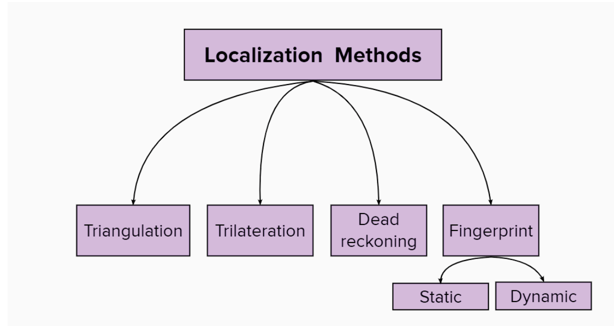
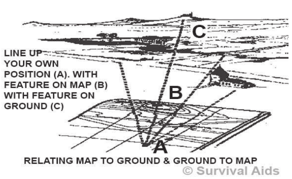
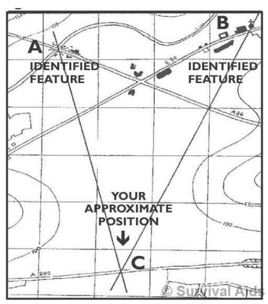
3.1 Localization methods I

Part III: Localisation

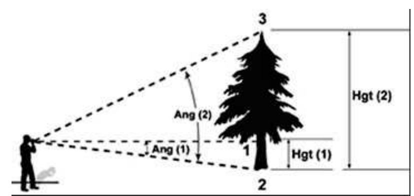


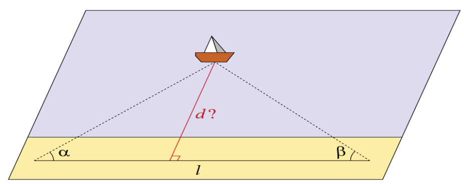
Localization: Where am I?



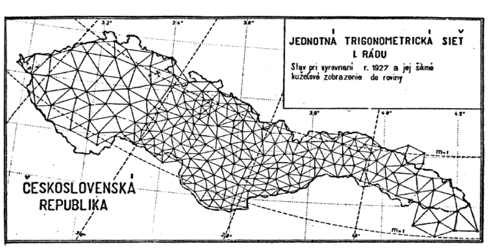


Triangulation (angles)



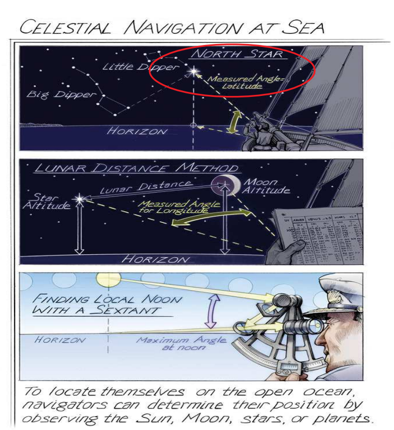


Triangulation for surveying

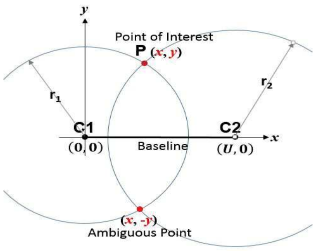


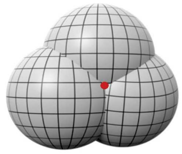
Marine navigation

– ocean (space): missing features



Trilateration (distances)





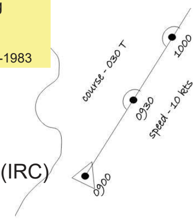
$$x = \frac{r_1^2 - r_2^2 + U^2}{2U}$$

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

Dead reckoning

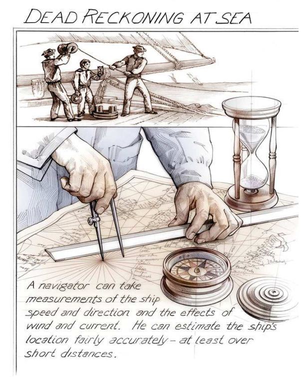
...process of determining the **position** of a vehicle at one time with respect to its position at a different time by the application of vectors representing **courses** and **distances.**

IEEE Std. 172-1983

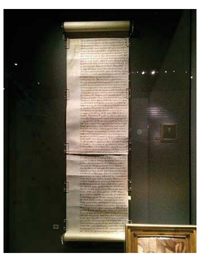


Odometry
– revolution count, usually using Incremental Encoder (IRC)

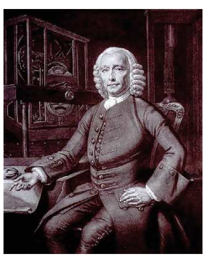
Inercial measurements (IMU)
– using an inertial sensors (accelerometers, gyroscopes + altitude, compass...)



