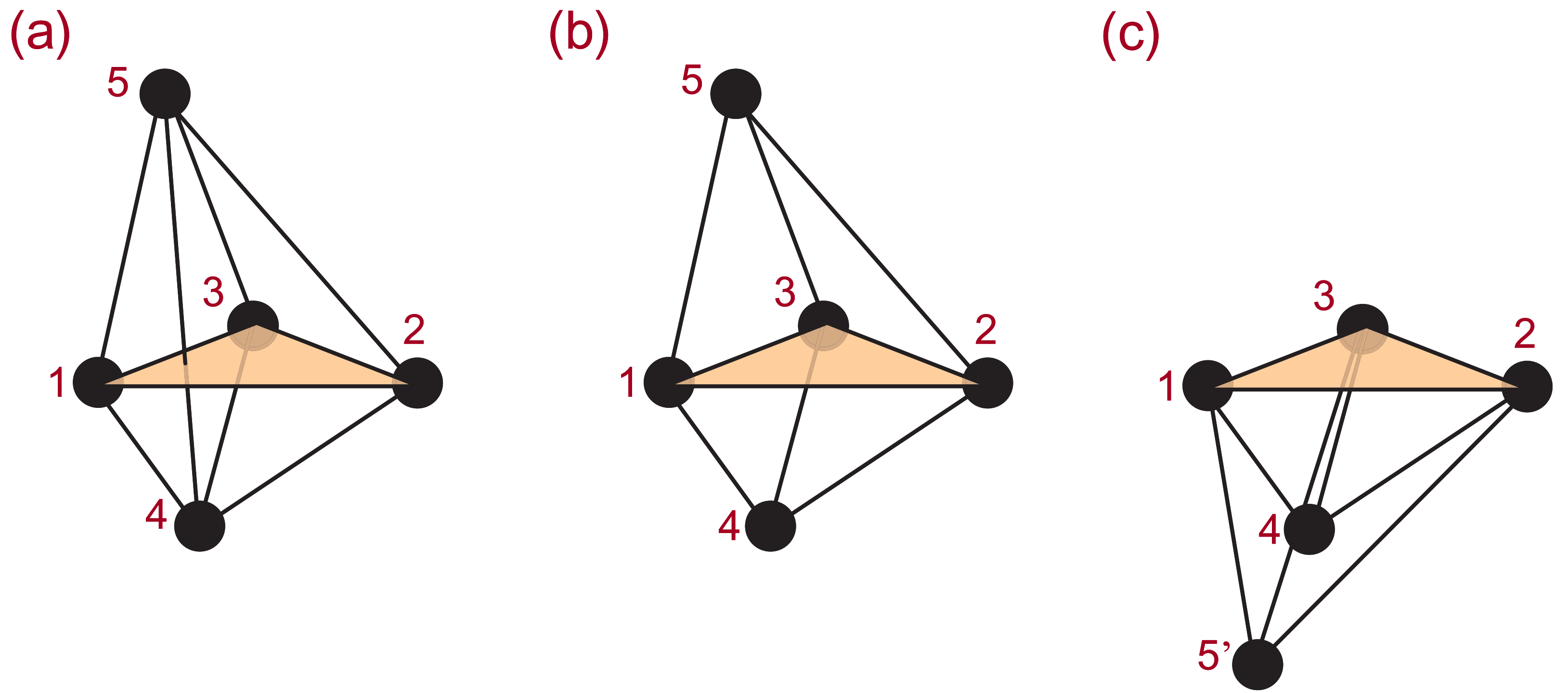


Collaborative (n-hop) Multilateration:



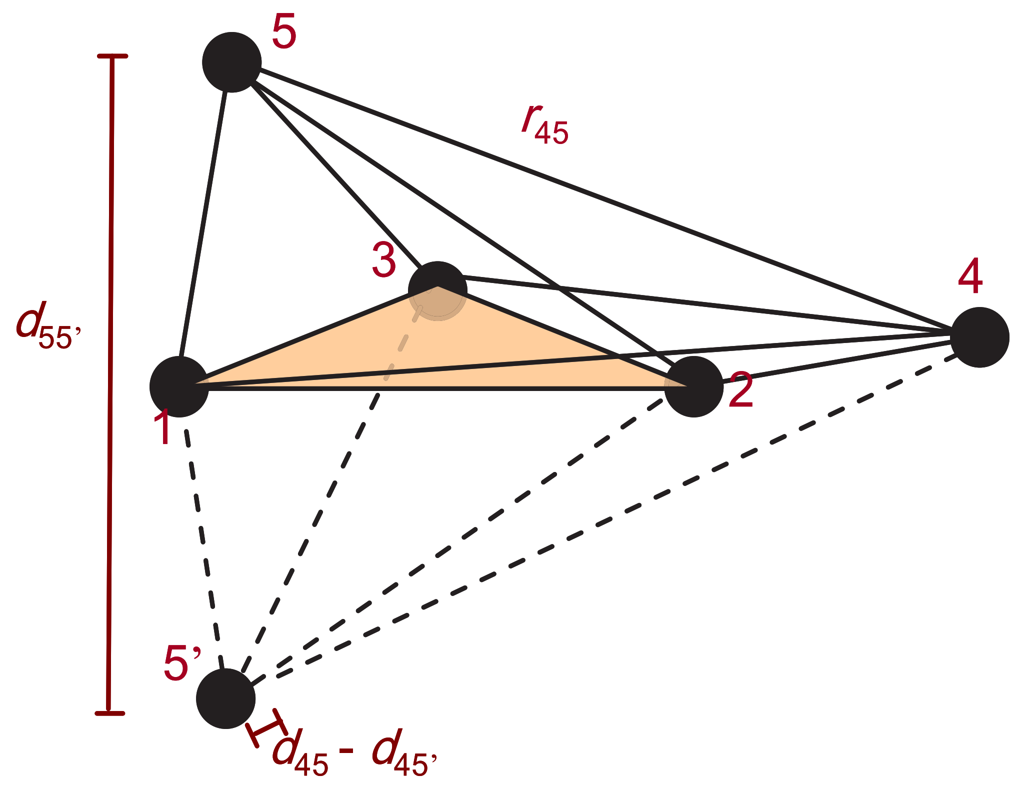
Positioning Based on Range Measurements

Ambiguity problem when creating the smallest rigid structure



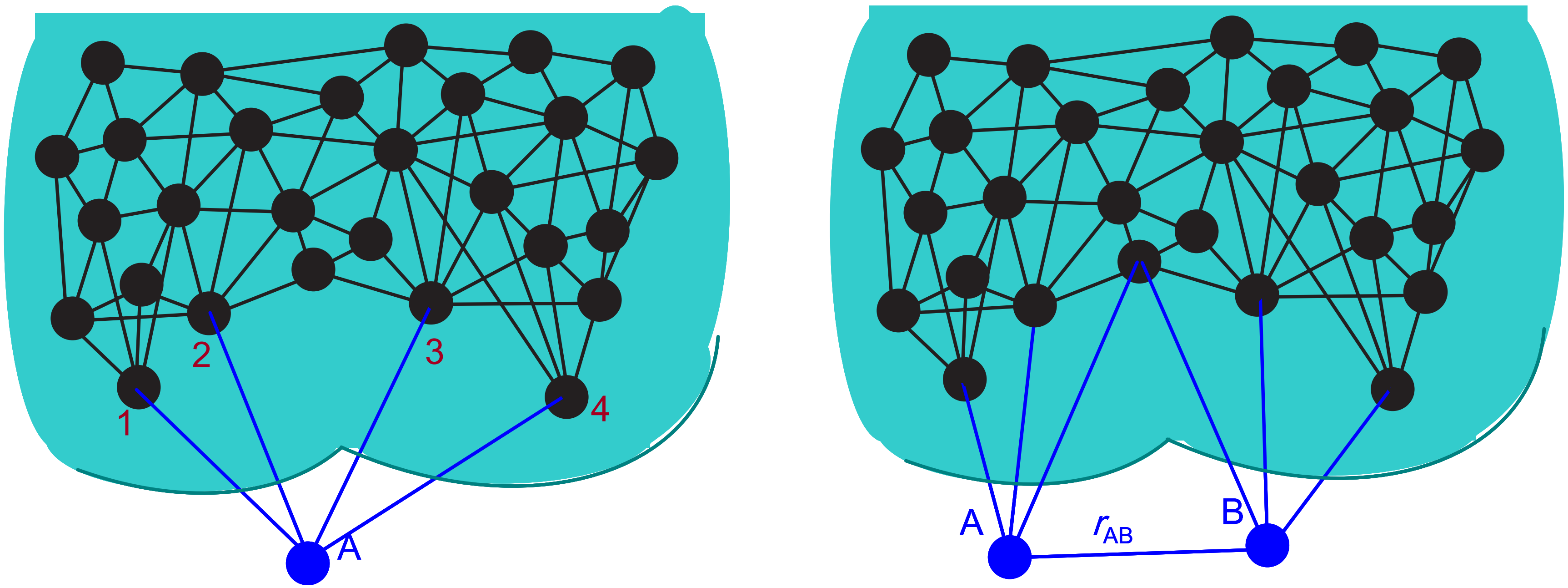
Positioning Based on Range Measurements

Solving flip ambiguity in the presence of noise



Positioning Based on Range Measurements

