Indoor Positioning

13.10.2010 15:30 – 16:30 HIL D53

Contents

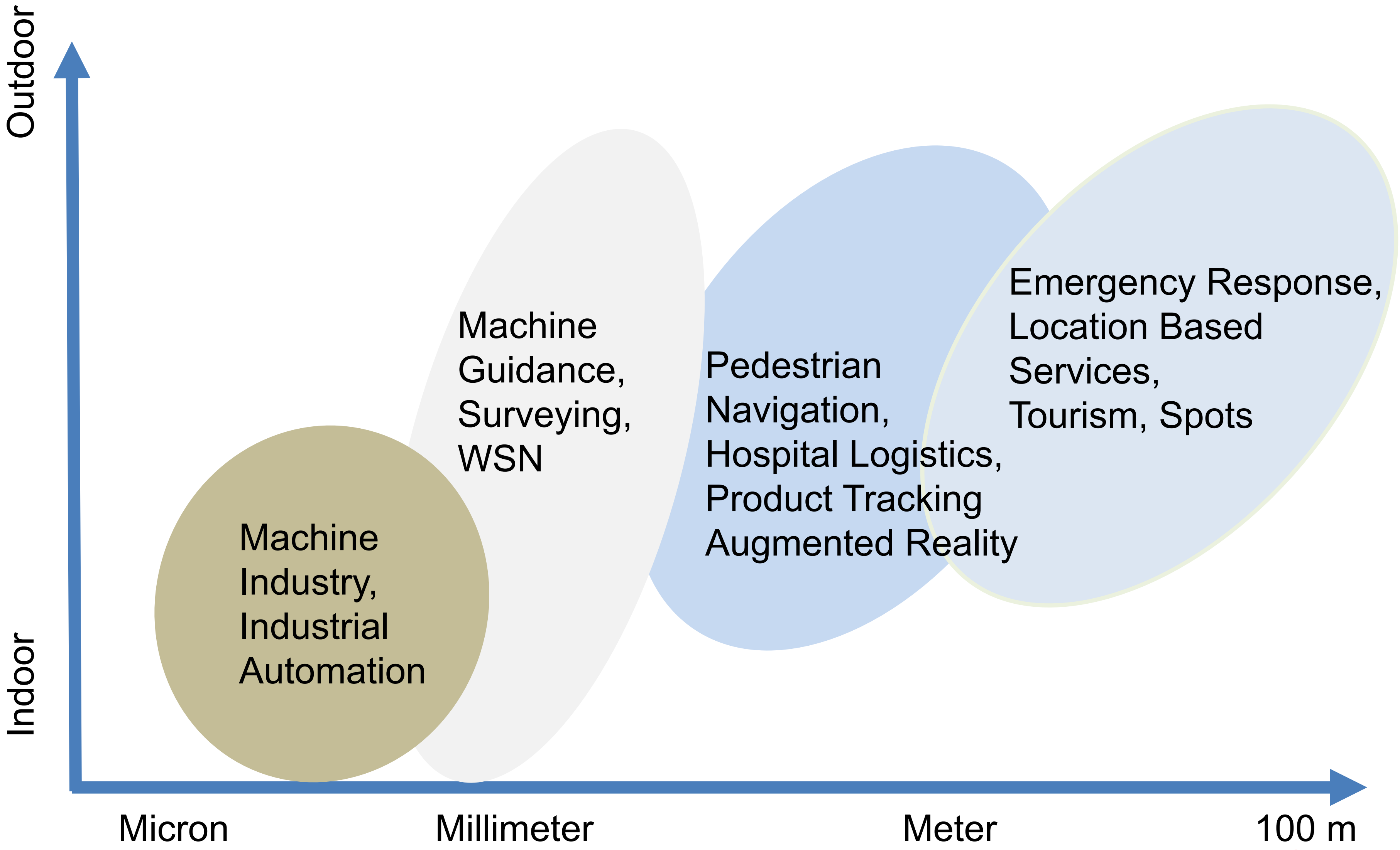
geomETH

What is positioning?

(Indoor-)

- Positioning
- Position determination
- Navigation ←→ Tracking
- Locating (Ortung)
- Localisation (Lokalisierung)

Applications



Which performances should system meet ?

- reliable
- fast
- safe
- accurate
- compatible to personal assistance systems
- ubiquitous
- real-time
- cheap
- …?

System Criteria

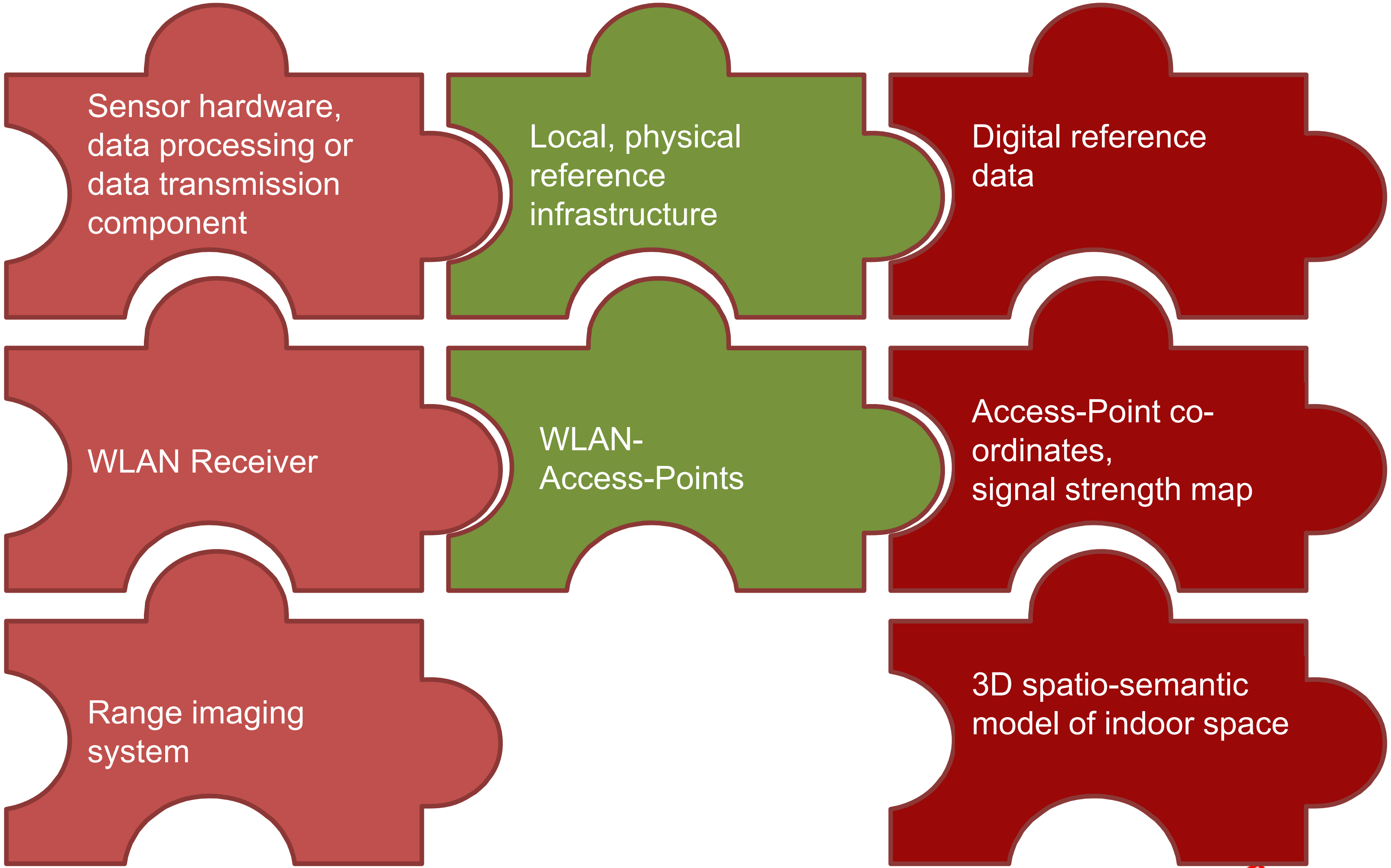
- Signal wavelength (Radio Frequencies, Light Waves, Ultrasound, RFID)
- Principle (trilateration, triangulation, signal strength)
- Active / passive sensors
- Application (industry, surveying, navigation)
- Costs
- Market Maturity (design, development, product)
- Infrastructure (deployed beacons, GIS)
- Coverage (room, building, city)
- Accuracy (µm – decametres)

Components of Indoor Positioning Systems

Components of current systems

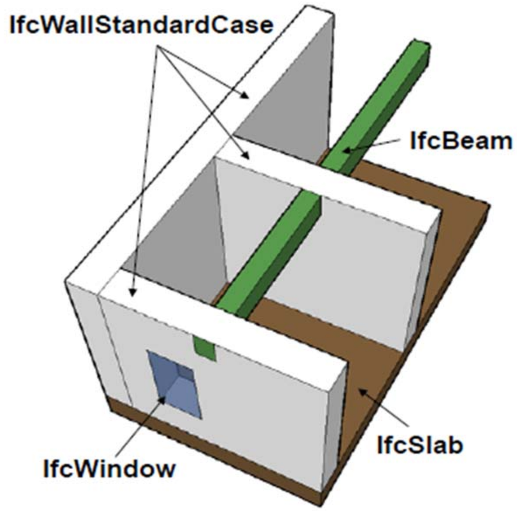
Example: WLAN-based System

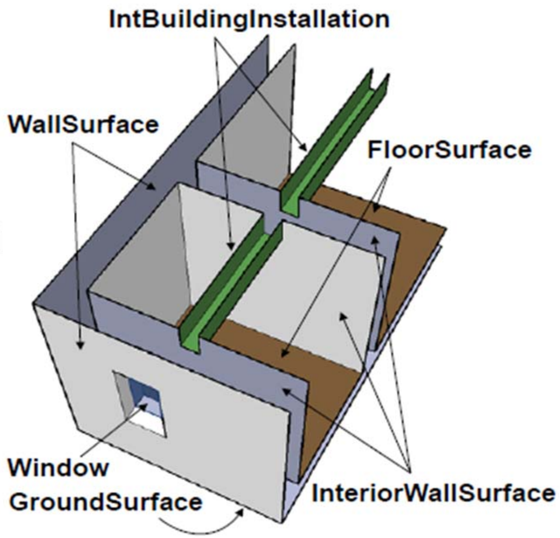
Research topic



Classification criteria for 3D models of indoor space

- Creation process:
  Construction / Reconstruction*
- Geometric Modeling:
- Constructive Solid Geometry / Boundary Representation*
-
  -evel of De
-
  RML, X3D) ... on
  (Industry F ... GIS-

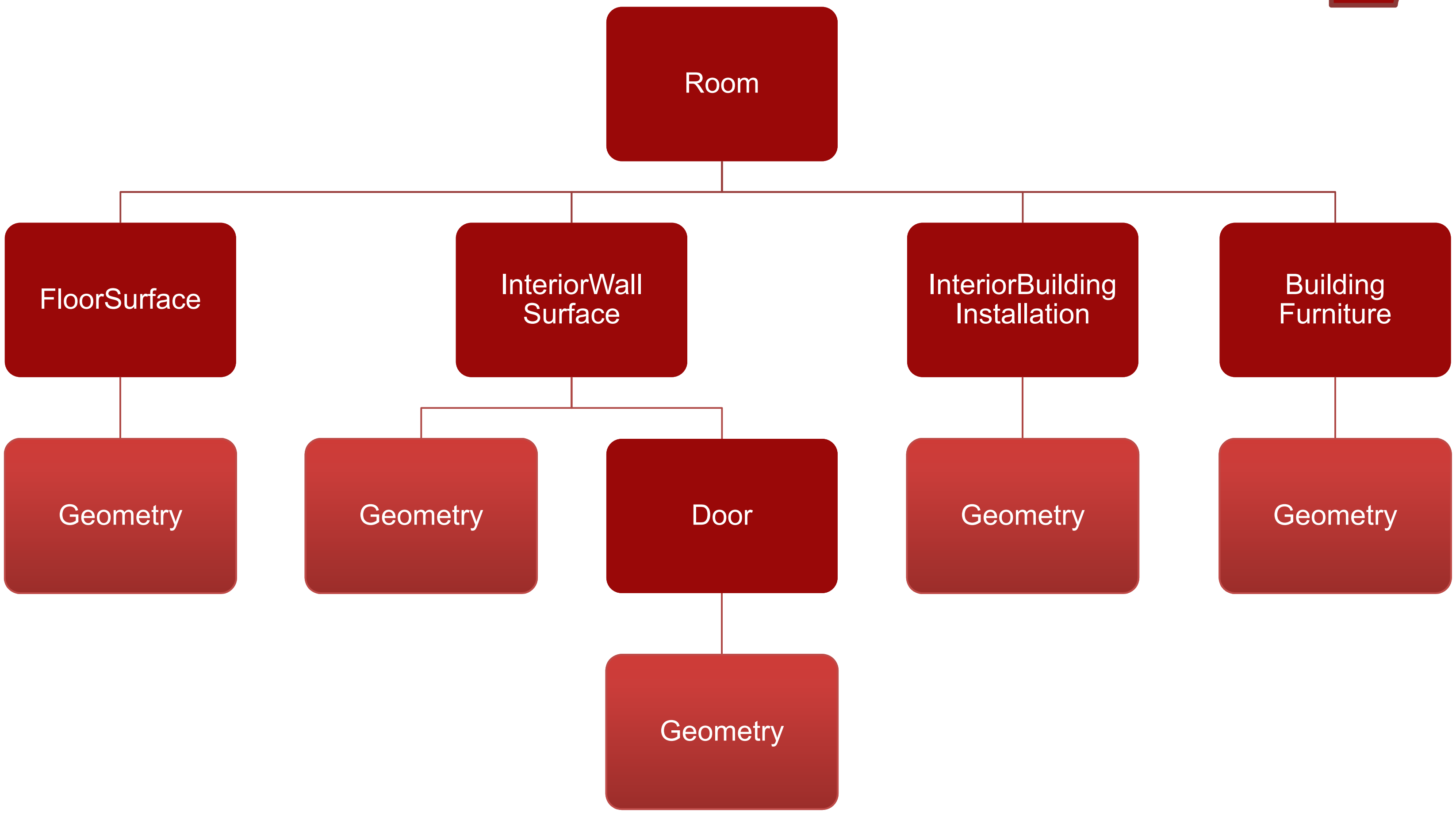




[Image source: Claus Nagel et al. 2009]