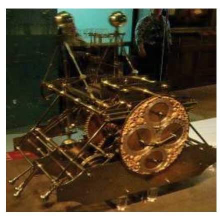
Longitude problem: clocks



The Longitude Act 1714



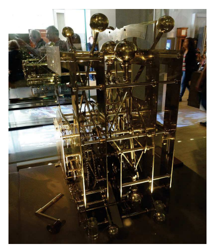
John Harrison



Chronometer H1

The Longitude Act 1714

- Act of Parliament of Great Britain passed in July 1714 at the end of the reign of Queen Anne
- It established the *Board of Longitude* and offered monetary rewards (Longitude rewards) for anyone who could find a simple and practical method for the precise determination of a ship's longitude.



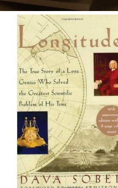
Chronometer H2

Chronometer H4

Rewards

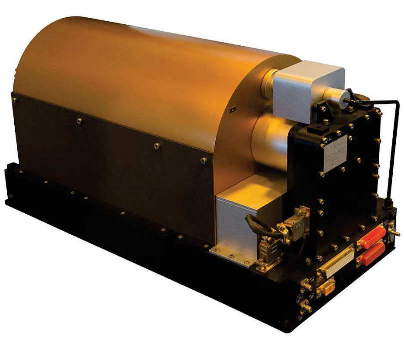
error < 1° of longitude (≈ 110 km)	£10,000
error < 40' (minutes)	£15,000
error < 30'	£20,000

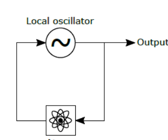
note: £10,000 is worth over £1.46 million in 2019



Sobel, Dava. Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time. New York: Walker, 1995. Print.

Atomic clock





1.5 femtoseconds / day

Space Passive Hydrogen Maser used in ESA Galileo satellites as a master clock for an onboard timing system

Fingerprint

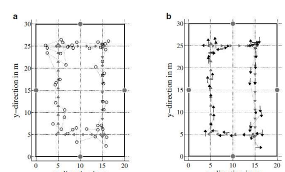


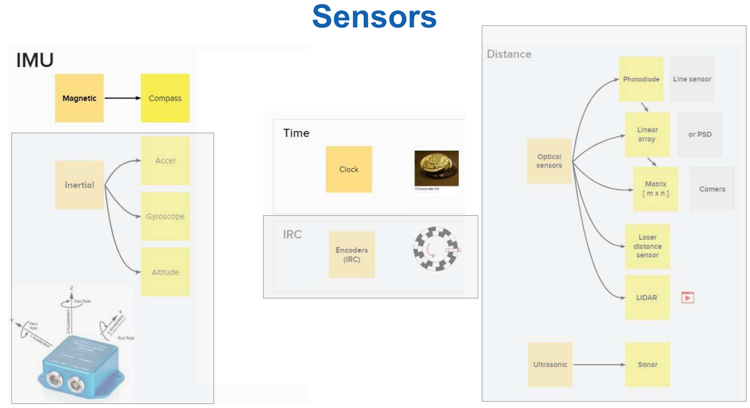
Fig. 4 Layout of the simulated area with access points (*gray dots*), reference path with attitudes (*gray arrows*) and (**a**) results from standard Wi-Fi positioning (*circles*), and (**b**) results using the new attitude and position tracking (*black arrows*), with $\sigma_o = 1$ dB and $\sigma_d = 1$ dB

Fig. 1 Example extracted from the Fraunhofer IIS awiloc® fingerprinting database in Nuremberg, visualized on an openstreetmaps.org map. *Dots* indicate fingerprint positions and the amount of detected access points at each position, as depicted in the scale-up

