Combination of Indoor and Outdoor Positioning

Dr. Rainer Mautz

ETH Zürich
Institute of Geodesy and Photogrammetry

Contents

User Requirements:

availability: 100% of the time

timeliness: realtime

reliability: no failures

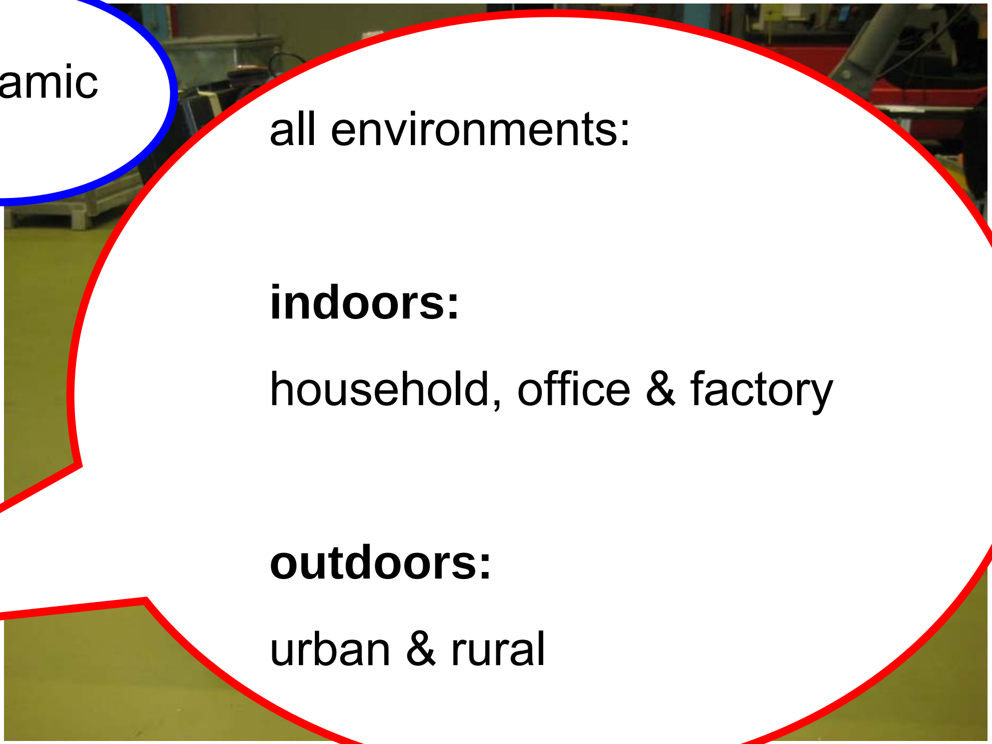
hybrid systems: to be avoided

local installations: none

accuracy: mm - cm

coverage: global

dynamic



all environments:

indoors:

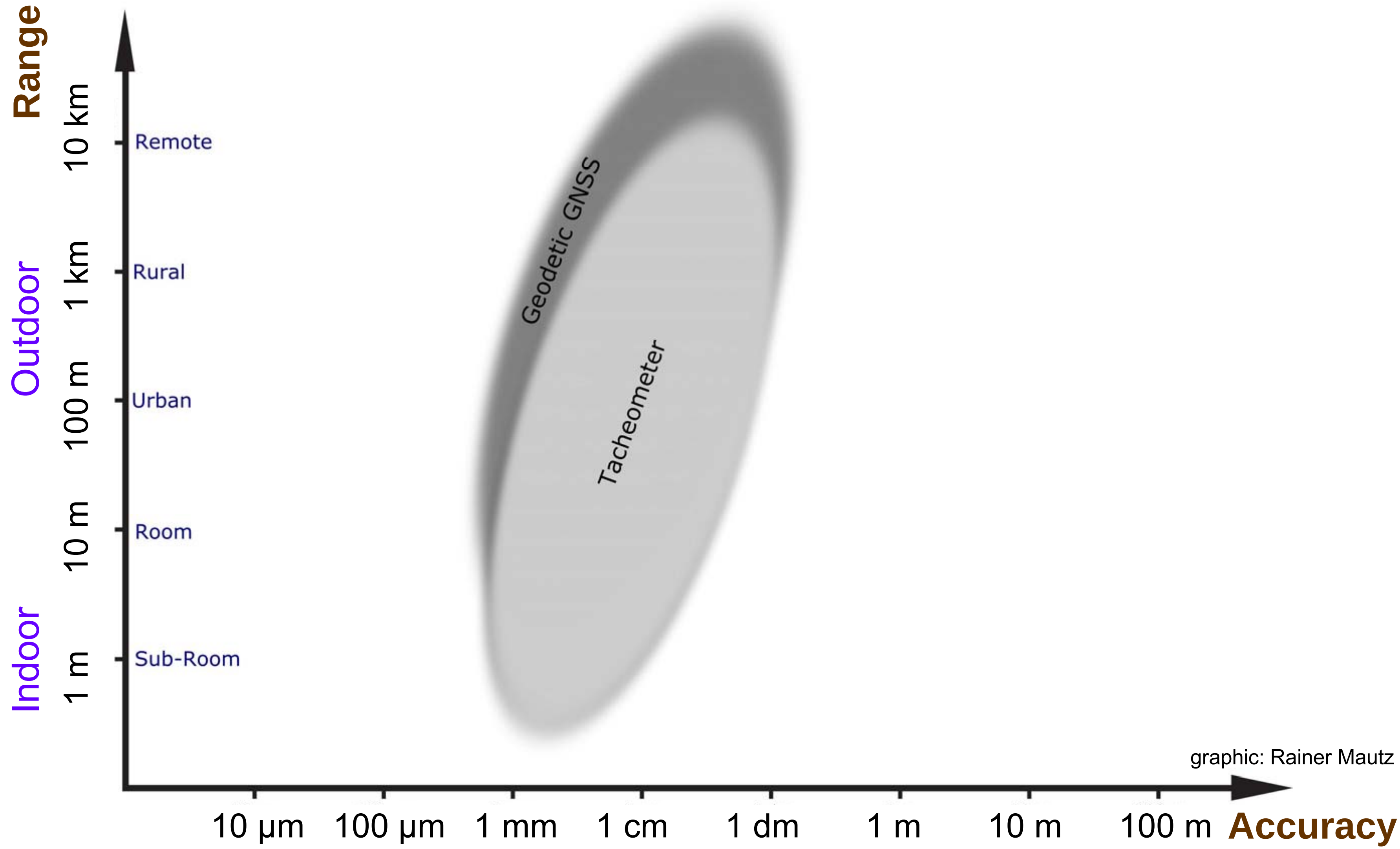
household, office & factory

outdoors:

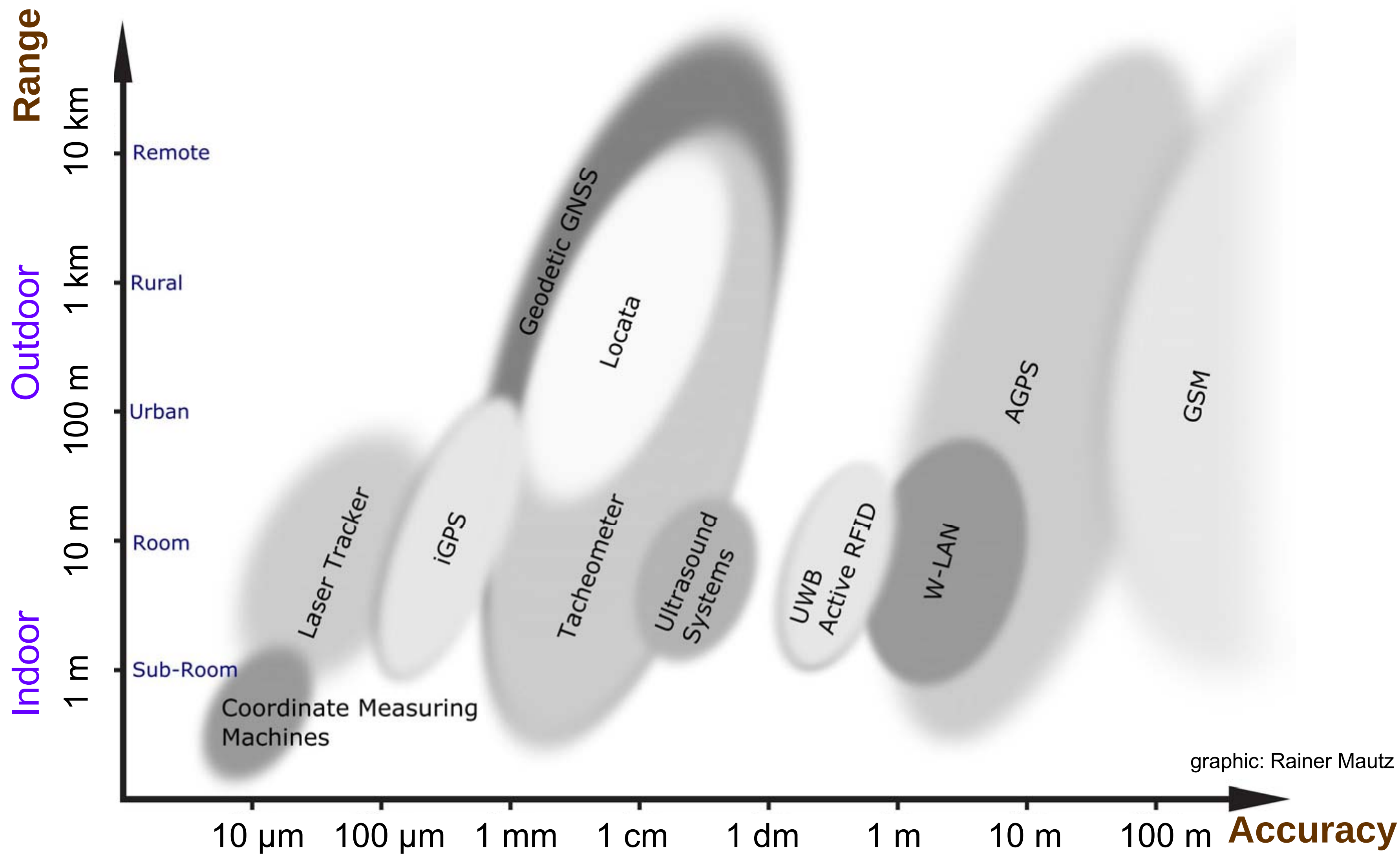
urban & rural

Classification of Positioning Systems:

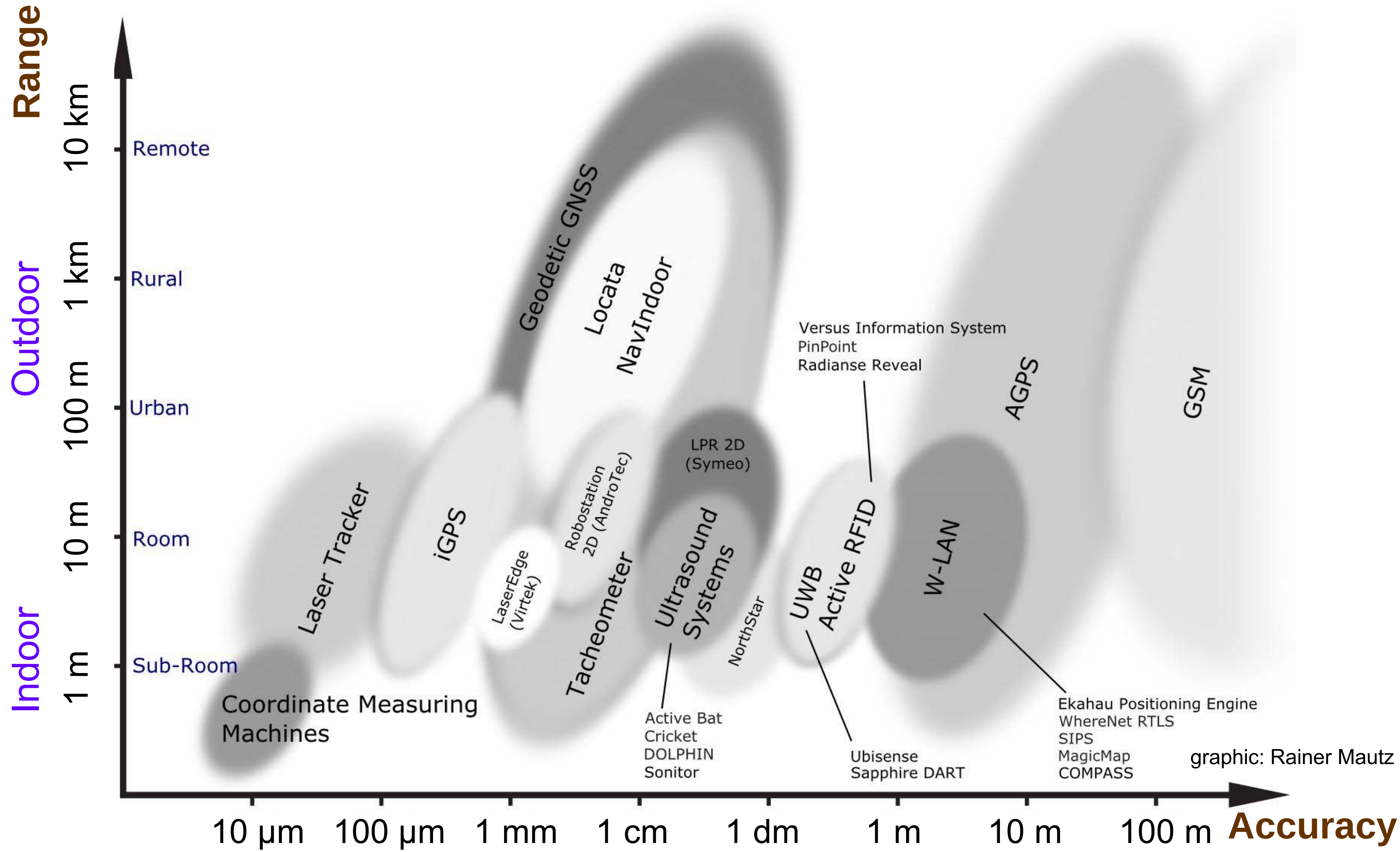
- Signal wavelength (Radio Frequencies, Light Waves, Ultrasound, RFID, Terahertz)
- Principle (trilateration, triangulation, signal strength)
- Environment (indoor, outdoor, urban, rural, remote)
- Active / passive sensors
- Accuracy (µm – km)
- Application (industry, surveying, navigation)