- *=CityGML

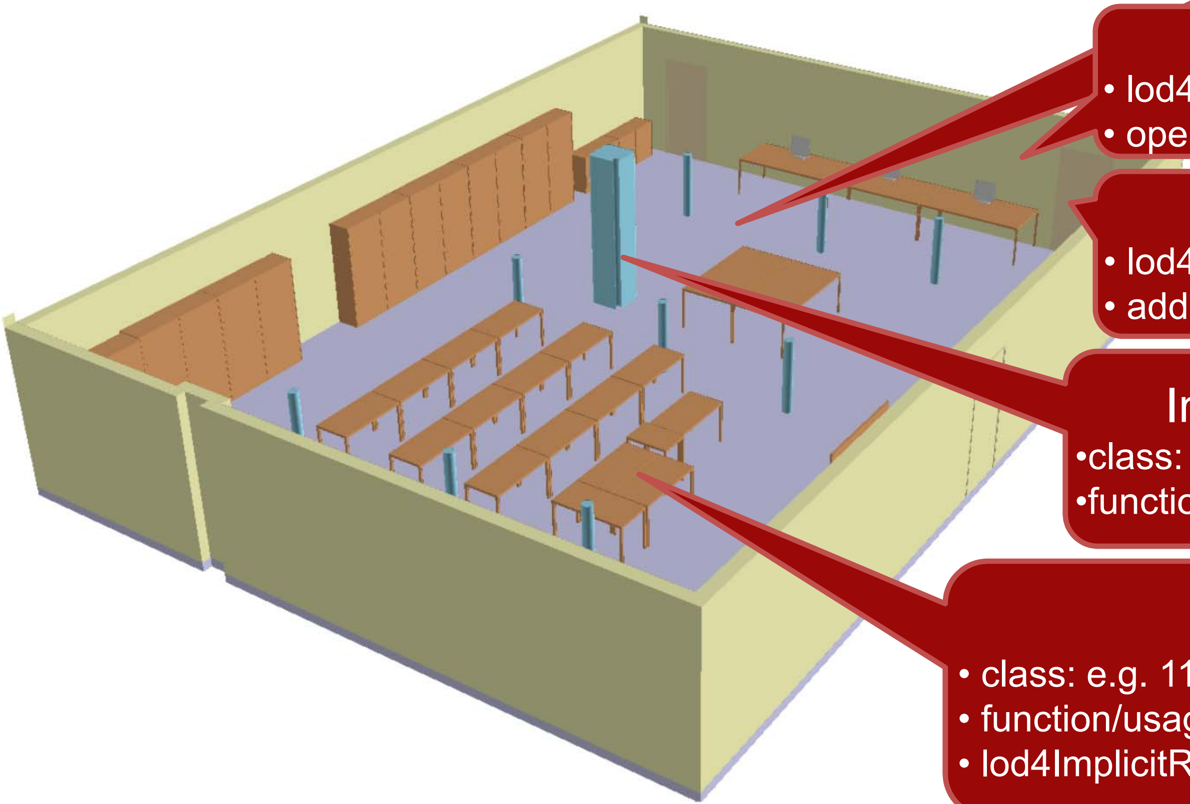
The CityGML indoor space model



The CityGML indoor space model

Room

- class: z.B. 1070 = education, research
- function/usage: z.B. 2720 = prison cell
- boundedBy: → FloorSurface-, InteriorWallSurface objects
- interiorFurniture: → BuildingFurniture objects
- roomInstallation: → InteriorBuildingInstallation objects



FloorSurface

- lod4MultiSurface: Geometry

InteriorWallSurface

- lod4MultiSurface: Geometry
- opening: → door objects

Door

- lod4MultiSurface: Geometry
- address: room number etc.

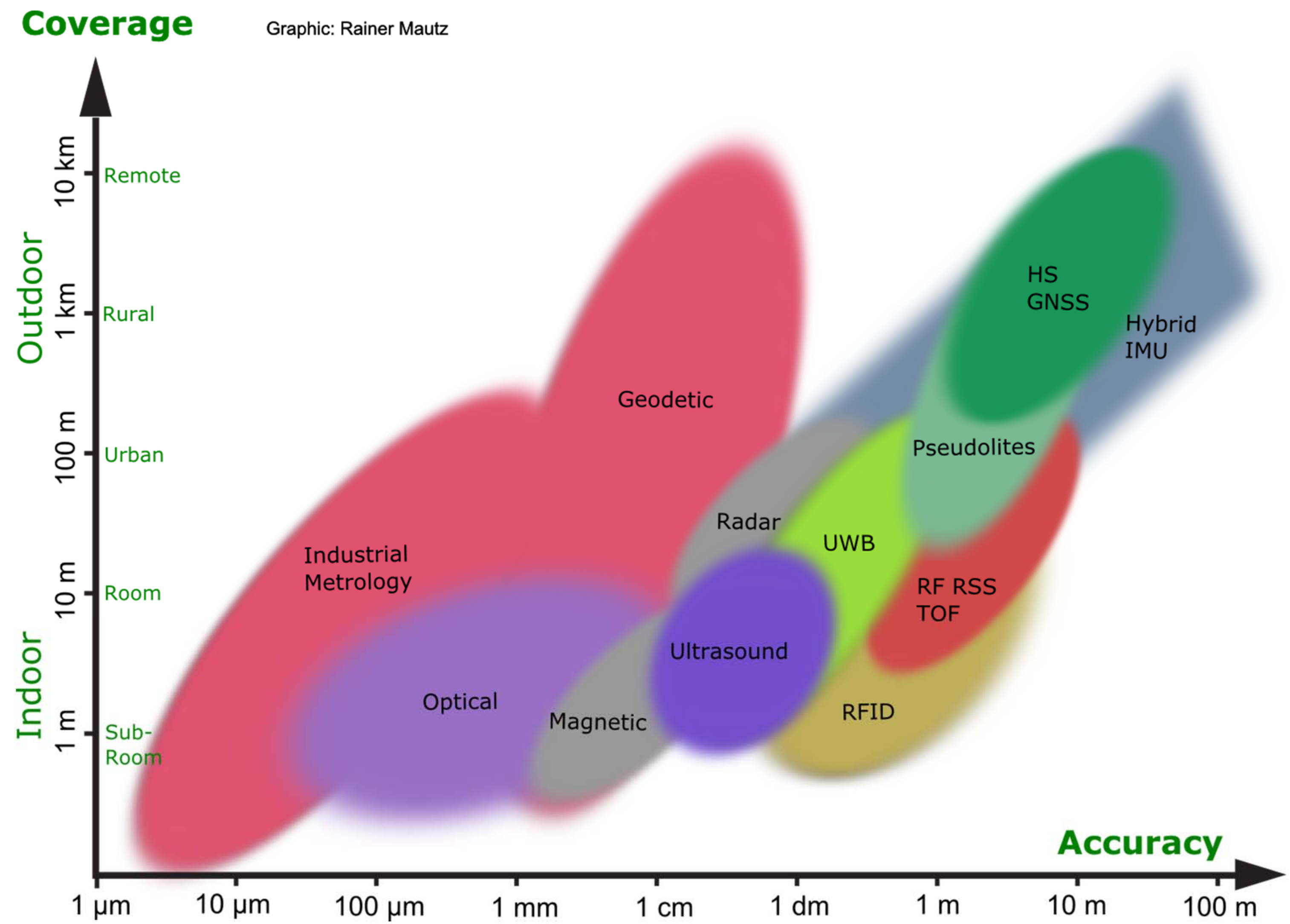
InteriorBuildingInstallation

- class: e.g. 6000 = statics
- function/usage: e.g. 7020 = column

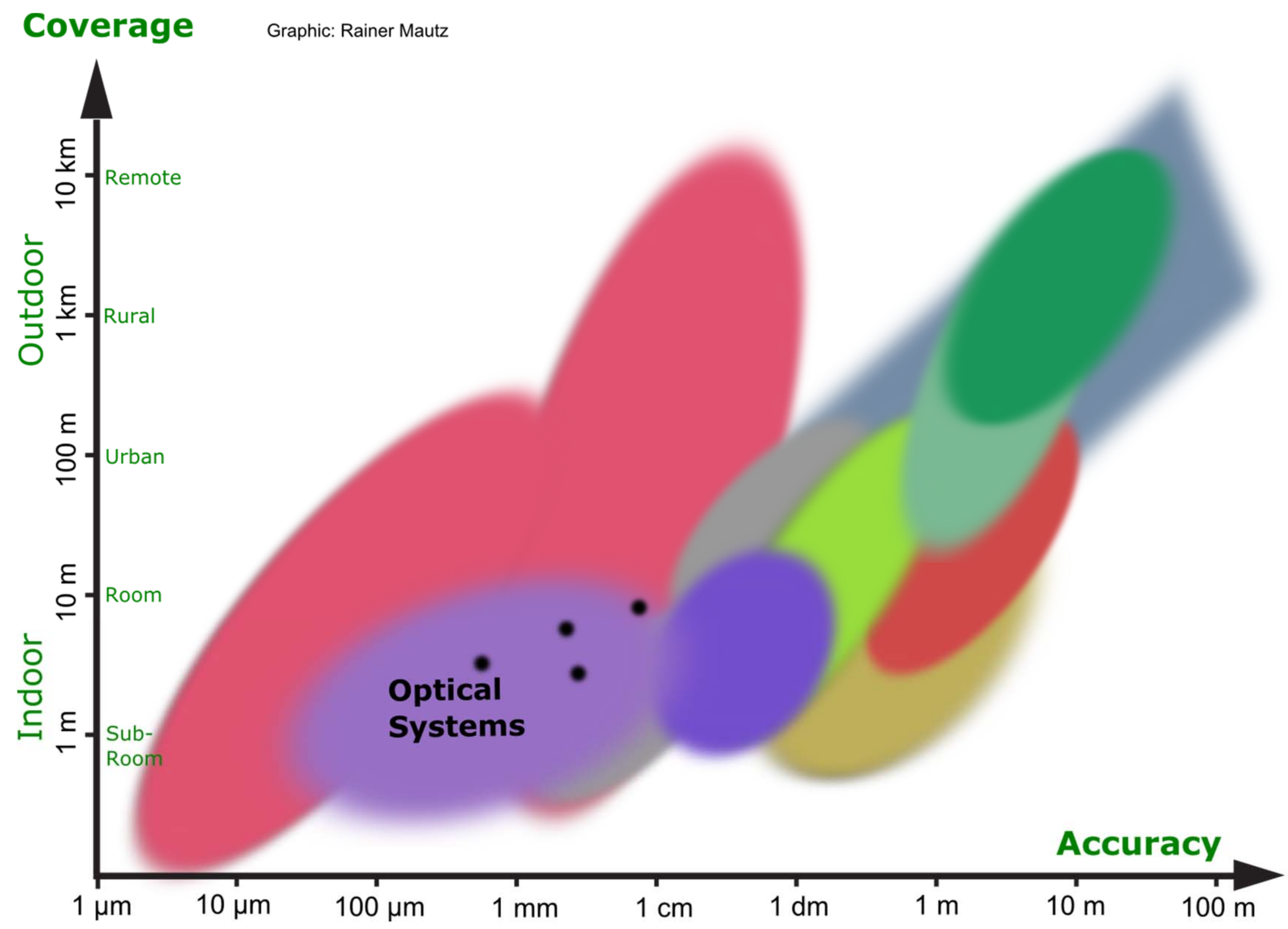
BuildingFurniture

- class: e.g. 1100 = education, research
- function/usage: e.g. 1230 = desk
- lod4ImplicitRepresenation: CAD drawing