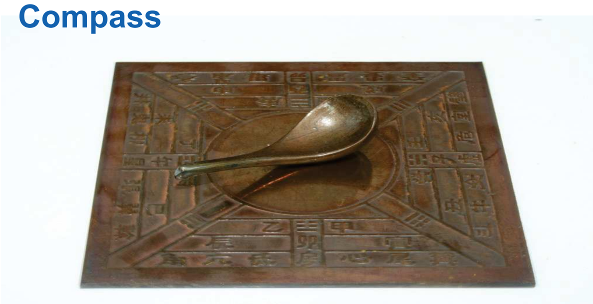
Seitz, J., Vaupel, T., Haimerl, S., Meyer, S., Gutierrez Boronat, J., Rohmer, G. and Thielecke, J.: *Wi-Fi Attitude and Position Tracking*, In Microelectronic Systems: Circuits, Systems and Applications, Springer Berlin Heidelberg, 2011.

3.2 Sensors for Localization

Sensors

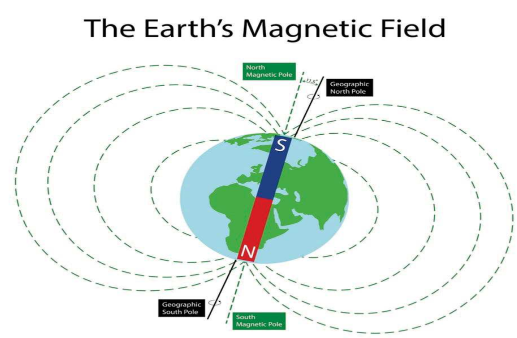


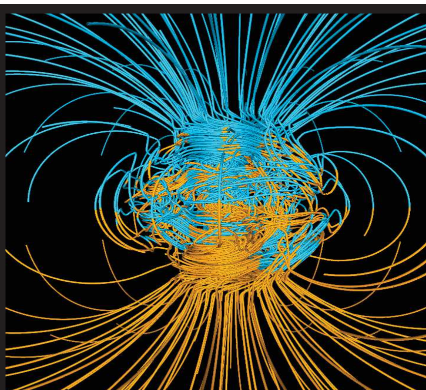
Compass



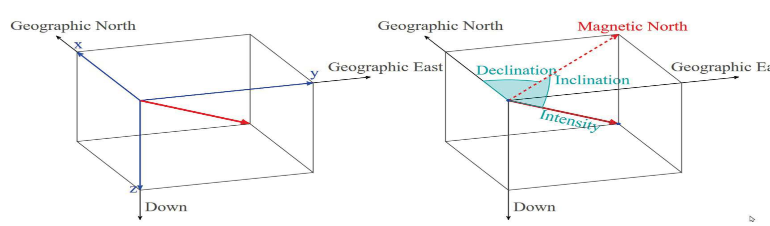
Model of a Han Dynasty (206 BC–220 AD) south-indicating ladle or sinan. It is theorized that the south-pointing spoons of the Han dynasty were magnetized lodestones.

Magnetic field sensors -- compass





https://en.wikipedia.org/wiki/Earth%27s_magnetic_field#/media/File:Geodynamo_Between_Reversals.gif

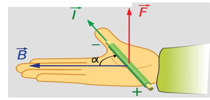


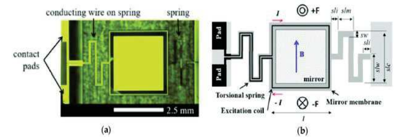
Magnetometer

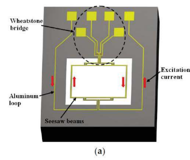
- AMR magnetometer
- GMR magnetometer
- Hall-Effect sensor
- Lorentz force-based MEMS sensor
- MEMS compass, and
- magnetic-field sensor

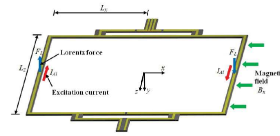
Lorentz force

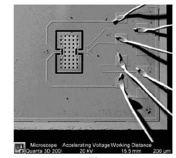
$$\mathbf{F} = I\boldsymbol{\ell} \times \mathbf{B}$$