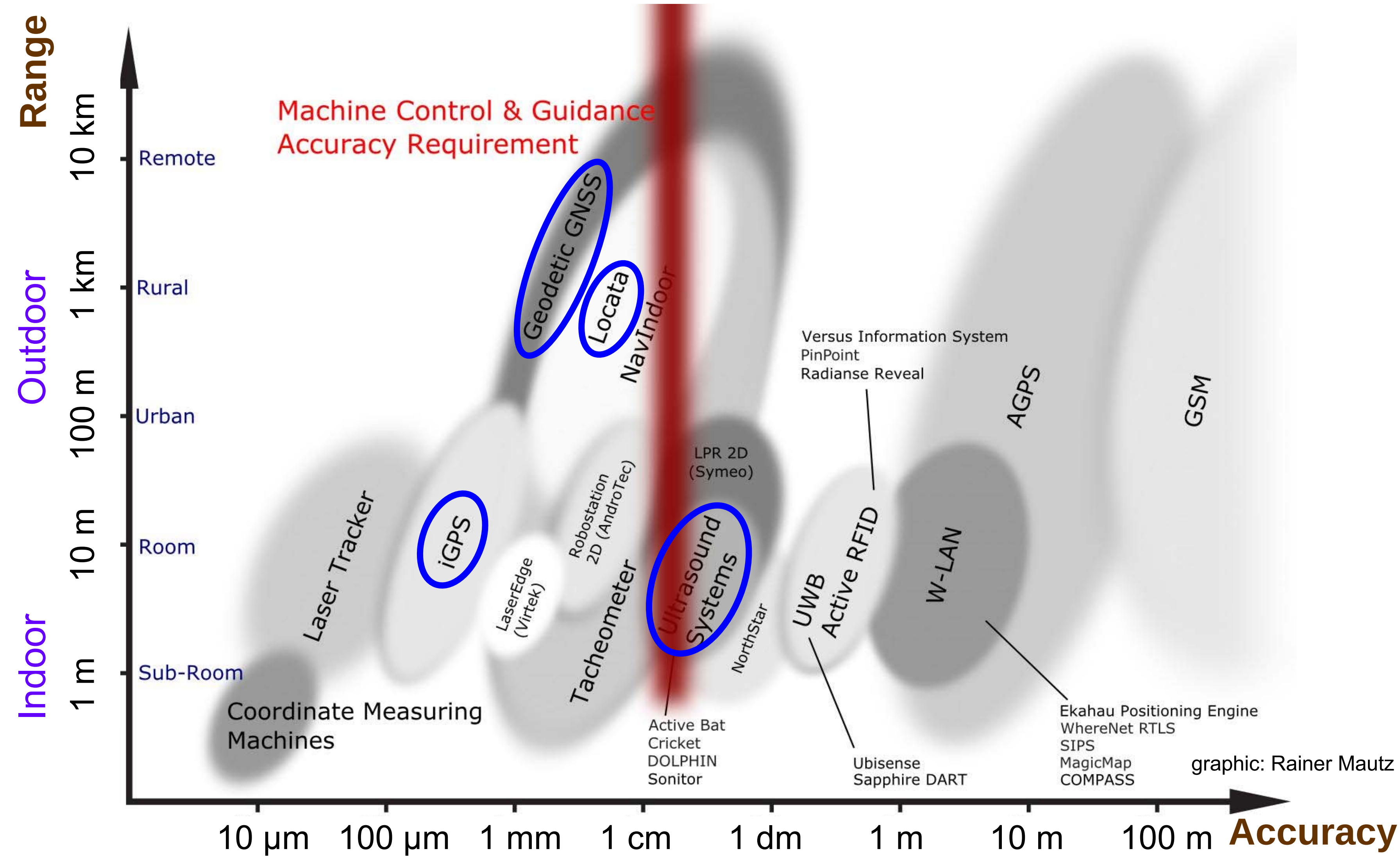


graphic: Rainer Mautz



graphic: Rainer Mautz


Range
Accuracy
Indoor
Outdoor
10 km
1 km
100 m
10 m
1 m
Remote
Rural
Urban
Room
Sub-Room
10 µm
100 µm
1 mm
1 cm
1 dm
1 m
10 m
100 m
Geodetic GNSS
Locata
NavIndoor
Versus Information System
PinPoint
Radianse Reveal
AGPS
GSM
LPR 2D (Symeo)
Robostation 2D (AndroTec)
Laser Tracker
iGPS
LaserEdge (Virtek)
Tacheometer
Ultrasound Systems
NorthStar
UWB
Active RFID
W-LAN
Coordinate Measuring Machines
Active Bat
Cricket
DOLPHIN
Sonitor
Ubisense
Sapphire DART
Ekahau Positioning Engine
WhereNet RTLS
SIPS
MagicMap
COMPASS
graphic: Rainer Mautz



graphic: Rainer Mautz

GNSS – Performance:

System	Principle	Coverage		Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
		Outdoor	Indoor							
Geodetic GNSS	TOA, lateration, differential technique	(✓)	×	✓	mm	global	RF	20 Hz	yes	moderate to high

limitations:

no direct line-of-sight:

- obstacles
- multipath

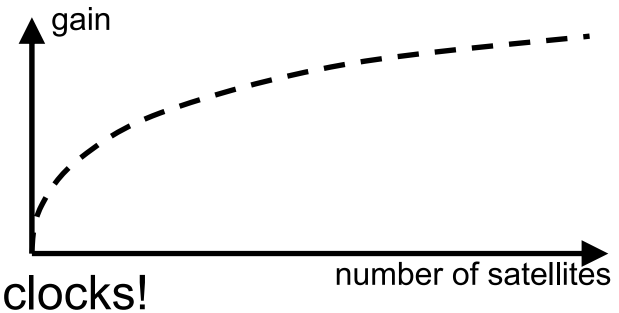
in addition:

- strong attenuation