Overview Indoor Positioning Techniques



Optical Systems



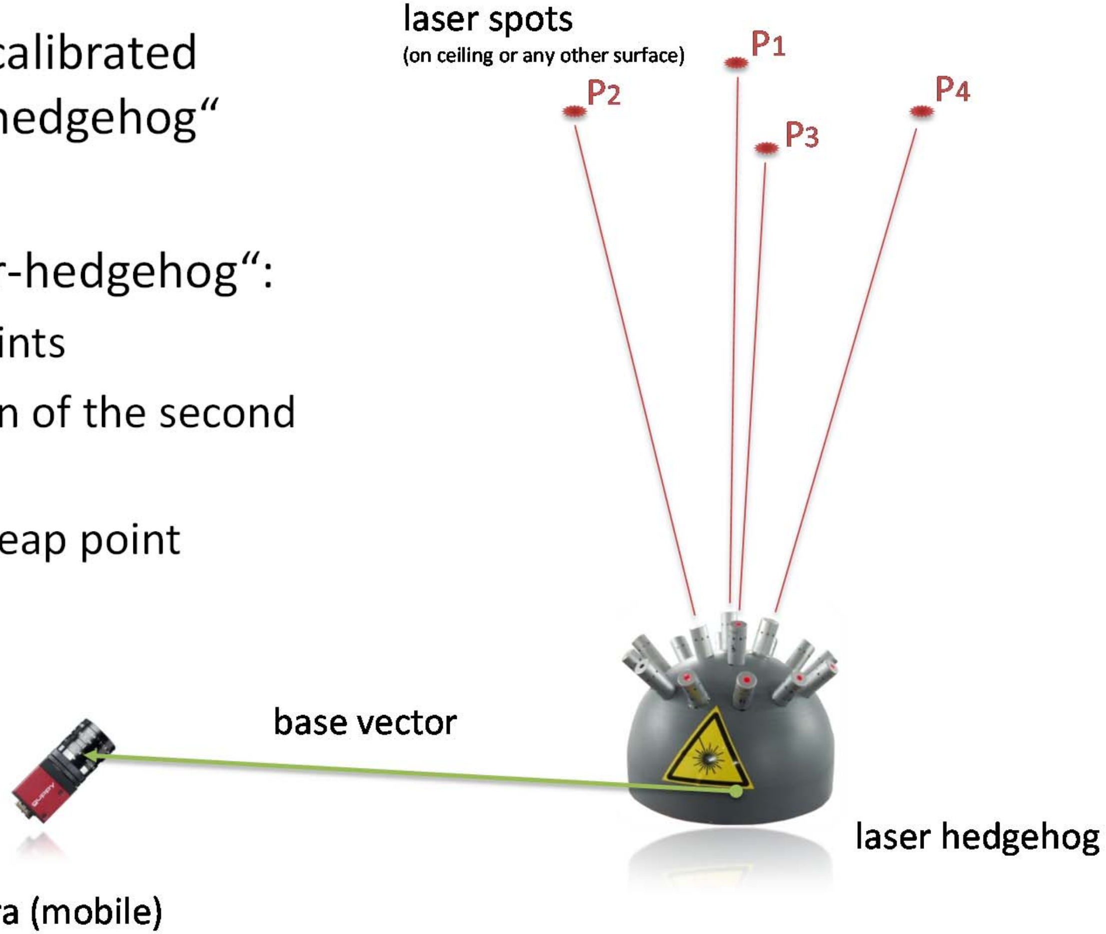
geomETH

CLIPS – Camera and Laser-based Indoor Positioning System

- Central idea is based on stereo photogrammetry

- Instead of two cameras => calibrated camera + calibrated „laser-hedgehog“

- Main functions of the „laser-hedgehog“:
  - Projection of reference points
  - Inverse Camera (Simulation of the second camera)
  - Use of a computational cheap point detection



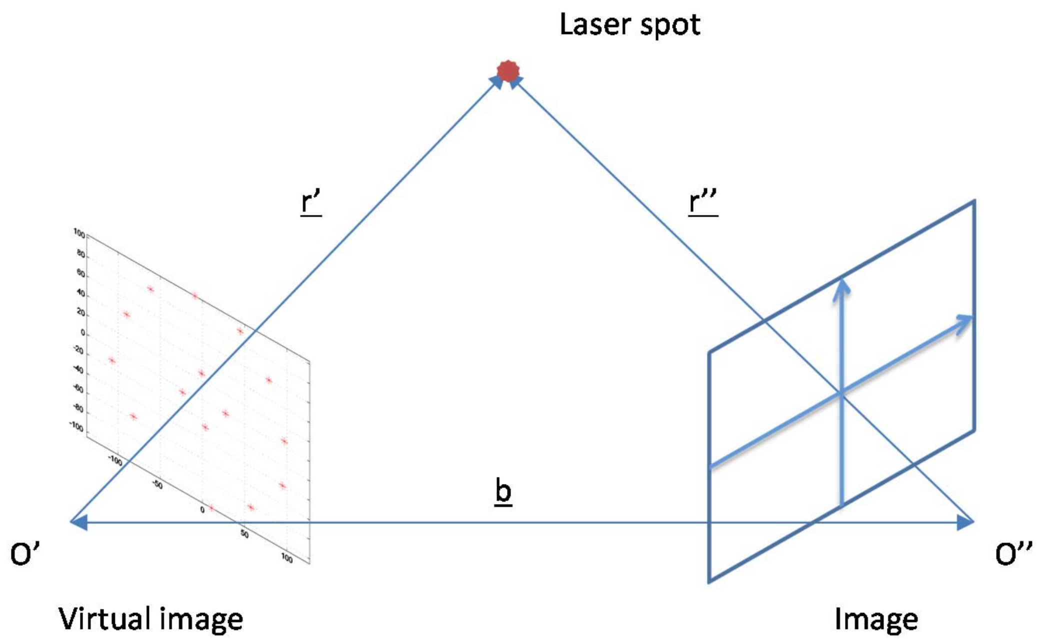
CLIPS - Point Detection

- Criteria
  - Independent from illumination
  - Reliable
  - Fast

- Algorithm
  - Combination of the RGB channels
  - Generic, adaptive template matching
  - ~ 1 sec / image with a resolution of 1024 x 768 pixels

Goal:

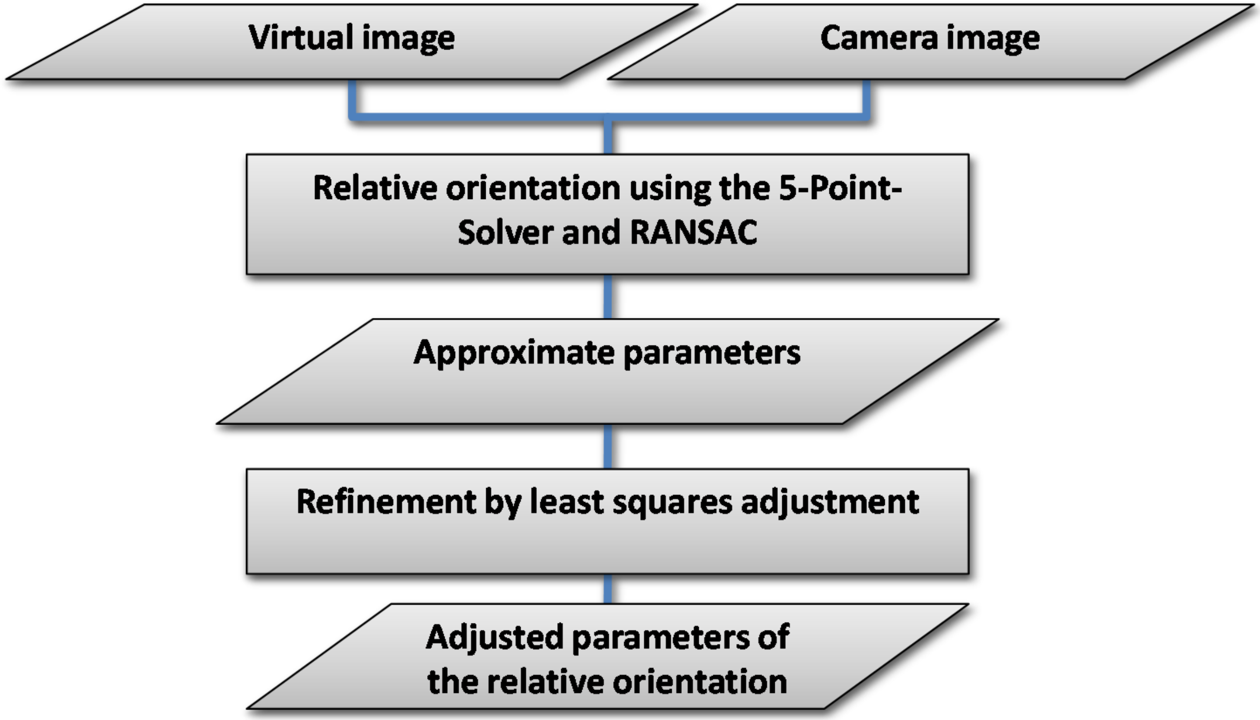
Determination of translation and rotation of the camera with respect to the laser-hedgehog



Describing the relative orientation with the six parameters of the exterior orientation

- base vector b: bx, by, bz
- rotation of camera: ω, φ, κ

CLIPS - Relative Camera Orientation



Assessment of the Prototype

- Determination of the 3D laser spot coordinates via a totalstation and CLIPS

- **Accuracy:** Comparision of both point clouds via similarity transformation

Measure	Value
scale m	0.9981
Standard deviation σ_0 [mm]	0.6

- **Precision:** Repetitive CLIPS measurements for each camera position

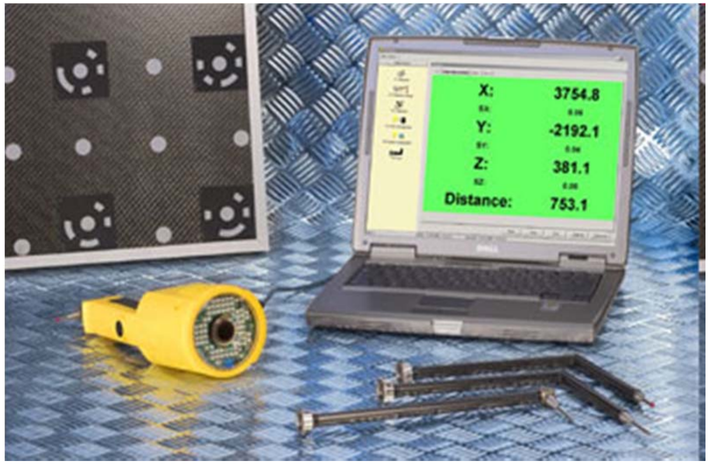
σ_x [mm]	σ_y [mm]	σ_z [mm]
0.16	0.16	0.35

Optical Positioning Systems: ProCam System (AICON)

System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
ProCam	optical	×	✓	✓	0.1 mm	any room	infrared	90 points / h	yes	high

Mobile probe with CCD camera.
Spatial resection of measuring head.

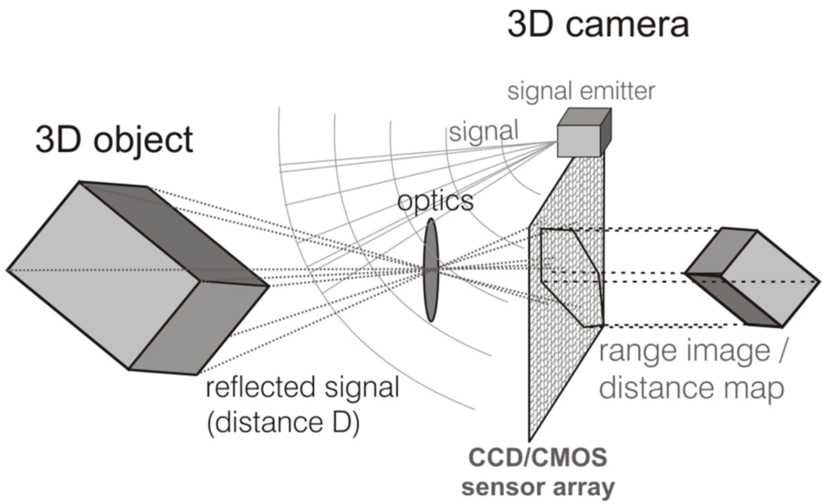
➢ relies on coded reference targets. (illuminated by an infrared flash)

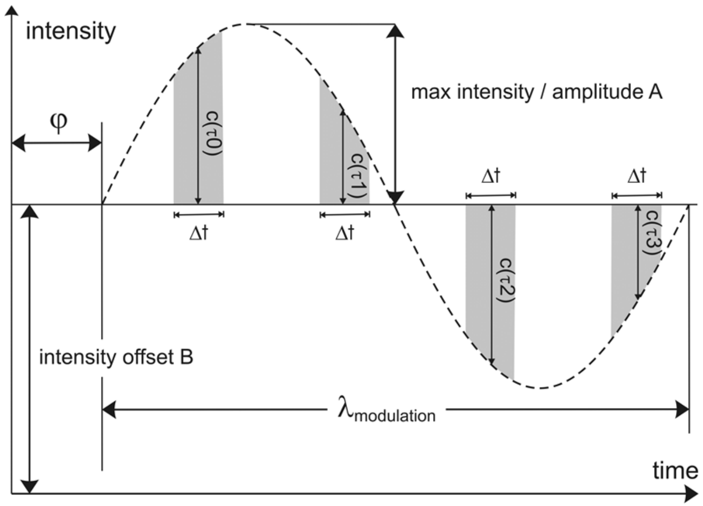


Pictures from: http://www.aicon.de

Range Imaging as measuring method

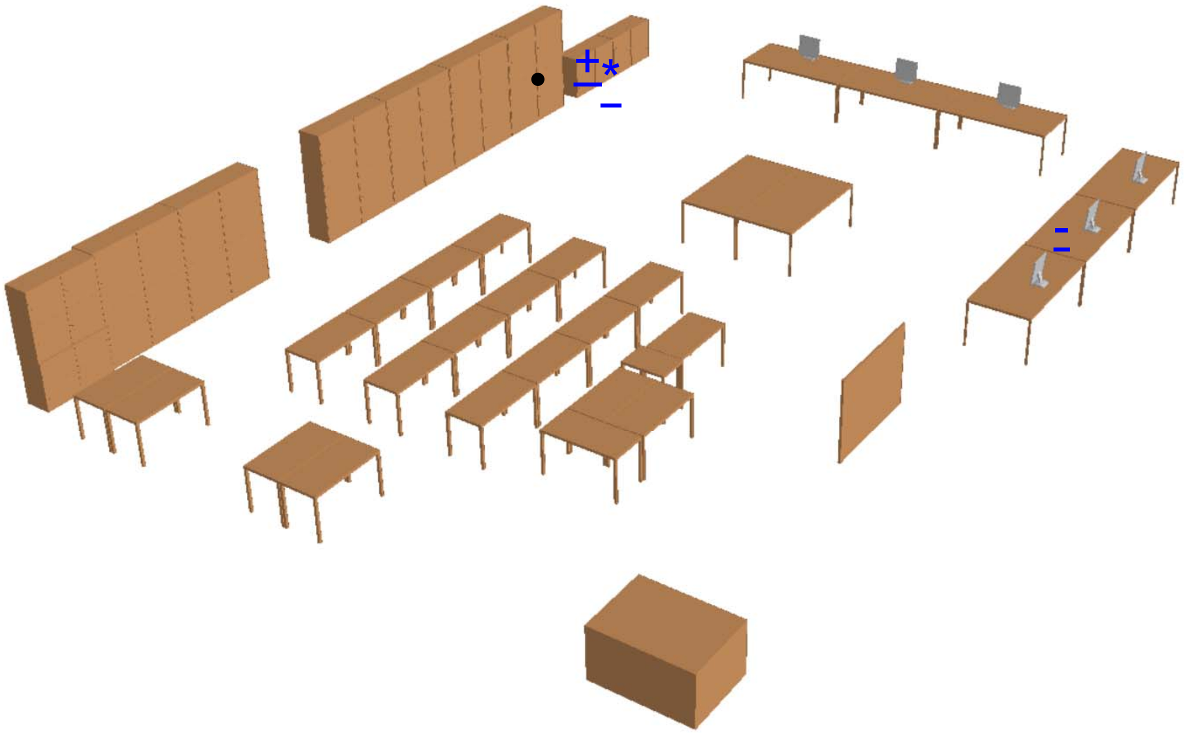
- combined CMOS/CCD-technology
- parallel acquisition of local brightness and range
- distance is measured by time-of-flight (TOF) principle for each pixel