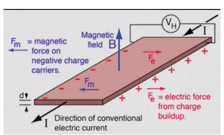








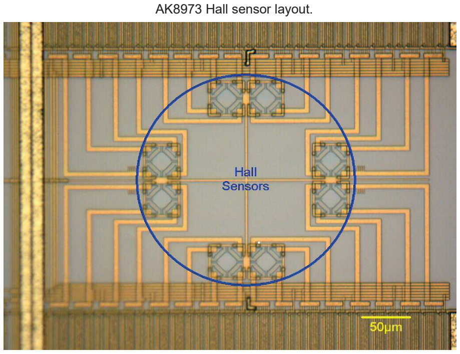
Hall effect



$$V_H = \frac{I_x B_z}{nte}$$

Lorentz force -> electrons deviations from stright path

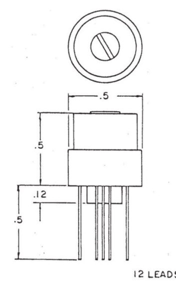
AK8973 Hall sensor layout.



https://www.memsjournal.com/2011/02/motion-sensing-in-the-iphone-4-electronic-compass.html

Dinsmore 1490

- miniature permanent magnet rotor
- jewel suspension + 4x Hall sensor
- response time 3.5 second (intentionally)
- weight 2.25 g
- temperature -20 – +85 deg C
- Vcc = 5 to 20 V



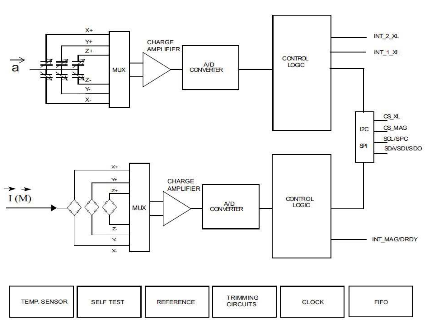
LSM303AGR

life.augmented

3 magnetic field channels
3 acceleration channels

- ±50 gauss magnetic dynamic range
- ±2/±4/±8/±16 *g* selectable acceleration full scales
- 16-bit data output
- SPI / I2C serial interfaces
- Analog supply 1.71 V to 3.6 V

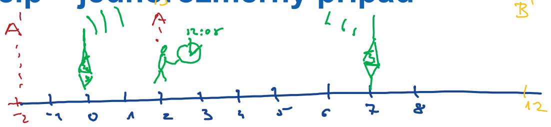
Internal temperature sensor
Self test procedures



Global Navigation Satellite System

GNSS

Princíp – jednorozmerný prípad



a) jeden vysielač: Na svojich hodinkách vidím 12:05
a počujem: „Som vysielač Ø a je 12:03"
=> Som 2 min od bodu 'Ø' => A, resp. A'

b) dva vysielače: Na hodinkách vidím 12:05
a počujem: „Som vysielač Ø a je 12:03"
„Som vysielač 7 a je 12:00"
=> prienik bodov B a B' => poloha je A∩B

Čo ak nemáme presné hodinky na ruke?

Počujem: Som 'Ø' a je 12:03
Som '7' a je 12:00

Je čas 12:0t } neznáme.
ak viem, že: 'Ø' a '7' sú vzdialené 7−0 = 7

Takže $(t-3) + (t-0) = 7$
od 'Ø', od '7'

$t-3+t-0=7$

$2t=10$

$t=5$ => je čas 12:05
a viem koľko je hodín

Princíp v rovine – priamka, rovina

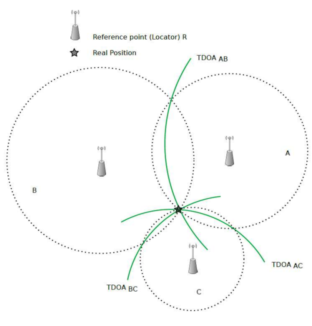
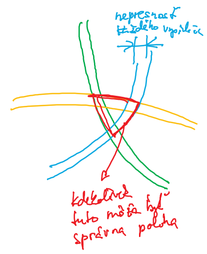
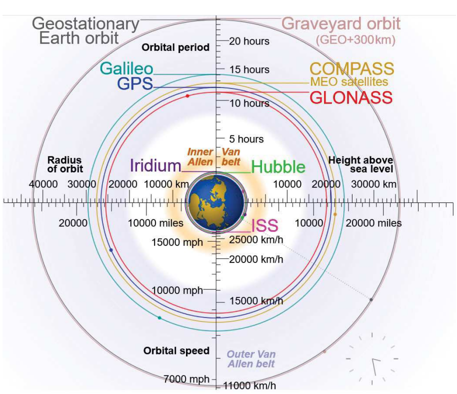


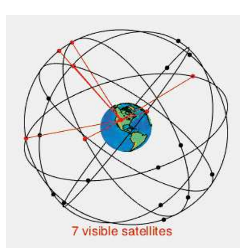
Figure 6. Time difference of arrival (TDoA)-based algorithms.