Expansion of a rigid structure by multilateration



AoA Measurement: iGPS

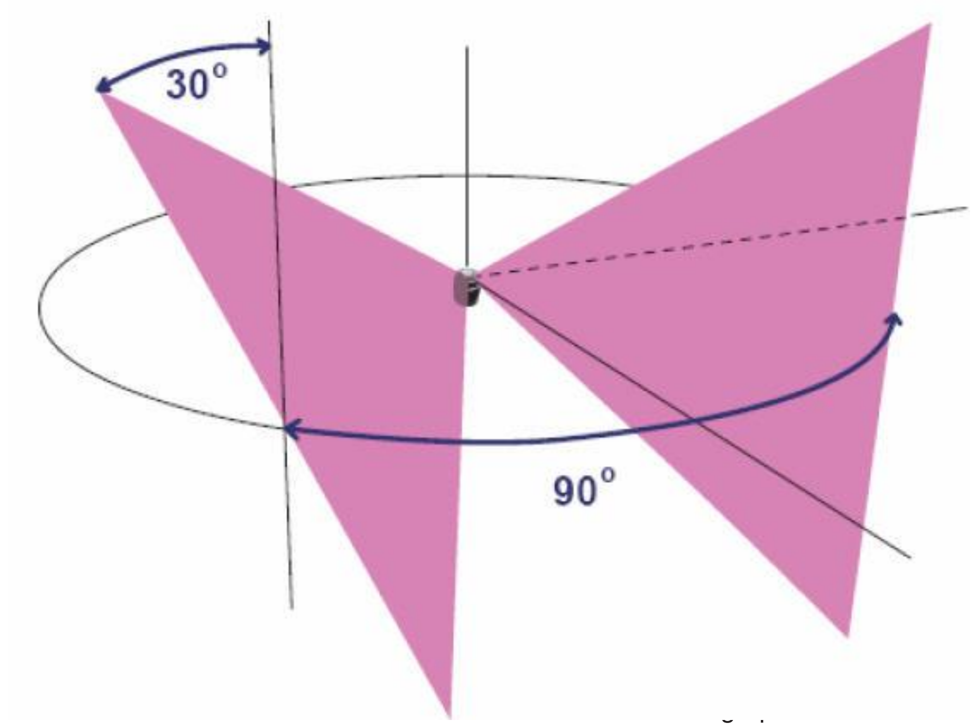
iGPS transmitter and sensor during a test in a tunnel

AoA Measurements: iGPS "laser resection"

Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
TOA angular measurements	✓	✓	✓	0.1 – 0.2 mm	2 - 50 m	RF	40 Hz	in progress	high