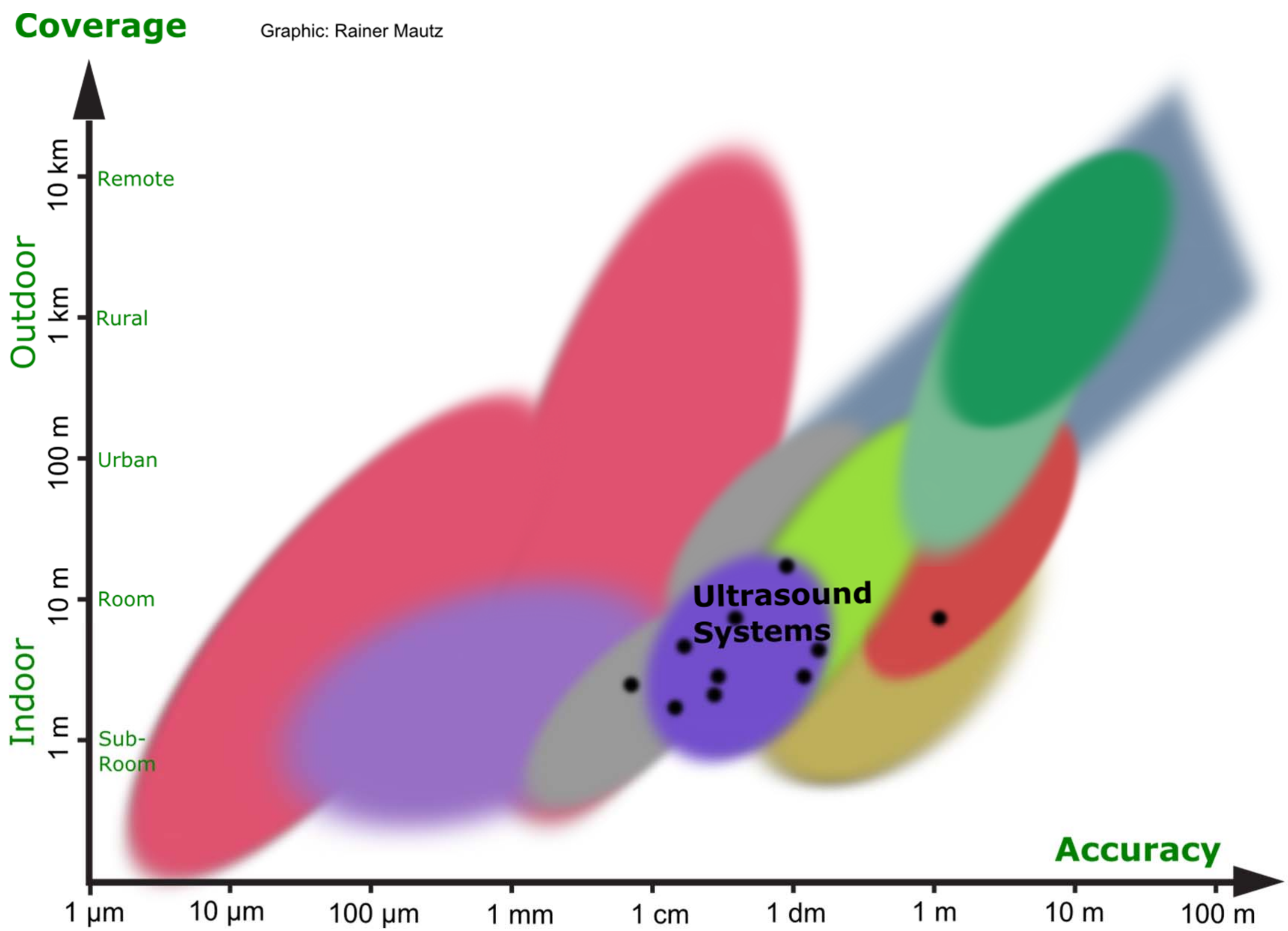


- Range Imaging:
  - dynamic measuring of 3D-coordinates in real time → acquiring rooms in their orientation + included objects
  - limits: relatively small range of ambiguity of the camera, mixed pixels, disturbing objects

Measurement examples



Ultra Sound Systems

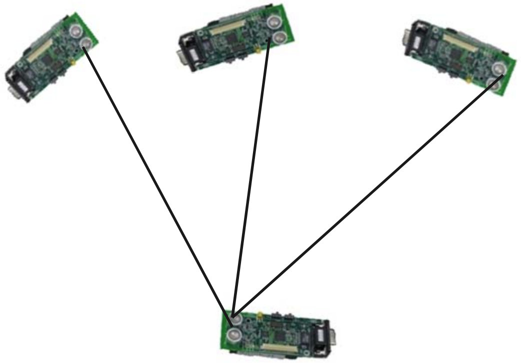


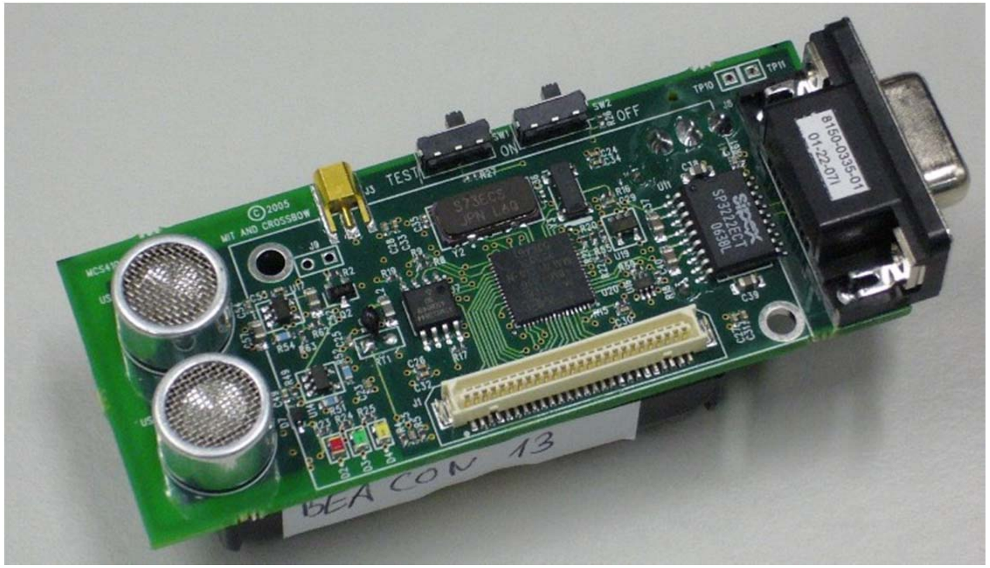
Ultrasound Systems – Crickets, Active Bat, Dolphin

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

Method:

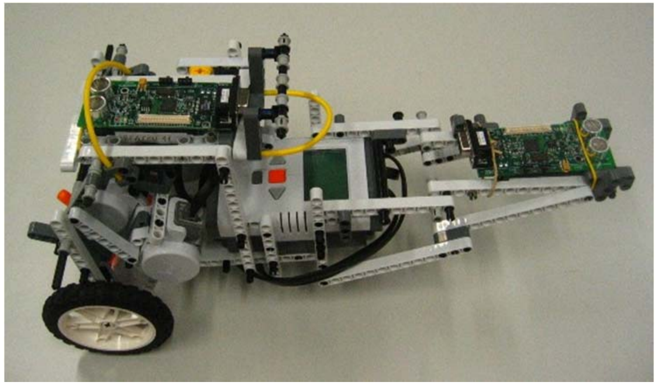
- TOA, TDOA (ultrasound & RF)
- Multilateration