Každé meranie je zaťažené nepresnosťou:

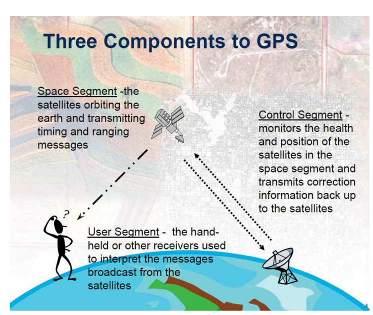


V priestore





Three segments of GPS



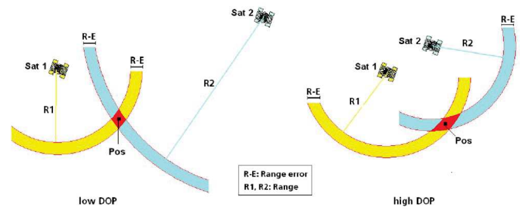
GPS = clocks

The Clock Problem

- To measure distance from speed of light we need a VERY accurate clock
  (clock error of 1/100 sec = distance error of 3000 km!).
- GPS Satellites have very accurate atomic clocks.
- Our receivers do not have atomic clocks, so how can we measure time with necessary accuracy?

Satellite Geometry

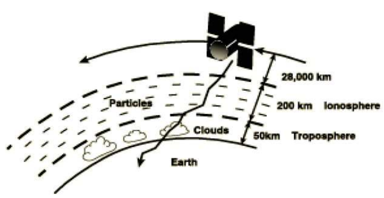
Precision



Atmospheric Effect

Precision

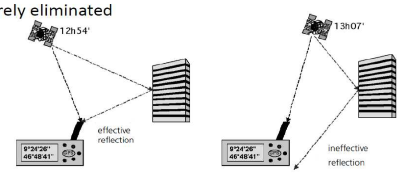
- GPS signal slowed down through the charged particles of the ionosphere and then through the water vapor in the troposphere
- Must correct for atmospheric effects with modeling



Multi-Path

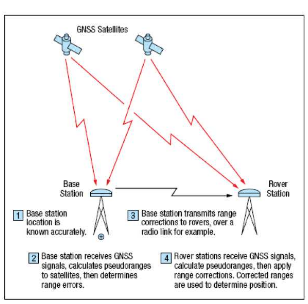
Precision

- Signals can be reflected on the way to the receiver. This is called "multipath propagation"
- These reflected signals are delayed from the direct signal, and if strong enough, can interfere with the direct signal
- Techniques have been developed whereby the receiver only considers the earliest-arriving signals and ignore multipath signals, which arrives later
- It cannot be entirely eliminated



Differential GPS (DGPS)

- Differential GNSS uses a fixed GNSS receiver, referred to as "base station" to transmit corrections to the rover station for improved positioning
- Error due to signal transmission through the atmosphere can be corrected using DGPS
- Atmospheric errors are the same over short distances.
- Error in base station, can be removed from remote (roving) receiver position, and code phase signal.



NMEA 0183

National Marine Electronics Association standard

combined **electrical** and **data** specification for communication between *marine electronics*
echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers,...

electrical EIA-422 (most hardware also EIA-232),
typ. Baud rate 4800, 8 data, none parity, 1 stop, no handshake

data – simple ASCII, serial protocol, data are transmitted in a "sentence"

```
$XXYYY,a1,a2,a3,....,an*cc<CR><LF>
```

XX: **GP** – GPS, **GL** – GLONASS, **GA** - Galileo
YYY: **RMC** - recommended minimum data - základné údaje, ktoré poskytujú všetky prijímače
GGA - sada údajov o odchýlkach pre presnejšiu lokalizáciu
GSA - zoznam čísiel max. 12 satelitov, použitých pre navigáciu
GSV – podrobnejšie údaje o sateliteoch - sila signálu a poloha na oblohe
GLL - Lat/Lon - len geografická poloha a čas (podmnožina údajov RMC)