- fading: reflections, diffraction, scattering
- no general model

Number of satellites in space

	GPS (United States)	**GLONASS** (Russia)	**Galileo** (EU)	**Beidou**, i.e. Compass (China)
Current number	31 MEO	16 MEO	1 MEO	1 MEO, 4 GEO
Future number	30 MEO	24 MEO	30 MEO	27 MEO, 5 GEO
Full operational capability	1995	2011	2013	ca. 2010

Today: 10 satellites (open sky)
2013: 40 satellites (open sky)



Implications on indoor environments ? marginal
Other improvements: integrity, anti-jam power, security, clocks!

Attenuation of various building materials (L1 = 1500 MHz)

Mat…	[dB]	Factor [-]
	1 - 4	0.8 – 0.4
	2 - 9	0.6 – 0.1
	5 - 31	0.…
	12 - 43	
Fer…	29 - 43	

Indoors:

100 times weaker

underground:

10000 times weaker

Signal Strengt… …ecibel Watt of GNSS Satellit…

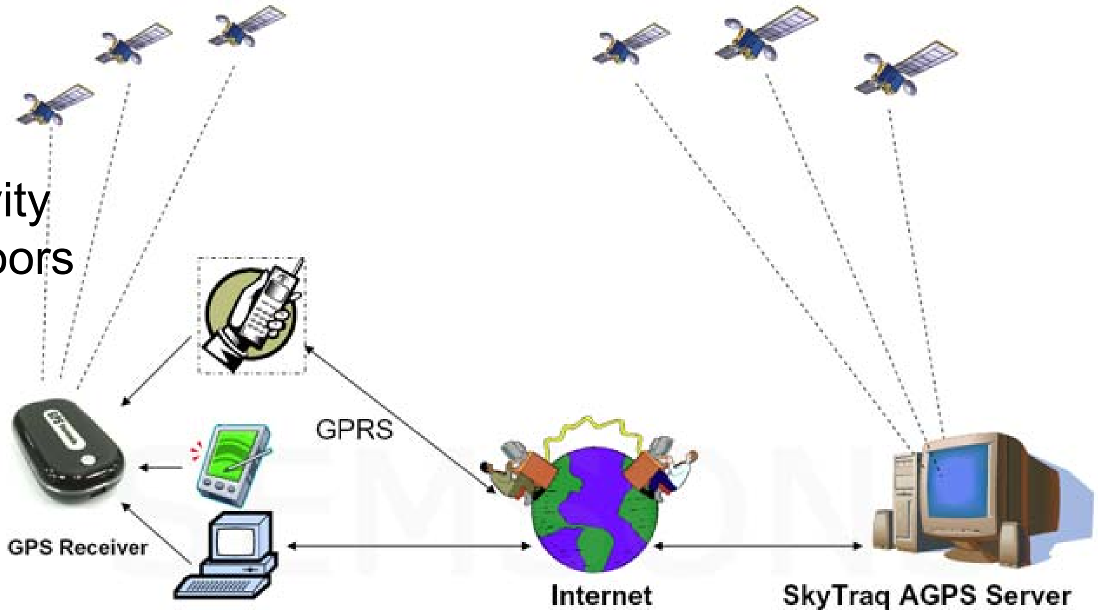
Environment	[dBW]	
Satellite	+14	signal strength … ed from satellite
Outdoors	-155	unaided fi… OK for standard receivers
Indoors	-176	dec… limit for high sensitive receivers
Underground	-191	decode limit for aided, ultra-high sensitive receivers