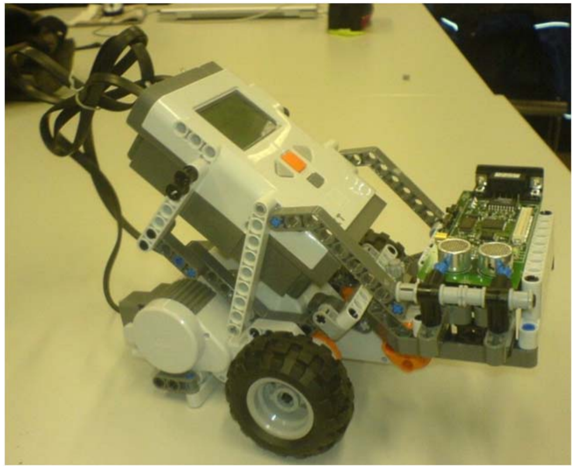


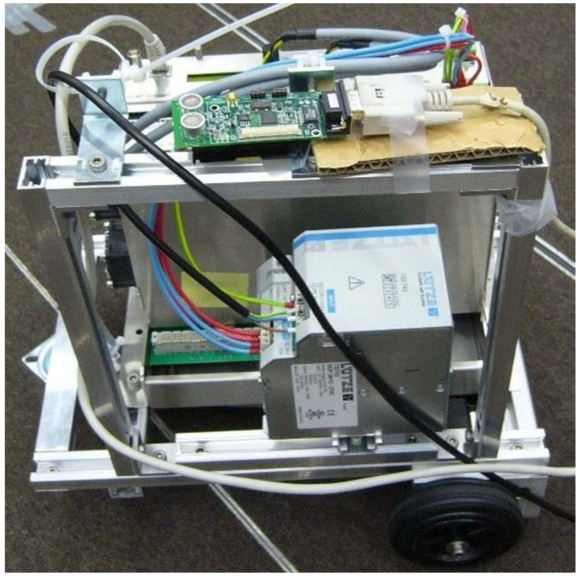


Ultrasound Systems – Crickets

Student Project: Robot Positioning

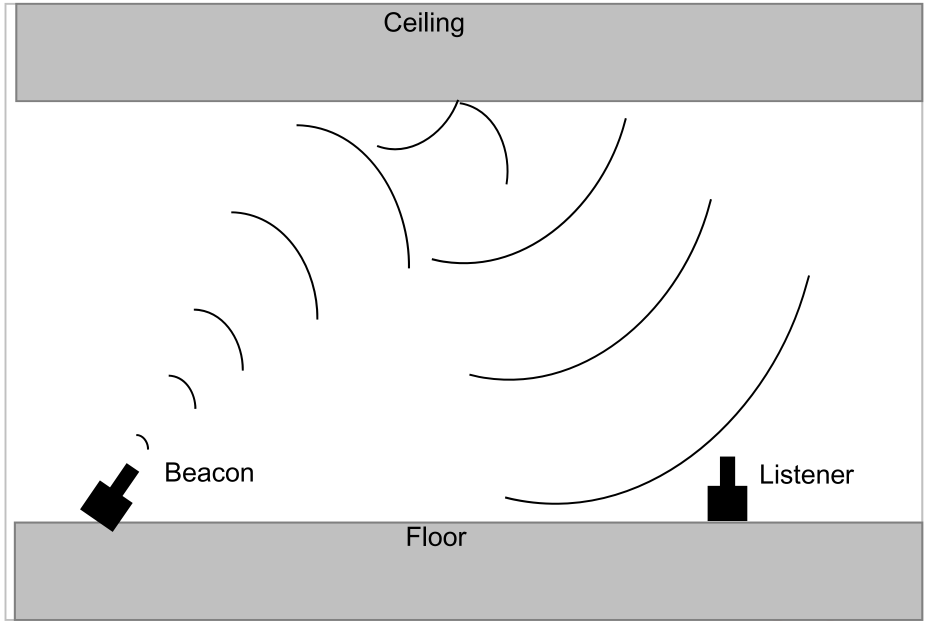




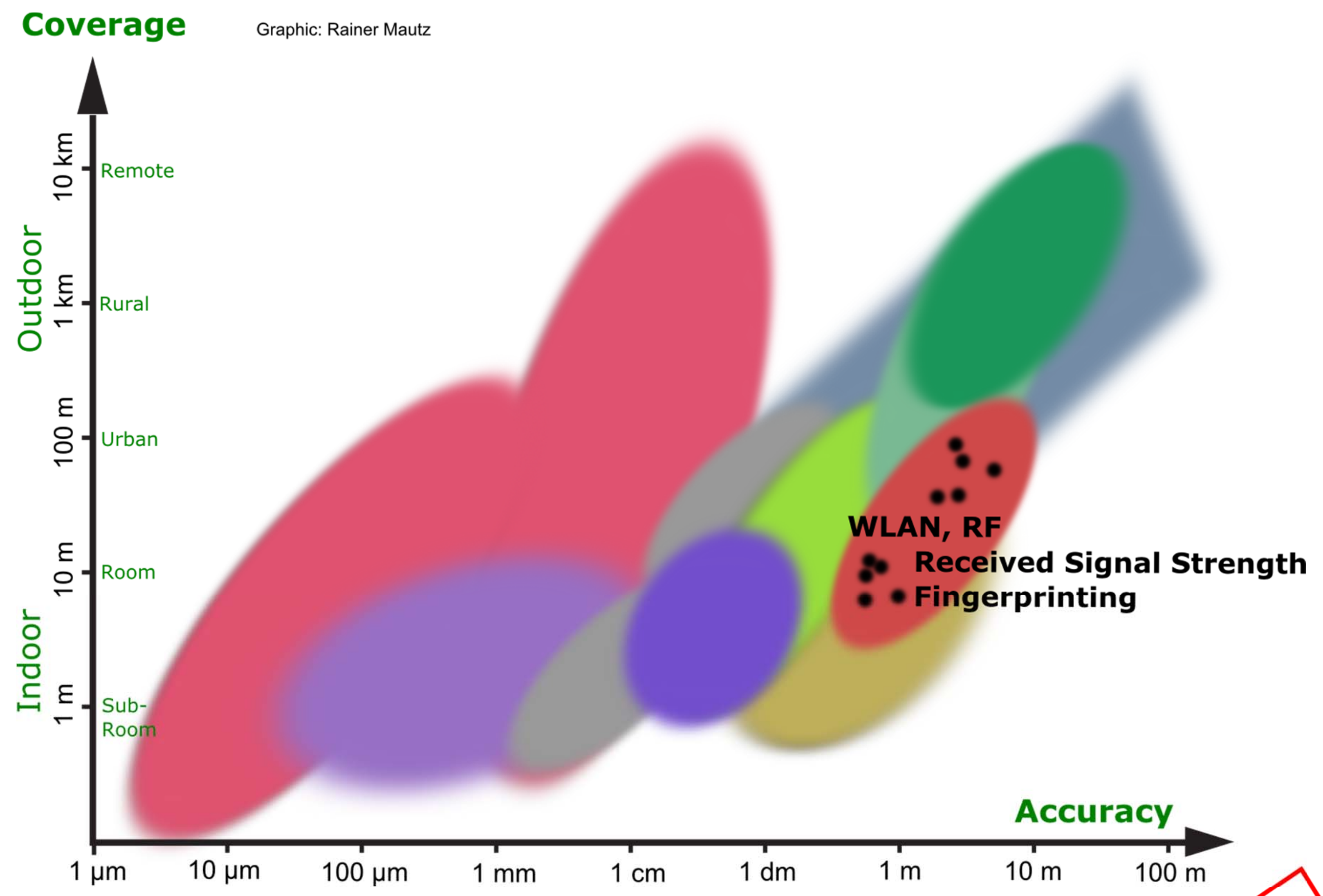


Problems:

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



Received Signal Strength (RSS) Fingerprinting



geomETH

Positioning based on Signal Strength

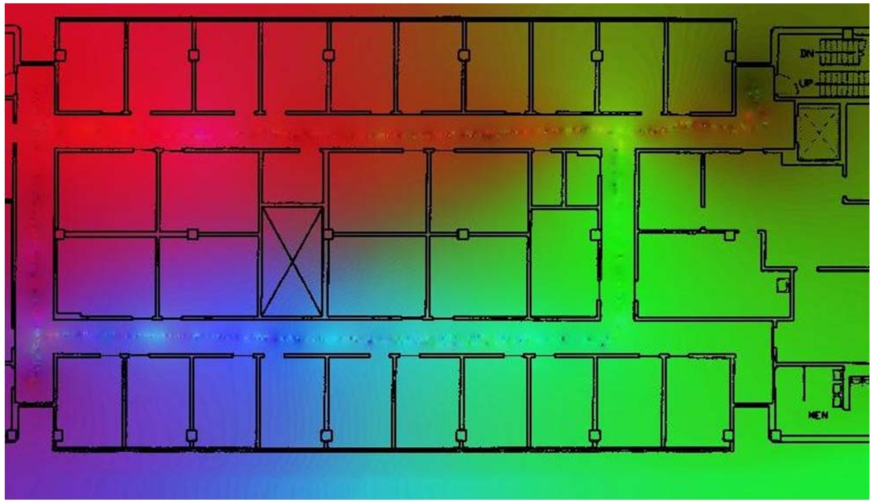
System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Sonitor	RSSI, Cell ID	×	✓	✓	m-level	15 m	ultrasound	0.3 Hz	yes	low
RFID	Signal Strength	×	✓	✓	dm-m	20 m	RF, 866 MHz		no	low

All signals can be used:

WLAN, Ultrasound, RF, GPRS, etc.

Problems:

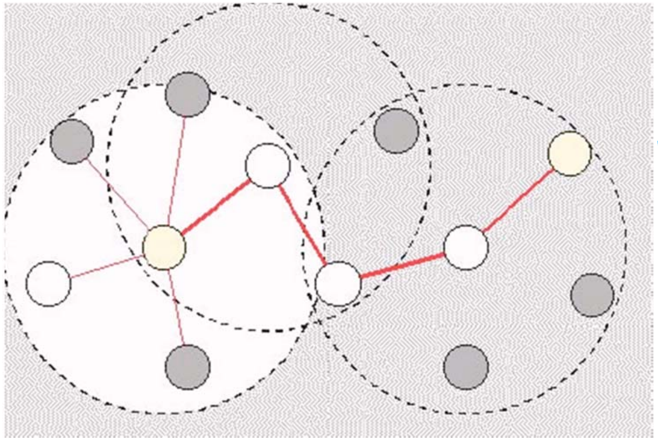
- reliability
- accuracy



USC Robotics Research Lab

Signal Strength Methods: Practical lessons

Practice

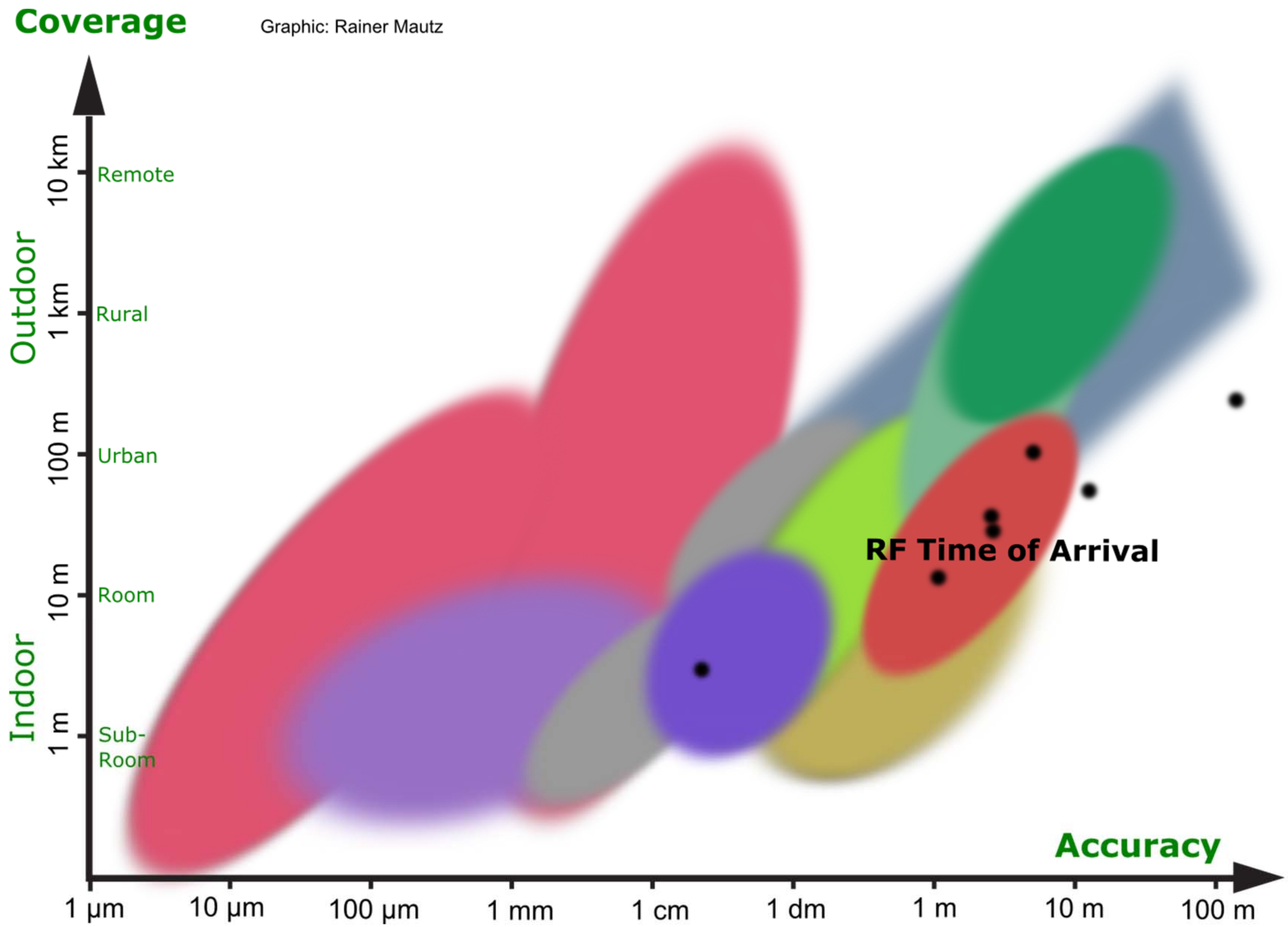


RSSI in sensor networks: good, but not for “reasonable” localization

For practical indoor localization

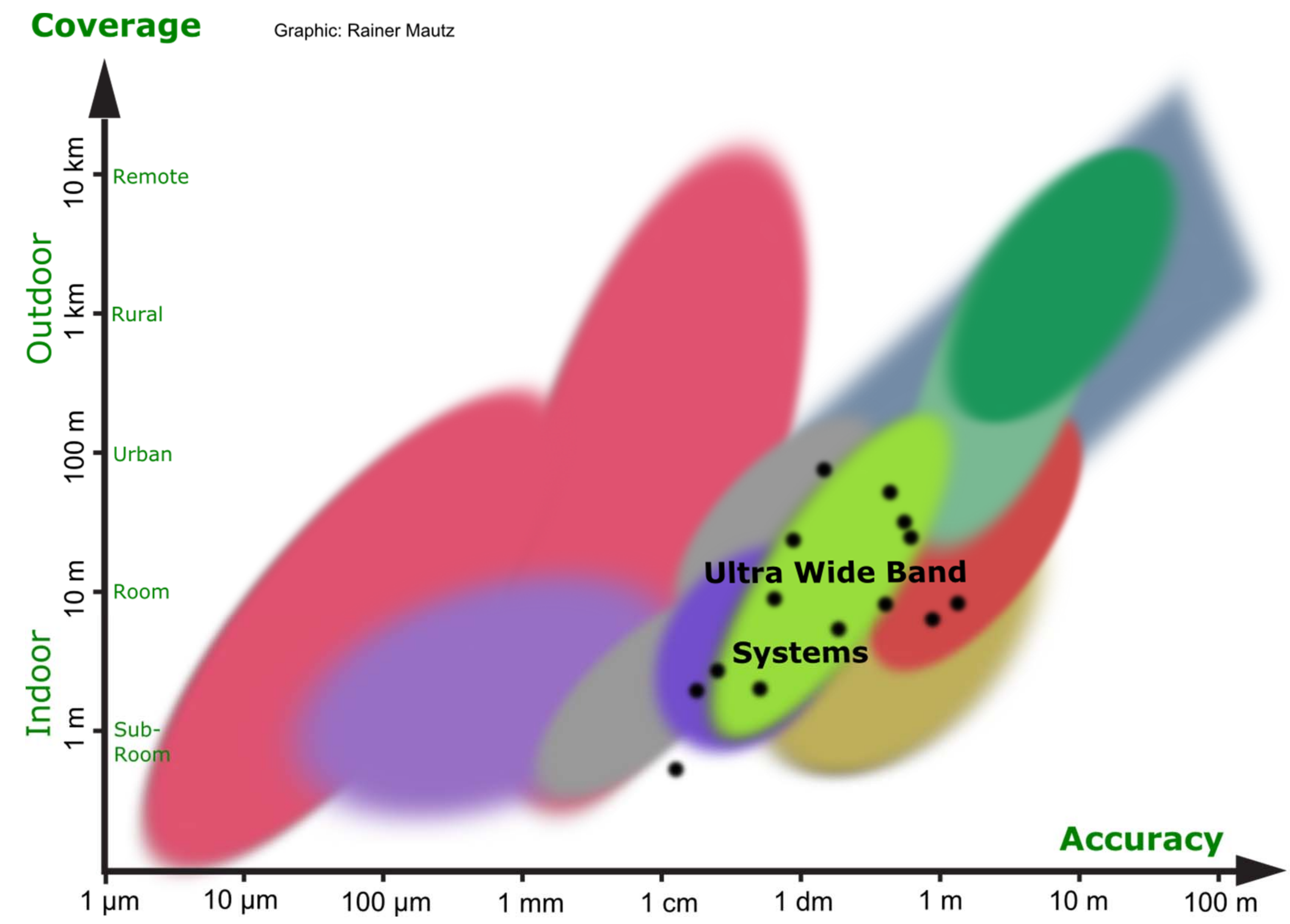
- Buy special hardware (e.g., UWB)
- Place huge amount of short range anchors for single-hop localization

Time of Arrival



geomETH

Ultra Wide Band



geomETH

Ultra-Wideband (UWB)

- Discard the usual dedicated frequency band paradigm.
- Instead share a large spectrum (about 1-10 GHz).