NMEA 0183

RMC veta

$GPRMC, 161229.487,A,3723.2475,N,12158.3416,W,0.13,309.62,120598, ,*10

Table 1-11 RMC Data Format

Name	Example	Units	Description
Message ID	$GPRMC		RMC protocol header
UTC Time	161229.487		hhmmss.sss
Status[1]	A		A=data valid or V=data not valid
Latitude	3723.2475		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12158.3416		dddmm.mmmm
E/W Indicator	W		E=east or W=west
Speed Over Ground	0.13	knots	
Course Over Ground	309.62	degrees	True
Date	120598		ddmmyy
Magnetic Variation[2]		degrees	E=east or W=west
Mode	*A*		*A=Autonomous, D=DGPS, E=DR*
Checksum	*10		
<CR> <LF>			End of message termination

1. A valid status is derived from the SiRF Binary M.I.D 2 position mode 1. See the *SiRF Binary Protocol Reference Manual.*
2. SiRF Technology Inc. does not support magnetic declination. All "course over ground" data are geodetic WGS84 directions.

NMEA 0183

GLL veta

$GPGLL, 3723.2475,N,12158.3416,W,161229.487,A,A*41

Table 1-5 GLL Data Format

Name	Example	Units	Description
Message ID	$GPGLL		GLL protocol header
Latitude	3723.2475		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12158.3416		dddmm.mmmm
E/W Indicator	W		E=east or W=west
UTC Time	161229.487		hhmmss.sss
Status	A		A=data valid or V=data not valid
Mode	*A*		*A=Autonomous, D=DGPS, E=DR (Only present in NMEA version 3.00)*
Checksum	*41		
<CR> <LF>			End of message termination

Copernicus II (12 Channel)

Size : 19x19x2.54mm
Sensitivity : -160dBm
Time to First Lock (cold start) : 38 sec
Dual serial ports with reconfigurable UART rates
NMEA, TSIP, and TAIP protocols

Update rate	
TSIP	1 Hz
NMEA	1 Hz
TAIP	1 Hz
Accuracy (24 hour static)	
Horizontal (without SBAS)	<2.5 m 50%, <5 m 90%
Horizontal (with SBAS)	<2.0 m 50%, <4 m 90%
Altitude (without SBAS)	<5 m 50%, <8 m 90%
Altitude (with SBAS)	<3 m 50%, <5 m 90%
Velocity	0.06 m/sec
PPS (static)	±60 ns RMS
PPS (stationary mode indoors at –145 dBm)	±350 ns RMS

Update rate	
TSIP	1 Hz
NMEA	1 Hz
TAIP	1 Hz
Accuracy (24 hour static)	
Horizontal (without SBAS)	<2.5 m 50%, <5 m 90%
Horizontal (with SBAS)	<2.0 m 50%, <4 m 90%
Altitude (without SBAS)	<5 m 50%, <8 m 90%
Altitude (with SBAS)	<3 m 50%, <5 m 90%
Velocity	0.06 m/sec
PPS (static)	±60 ns RMS
PPS (stationary mode indoors at –145 dBm)	±350 ns RMS

NEO-6

50 Channels GPS L1 frequency, C/A Code SBAS: WAAS, EGNOS, MSAS	
	NEO-6G/Q/T
Cold Start[2]	26 s
Warm Start[2]	26 s
Hot Start[2]	1 s
Aided Starts[3]	1 s
	NEO-6G/Q/T
Tracking & Navigation	-162 dBm
Reacquisition[5]	-160 dBm
Cold Start (without aiding)	-148 dBm
Hot Start	-157 dBm
	NEO-6G/Q/M/T
	5Hz
GPS	2.5 m
SBAS	2.0 m
SBAS + PPP[7]	< 1 m (2D, R50)[8)]
SBAS + PPP[7]	< 2 m (3D, R50)[8]

ublox

Accuracy: 1.8m
Search channels: 66
Tracking channels: 22
Sensitivity: -165dBm
Update rate: 10Hz

BCM47755

dual frequency

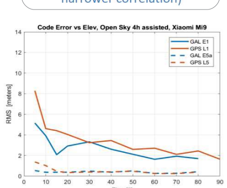
1. ARM-based 32-bit Cortex-M4F
2. ARM-based Cortex-M0

BROADCOM.