How to overcome attenuation?
- Increase receiver sensibility
- Increase satellite signal power
- Use ultra wideband GNSS signals

Assisted GNSS (AGNSS, AGPS)

ephemeris, almanac via mobile phone

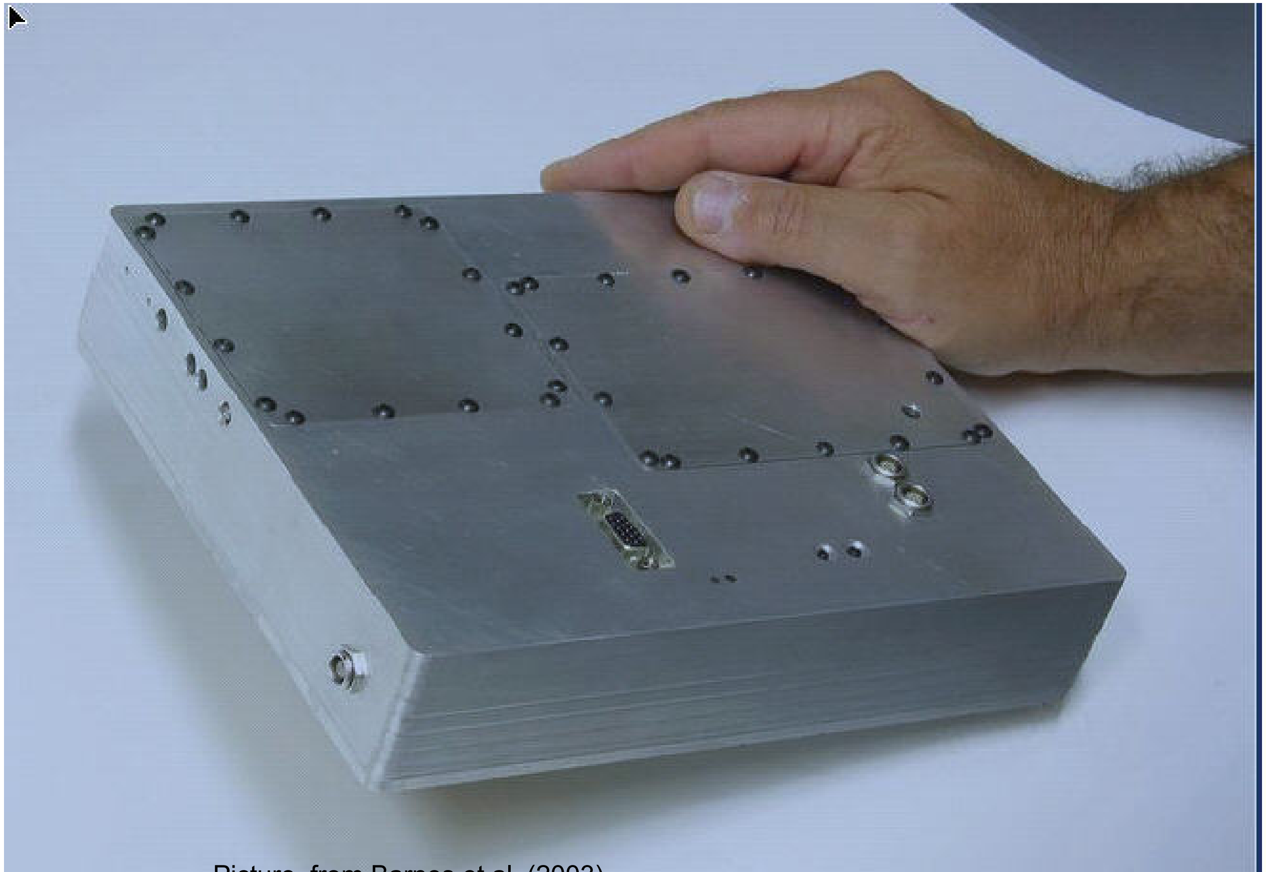
(+) hot start, quicker position fix
(-) long acquisition times indoors
(-) high power needs for high sensitivity
(-) accuracy degrades to m-level indoors