- Use extremely short duration pulses (sub-nanosecond) instead of continuous waves to transmit information. Depending on application 1M-2G pulses/second

Advantages:

- Potential to penetrate walls
- Robust towards multipath

UWB: From measurement to location estimation

Measurements

UWB Sensors

Parameter estimation

System calibration
Background subtraction
Threshold detection
LS estimator

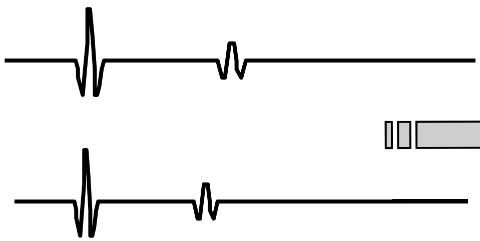
- angle
- **time delay (ToA, TDoA)**
- amplitude

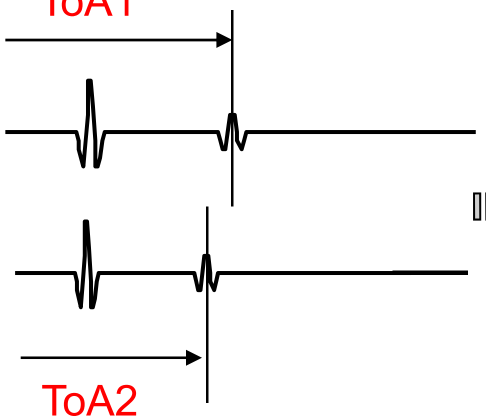
Data fusion

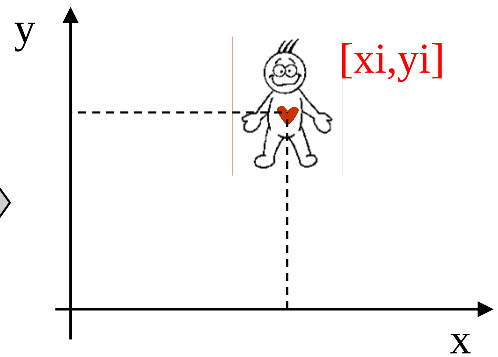
Signal processing techniques

- 2D or 3D object coordinates
- Least Squares Adjustment

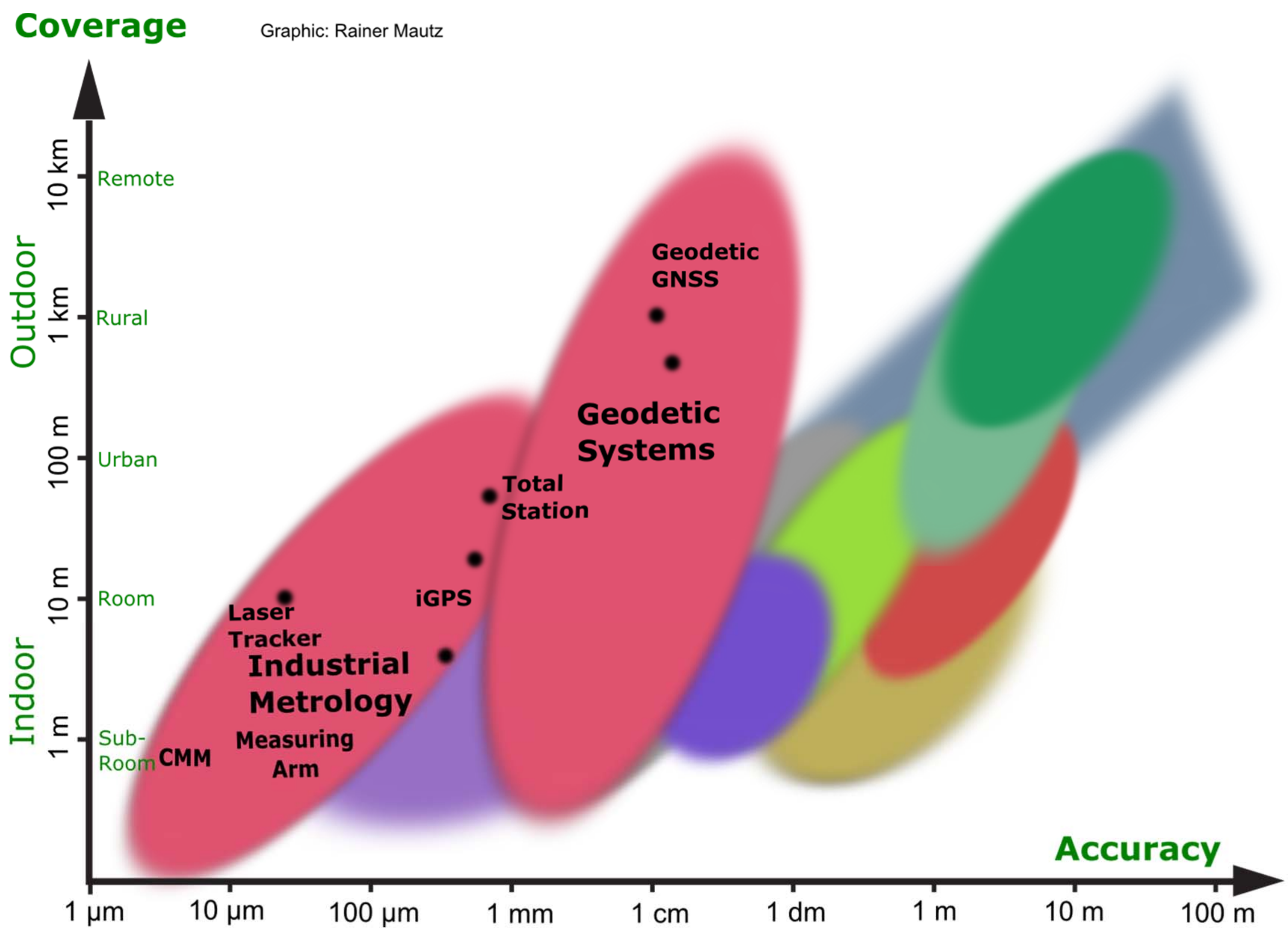
Impulse responses







geomETH


Coverage
Graphic: Rainer Mautz
Outdoor
Indoor
10 km
1 km
100 m
10 m
1 m
Remote
Rural
Urban
Room
Sub-
Room
Geodetic
GNSS
Geodetic
Systems
Total
Station
iGPS
Laser
Tracker
Industrial
Metrology
Measuring
Arm
CMM
Accuracy
1 µm
10 µm
100 µm
1 mm
1 cm
1 dm
1 m
10 m
100 m

iGPS (Nikon)

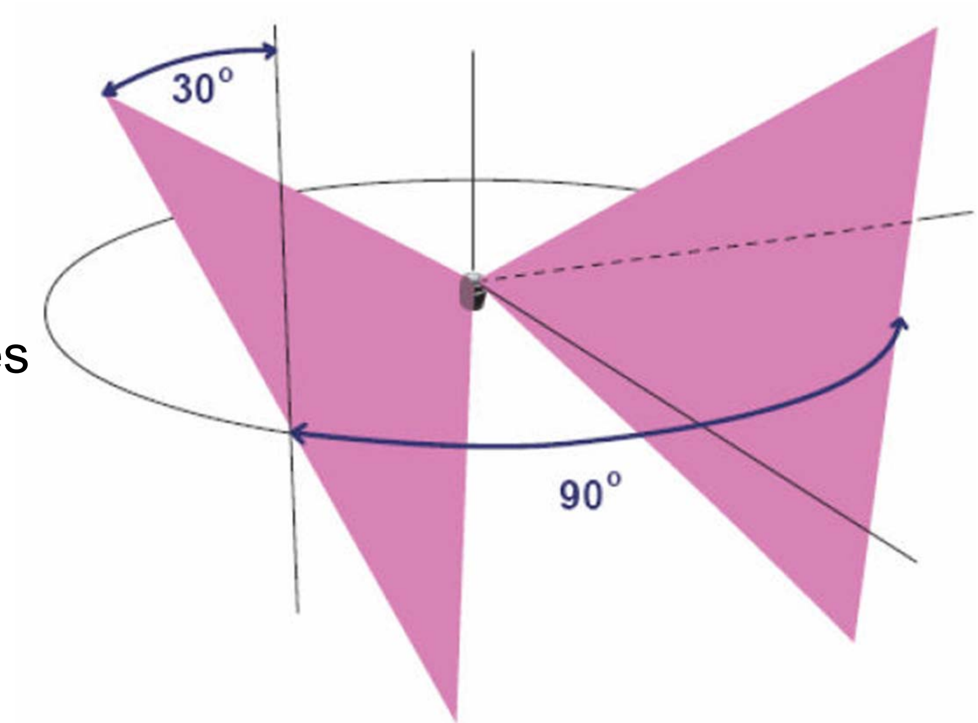
iGPS transmitter and sensor during a test in a tunnel

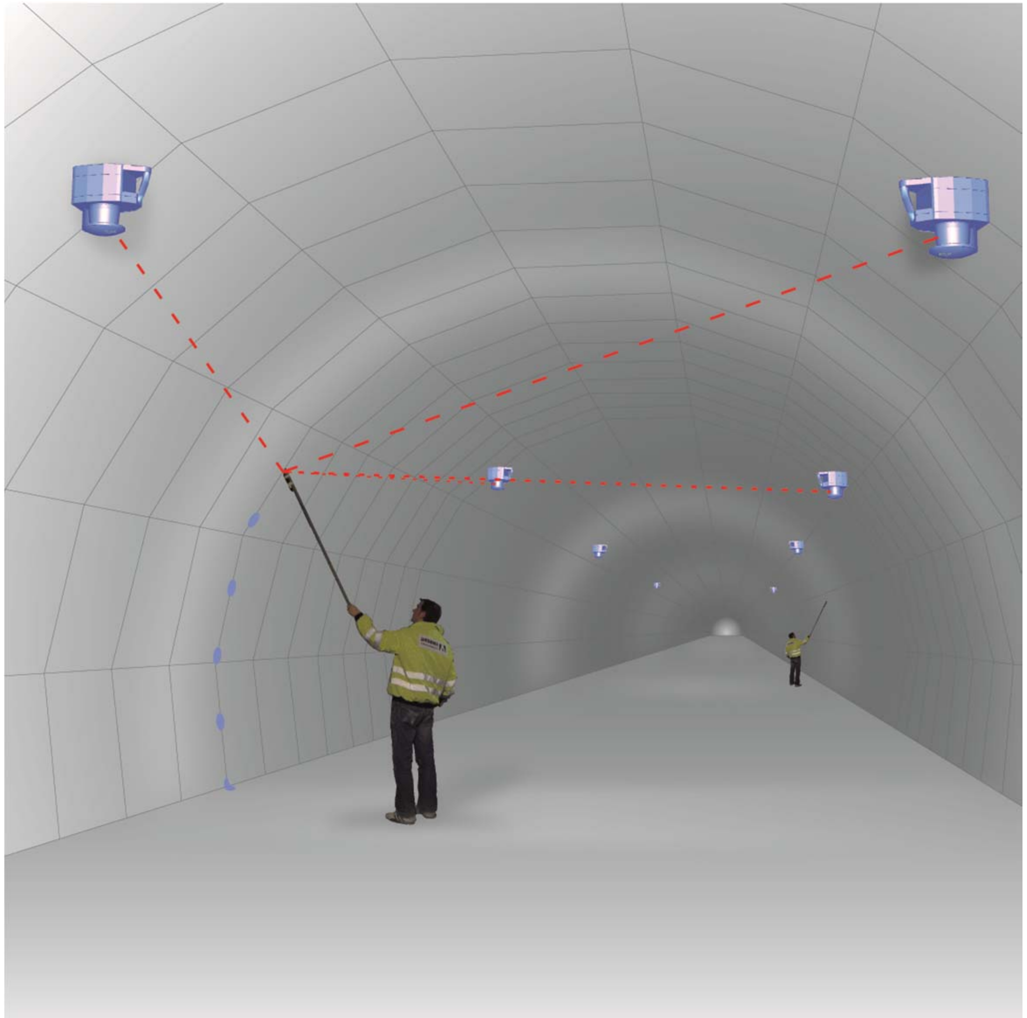
AoA Measurements: iGPS “laser resection”

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 times
- position determination with spatial forward intersection





Application of iGPS in a tunnel.

Master Thesis, ETH Zurich by DAVID ULRICH: Innovative Positionierungs-systeme im Untertagebau, July 2008