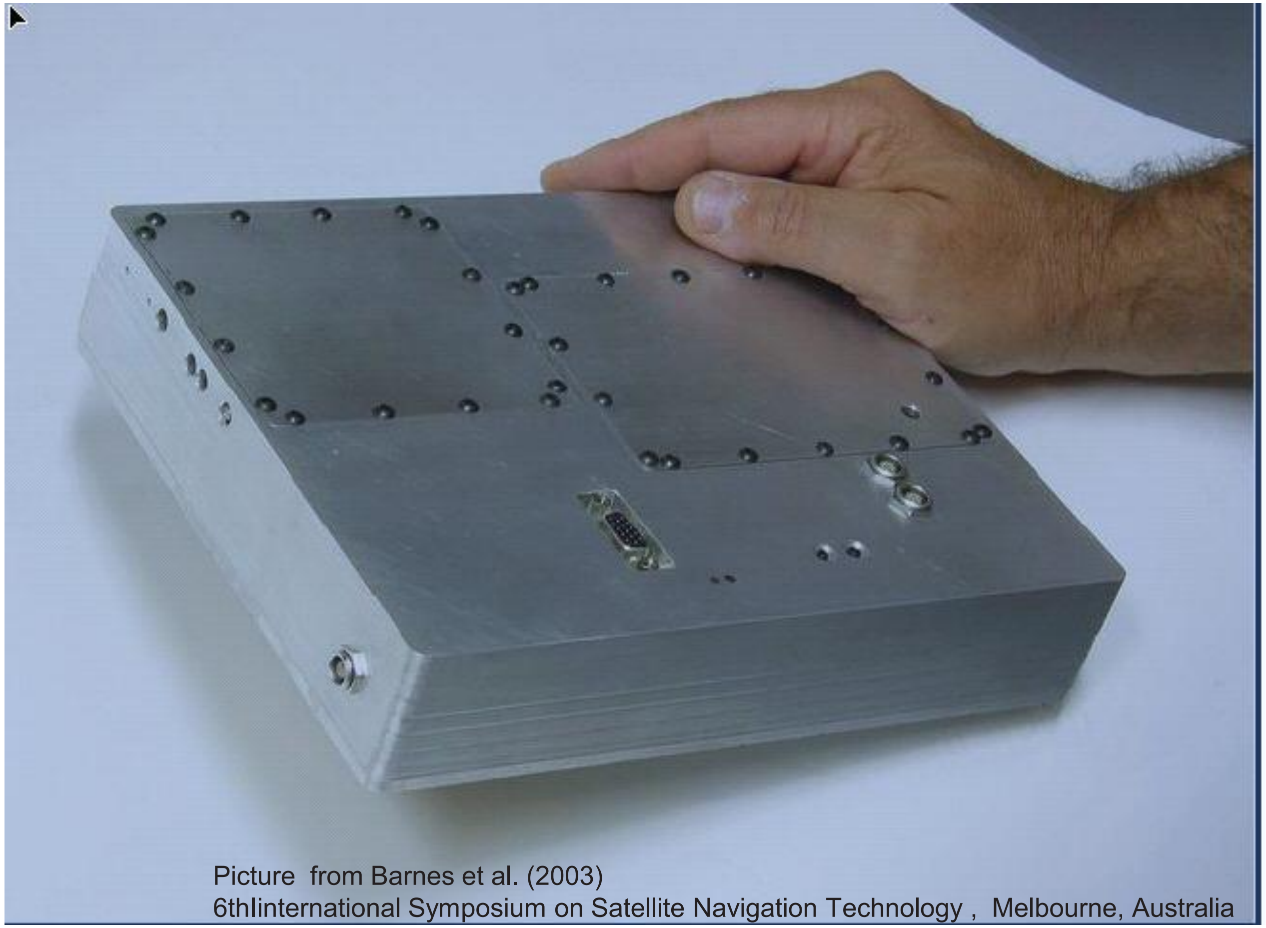
Key design:

- two or more fixed transmitters
- rotating fan-shaped laser beams
- infrared signal
- various sensors detect arrival time
- position determination with spatial forward intersection