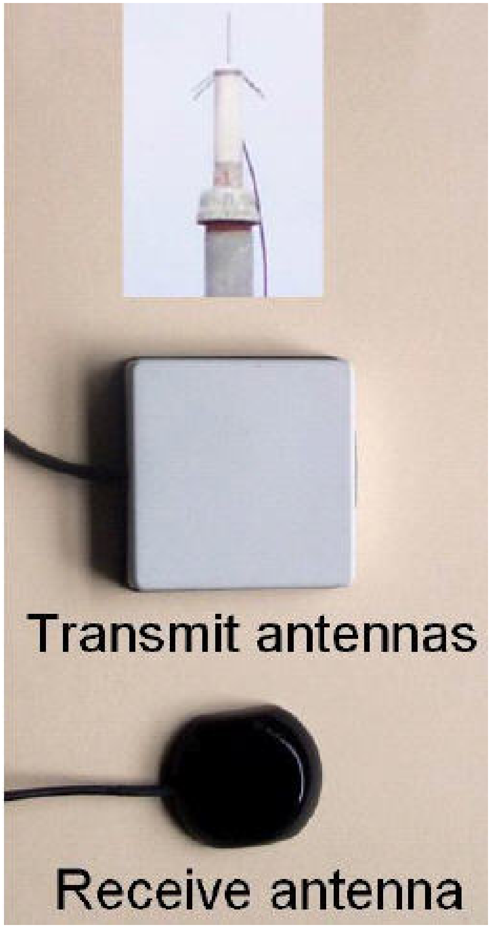
graphic from: www.semsons.com

Alternative Positioning Systems

Locata: Terrestrial pseudolite transceivers



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

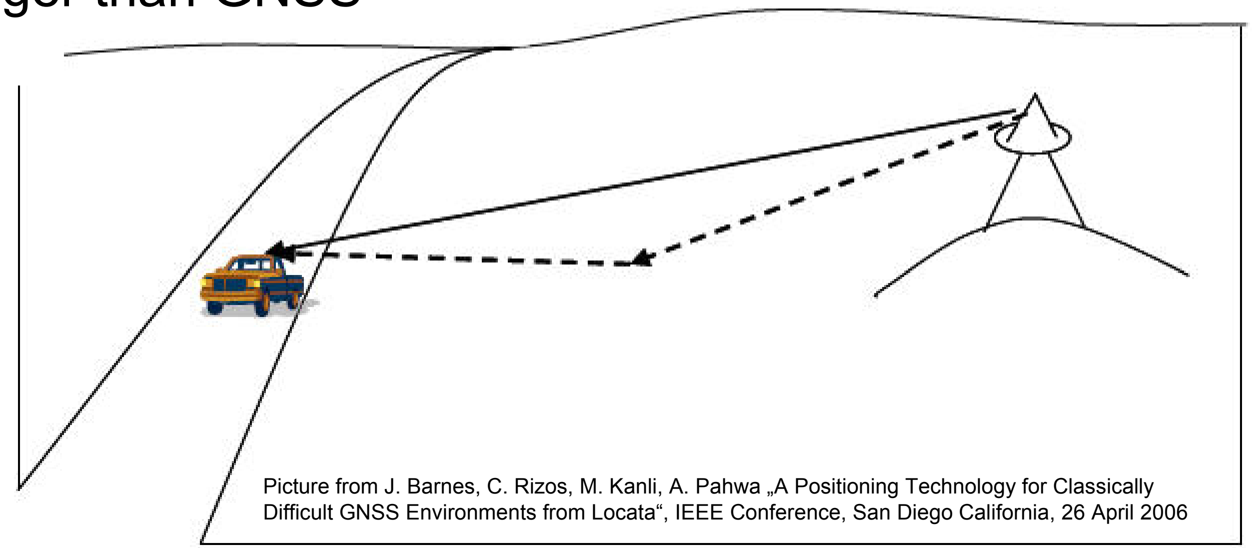


Locata – Key Parameters:

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

iGPS

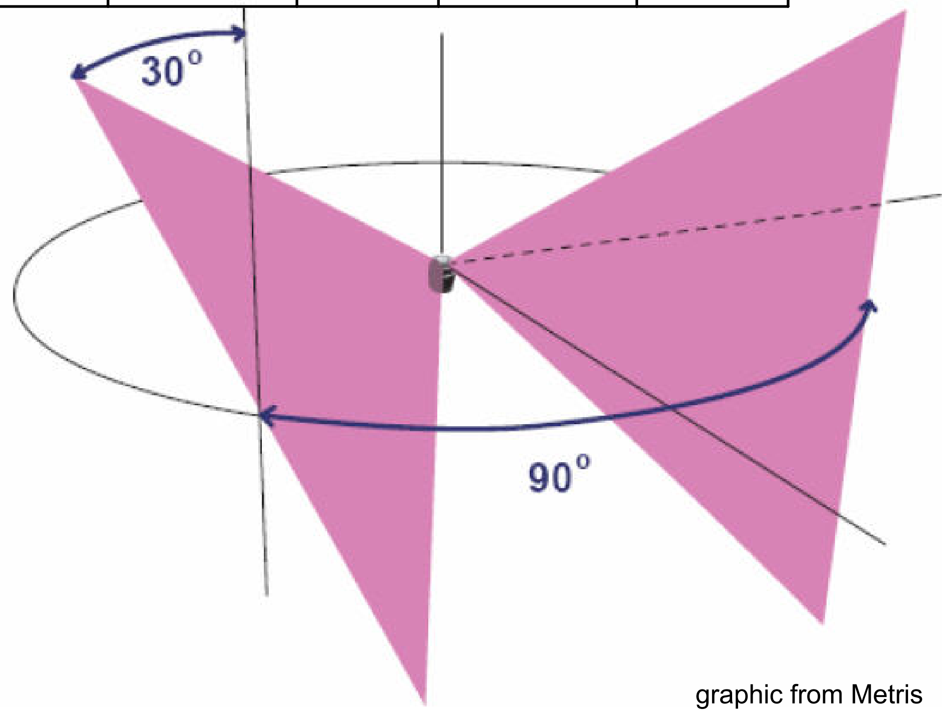
iGPS transmitter and sensor during a test in a tunnel

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:

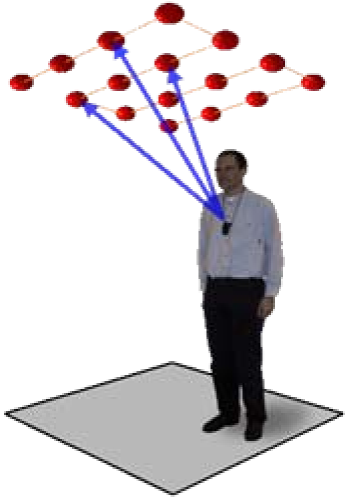
- two or more fixed transmitters
- rotating fan-shaped laser beams
- infrared signal
- various sensors detect arrival times
- position determination with spatial forward intersection



graphic from Metris

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	develop ment	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



Picture: Cambridge University

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	develop ment	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

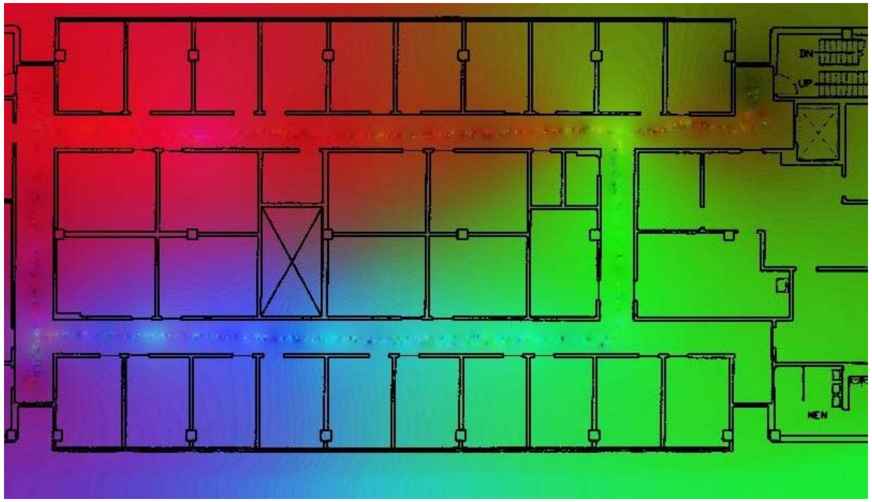
System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Sonitor	RSSI, Cell ID	×	✓	✓	m-level	15 m	ultrasound	0.3 Hz	yes	low
RFID	Signal Strength	×	✓	✓	dm-m	20 m	RF, 866 MHz		no	low

All signals can be used:

WLAN, Ultrasound, RF, GPRS, etc.

Problems:

- reliability
- accuracy



Picture from: USC Robotics Research Lab

Conclusions

Outdoors: GNSS dominating system for open-sky
Indoors: No overall solution yet

Several indoor systems on the market
- low accuracy
- sophisticated set ups
- limited coverage area
- inadequate costs

Outlook

signals will penetrate buildings
use existing infrastructure
higher accuracy local installations unavoidable

End