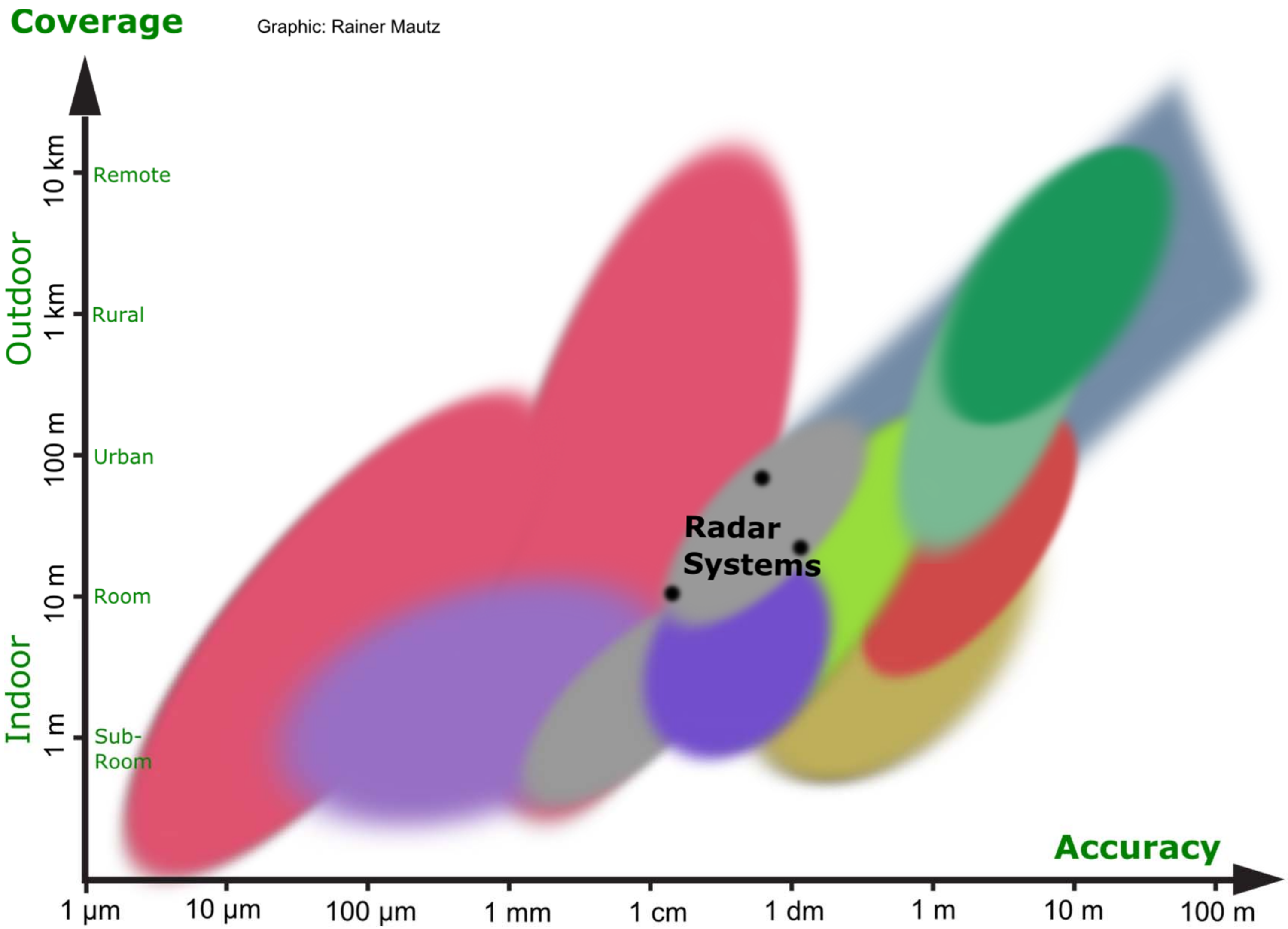
Results

Strengths:
- High accuracy (0.1 mm) confirmed
- Real-time, 40 Hz confirmed

Problems:
- Multipath
- Influence of light sources

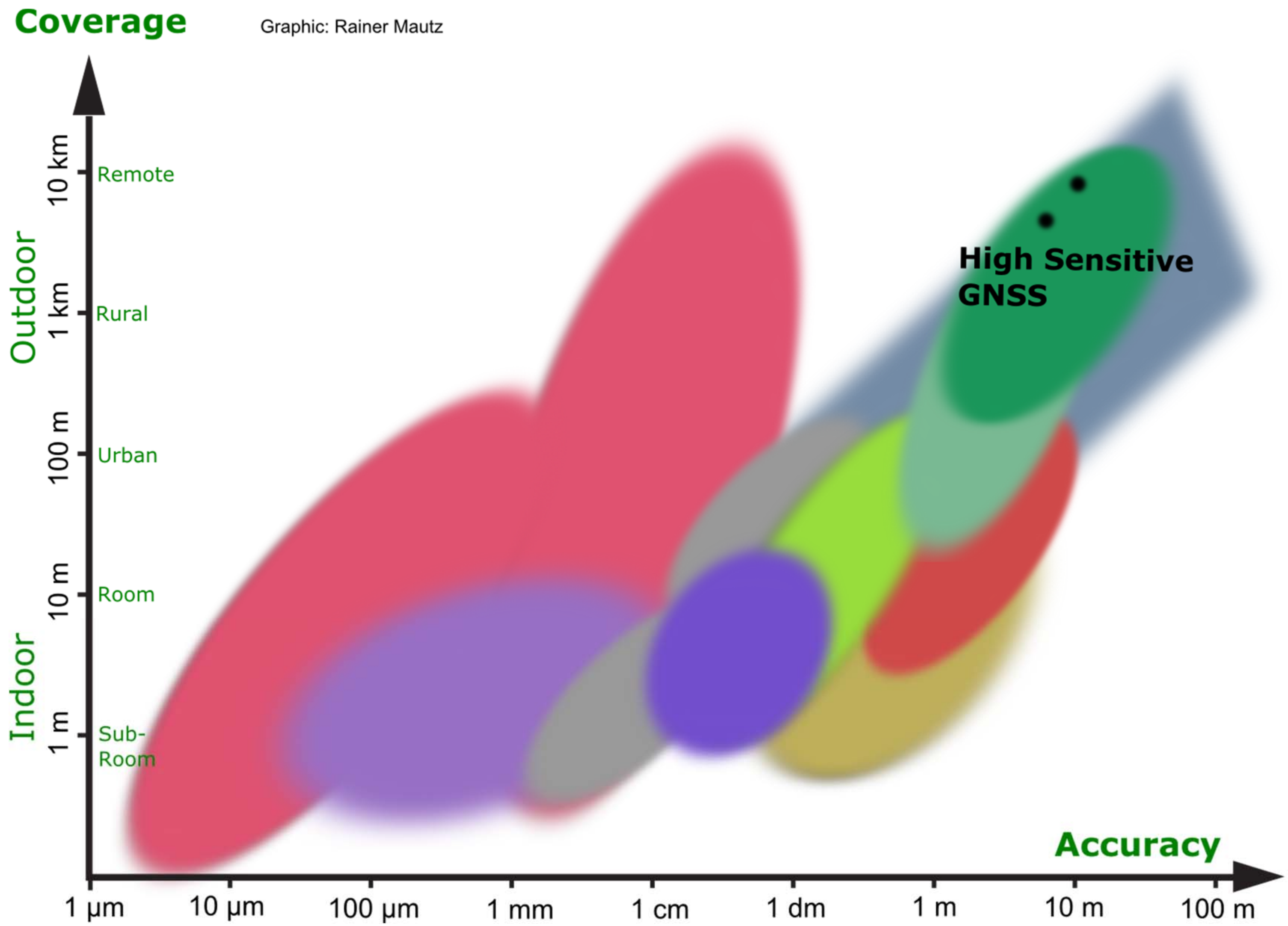
geomETH

Radar Systems



geomETH

High Sensitive GNSS



geomETH

GNSS – Performance:

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

Outdoors:

Globally available (besides urban canyons)

Fully developed

Correction model well known (ionosphere, troposphere)

mm – cm accuracy

Needs line of sight to sattelites

indoors additionally:

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

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

High Sensitive GNSS Receiver

Application: Emergency Calls, LBS

SiRFStar III (> 200.000 Korrelators)
Global Locate A-GPS Chip (Assisted-GPS)

Strengths:
No additional infrastructure in buildings
Also helpful in GNSS difficult environments with signal shadowing

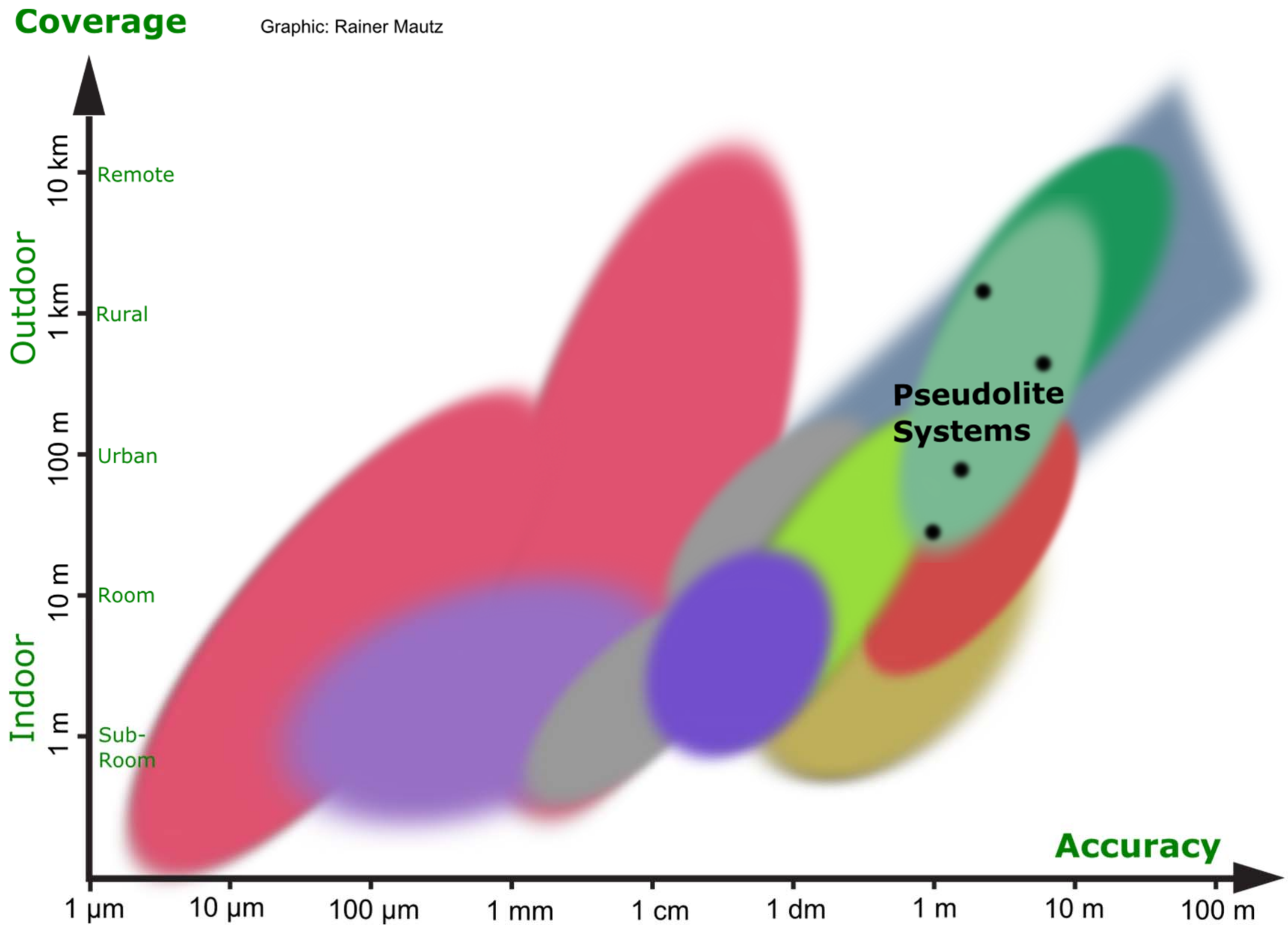
Drawbacks:
Long Acquisition TTFF: 60 s (assisted: 12 s)
Computational expensive
Accuracy: 14 m (evaluation from Thales)
6 m (forest)

How could theses issues be solved?

- phase measurement → cm
- higher signal amplitude at satellite
- efficient parallel computing
- Ultra Wideband GNSS Signals

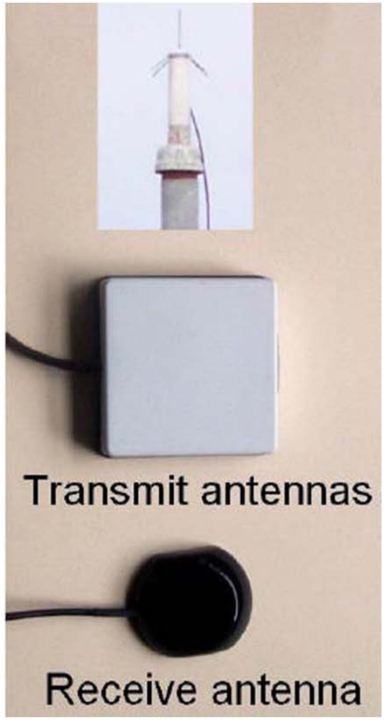
geomETH

Pseudolite Positioning Systems



Pseudolite Positioning Systems - Locata

Terrestrial pseudolite transceivers, Locata Corporation in Canberra
Augmentation for GNSS in urban canyons, pit mines, buildings



Picture from Jonas BERTSCH: *On-the-fly Ambiguity Resolution for the Locata Positioning System*, Master Thesis, ETH Zurich, February 2009.

Pseudolite Positioning Systems - Locata

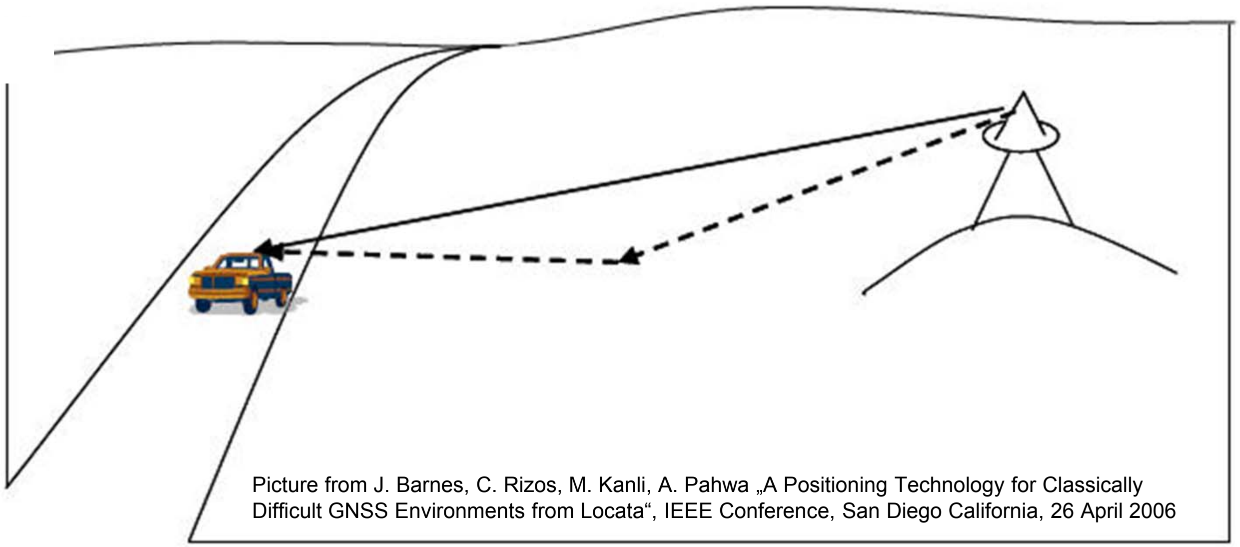
System	Principle	Outdoor	Indoor	Real-time	Accuracy	Range	Signal Frequency	Data Rate	Market	Cost
Locata	TOA, lateration	✓	✓	✓	2 mm static 1 cm RTK,	2 - 3 km	RF	1 Hz	in progress	high