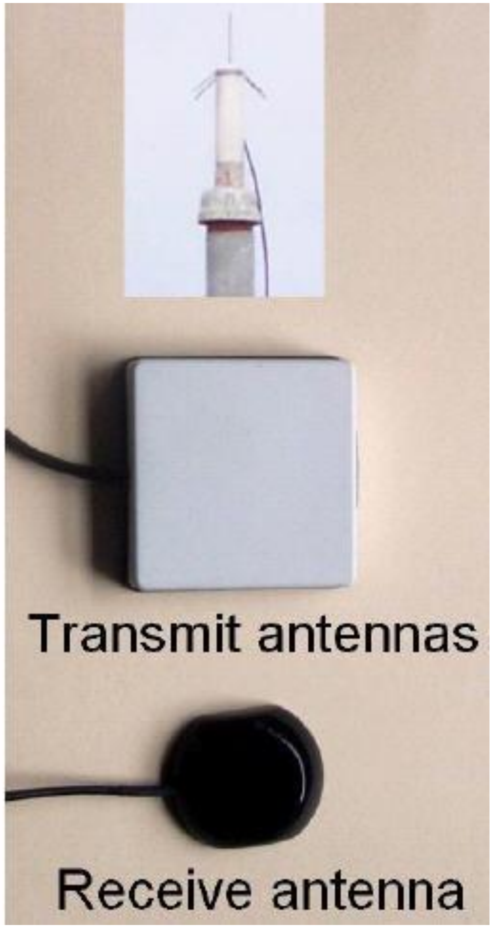


Alternative Positioning Systems

Locata: Terrestrial pseudolite transceivers



Picture from Barnes et al. (2003)
6thInternational Symposium on Satellite Navigation Technology , Melbourne, Australia

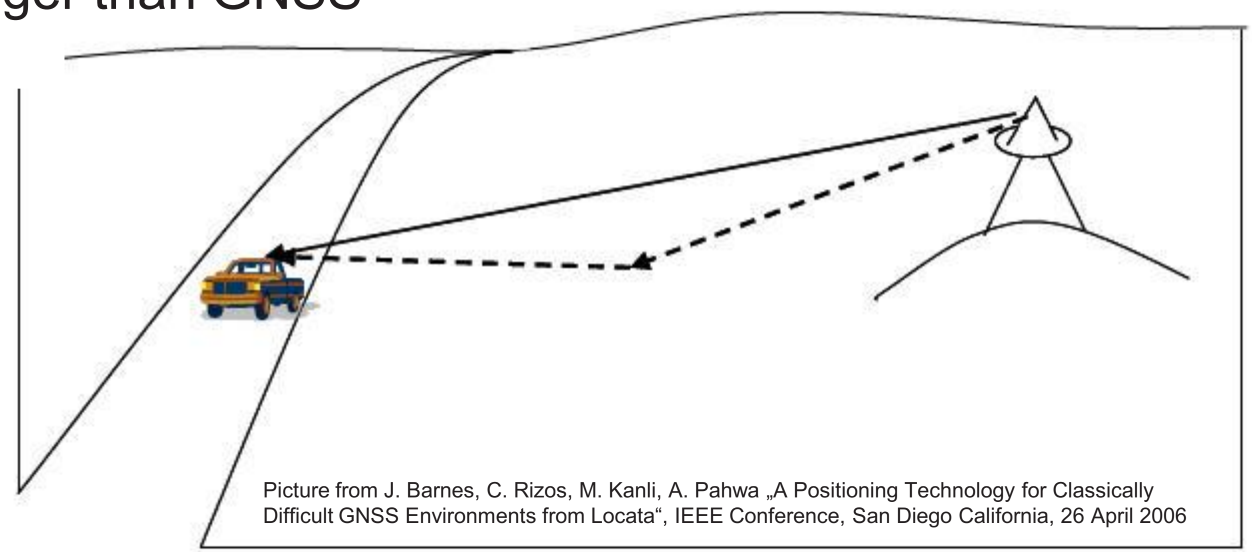


Locata – Key Parameters:

System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Locata	TOA, lateration	✓	✓	✓	2 mm static 1 cm RTK,	2 - 3 km	RF	1 Hz	in progress	high

(+) RTK: 1 – 2 cm deviations at 2.4 m/s
(+) signal magnitude stronger than GNSS
(+) indoors dm

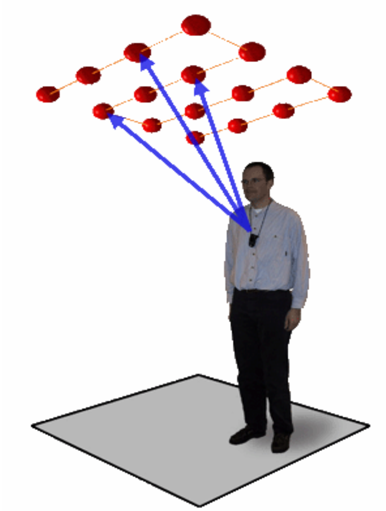
Problem:
multipath (low elevation)