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

Challanges:

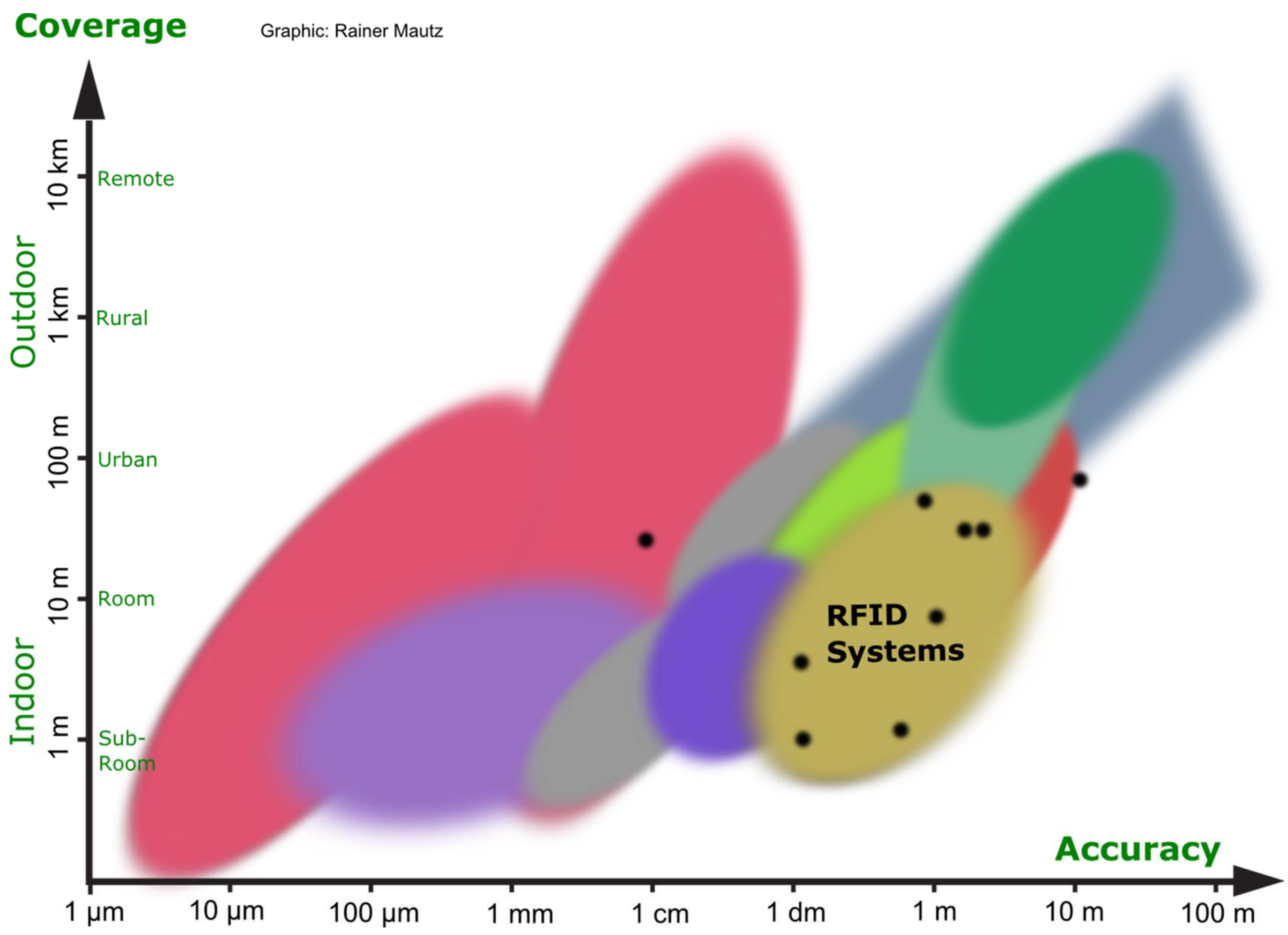
multipath (low elevation)

Synchronisation
< 30 pico-seconds



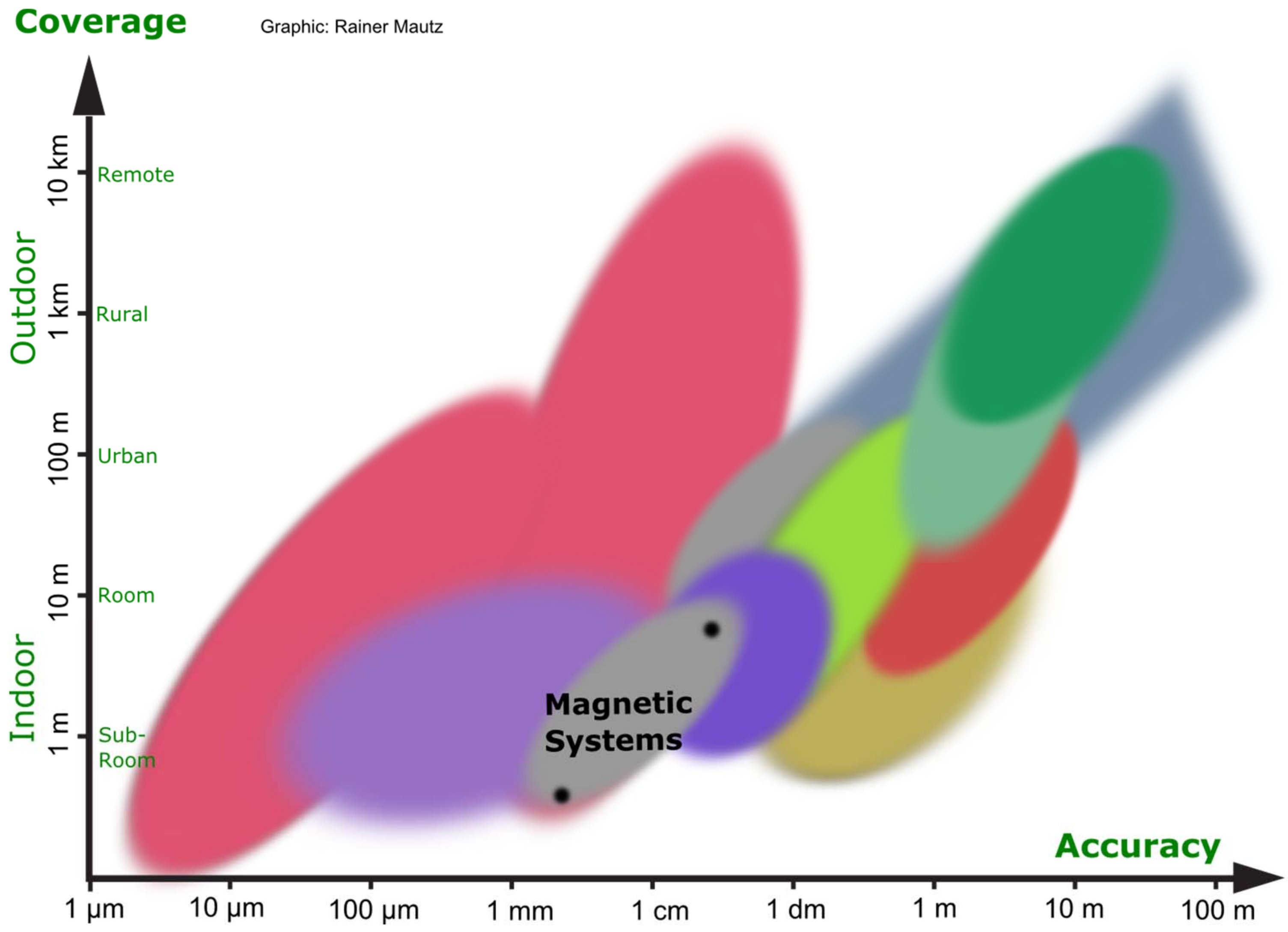
Picture from J. Barnes, C. Rizos, M. Kanli, A. Pahwa „A Positioning Technology for Classically Difficult GNSS Environments from Locata“, IEEE Conference, San Diego California, 26 April 2006

RFID Systems

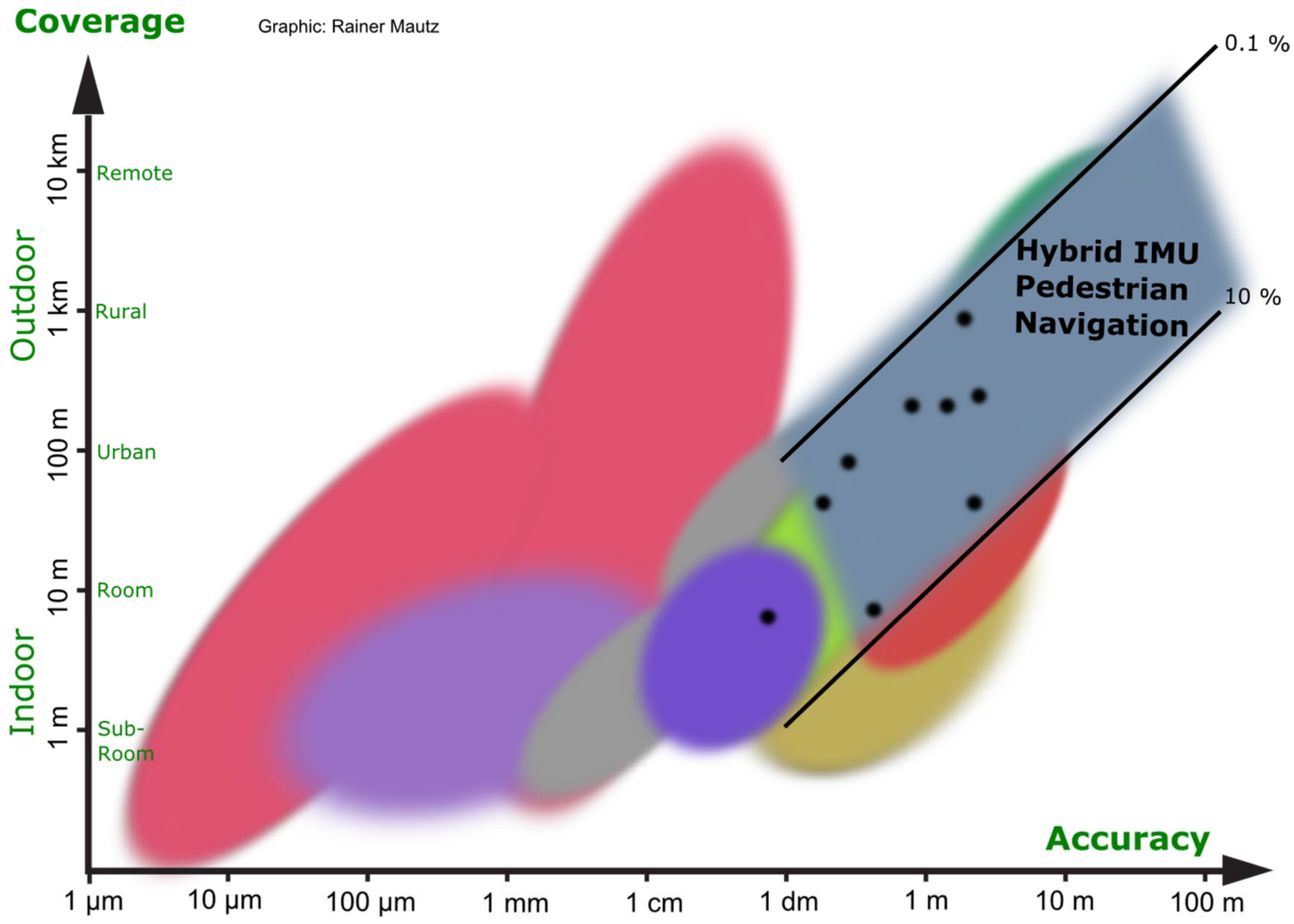


geomETH

Magnetic Systems



Pedestrian Navigation



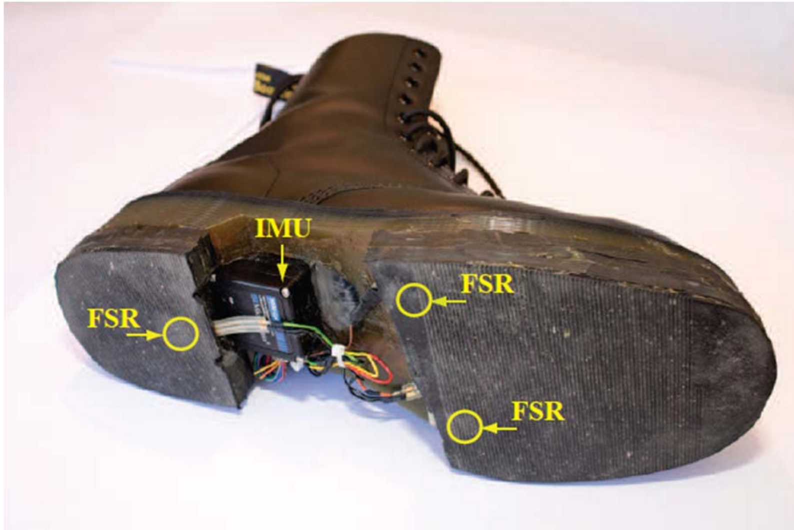
geomETH

Pedestrian Navigation – Foot Mounted INS

Inertial Systems (Dead Reckoning Systems)

- Positioning by integrating accelerations and velocities with permanent motion pattern analysis
- Many problems have to be solved:
  - Noise
  - Drift
  - Temperature

  } stable average
  - Calibration
  - Accuracy



- Position, velocity, and orientation from foot mounted IMU
- ZUPT (zero velocity updates) to limit error growth

Xsense MTi