Picture from J. Barnes, C. Rizos, M. Kanli, A. Pahwa „A Positioning Technology for Classically Difficult GNSS Environments from Locata“, IEEE Conference, San Diego California, 26 April 2006

TDoA: Ultrasound Systems – Crickets, Active Bat, Dolphin

System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Cricket	TOA, lateration	✗	✓	✓	1 – 2 cm	10 m	ultrasound	1 Hz	development	low
Active Bat	TOA, lateration	✗	✓	✓	1 – 5 cm	1000 m^2	ultrasound	75 Hz	no	moderate
DOLPHIN	TOA, lateration	✗	✓	✓	2 cm	room scale	ultrasound	20 Hz	no	moderate



Cambridge University

TDoA: Ultrasound Systems – Crickets, Active Bat, Dolphin

System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Cricket	TOA, lateration	✗	✓	✓	1 – 2 cm	10 m	ultrasound	1 Hz	development	low
Active Bat	TOA, lateration	✗	✓	✓	1 – 5 cm	1000 m^2	ultrasound	75 Hz	no	moderate
DOLPHIN	TOA, lateration	✗	✓	✓	2 cm	room scale	ultrasound	20 Hz	no	moderate

Problems:

- dependency on temperature
- maximal range
- deployment of reference beacons
- multipath
- reliability
- interference with other sound sources

Positioning based on Signal Strength

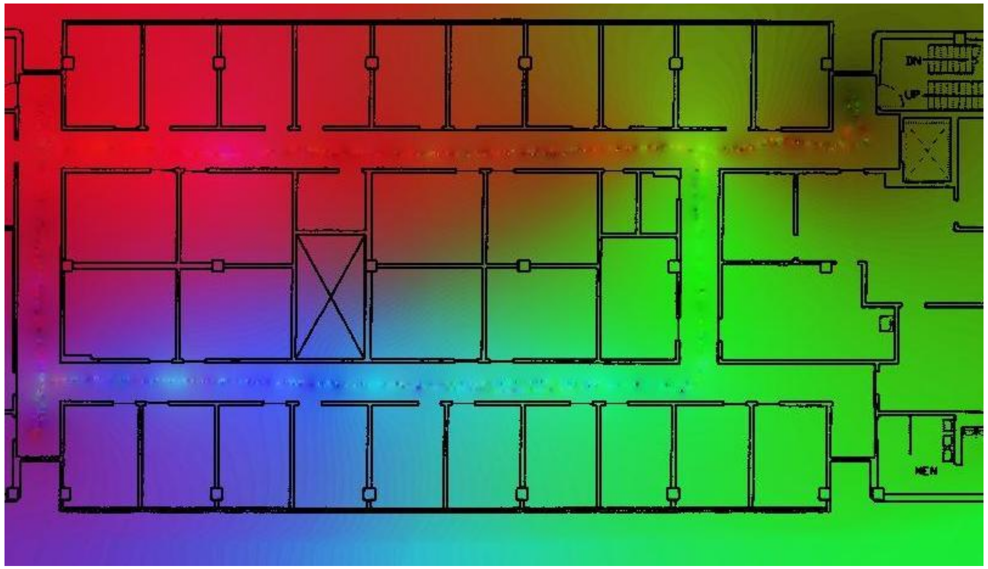
System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Sonitor	RSSI, Cell ID	×	✓	✓	m-level	15 m	ultrasound	0.3 Hz	yes	low
RFID	Signal Strength	×	✓	✓	dm-m	20 m	RF, 866 MHz		no	low

All signals can be used:

WLAN, Ultrasound, RF, GPRS, etc.

Problems:

- reliability
- accuracy



USC Robotics Research Lab

RSSI in sensor networks: not for geodetic (reliable, precise) applications!

Auto-Positioning Algorithm

Mobile listener collects distance measurements

$$redundancy = R - 3(B + P) + 6,$$

R = observed ranges, B = fixed beacons P = listener positions

Example below: redundancy = 0 (R = 24, B = 4, P = 6)