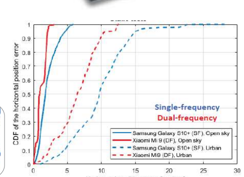
Simultaneously receive the following signals:

GPS L1 C/A
GLONASS L1
BeiDou (BDS) B1
QZSS L1
Galileo (GAL) E1
GPS L5
Galileo E5a
QZSS L5

Better multipath and noise rejection with L5/E5a signals (higher bandwidth, narrower correlation)



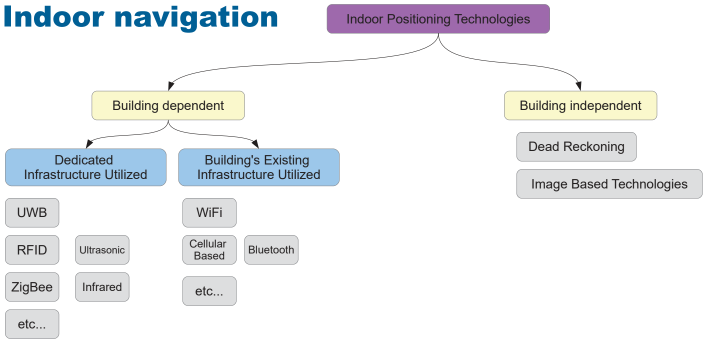
Slightly accuracy improvement with dual-frequency



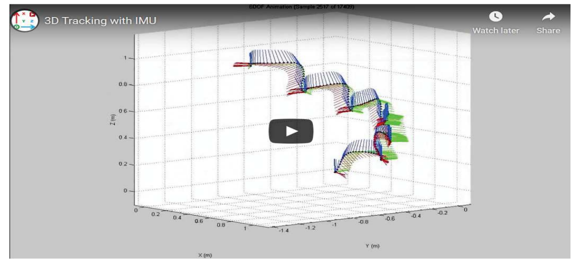
Tomasz Lewandowski: Outcomes from dual-frequency and Galileo alone smartphone test campaigns. 4th Annual Raw Measurements Task Force Workshop Airbus, https://www.gsa.europa.eu/sites/default/files/expo/2.2_tomasz_lewandowski_-_airbus_.pdf

3.3 Localization methods II

Indoor navigation



Inertial Measurement Unit (IMU)



https://x-io.co.uk/gait-tracking-with-x-imu/

S. O. H. Madgwick, A. J. L. Harrison and R. Vaidyanathan, "Estimation of IMU and MARG orientation using a gradient descent algorithm," 2011 IEEE International Conference on Rehabilitation Robotics, 2011, pp. 1-7, doi: 10.1109/ICORR.2011.5975346.

Real Time Location Systems

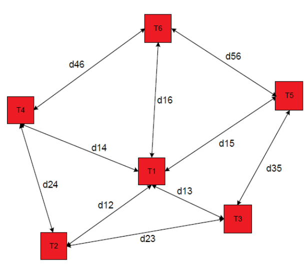


Figure 3: Relative location among a group of nodes

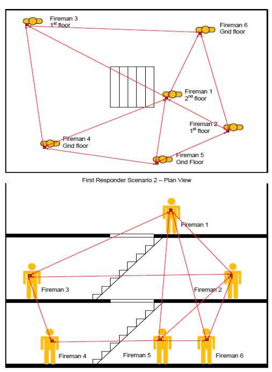


Figure 4: First responder scenario

Real Time Location Systems

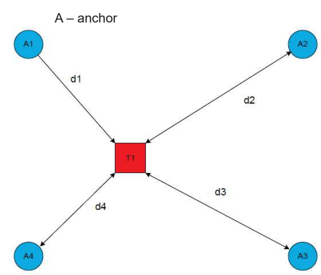


Figure 2: RTLS with fixed infrastructure

Monitoring and localization of patients in hospital

Monitoring and localization of goods, packages etc. in warehouses and logistics.

Animals monitoring and localization

Monitoring status and movements of material, stocks and products in industry.

Real Time Location Systems

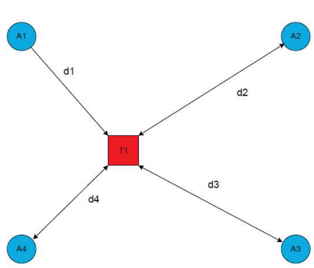


Figure 2: RTLS with fixed infrastructure

Evaluation:

Received Signal Strength (RSS)

Time Of Arrival (TOA)

Time Difference Of Arrival (TDOA)

Angle of arrival (AOA)

WiFi based Indoor Location Systems

Received Signal Strength (RSS), Trilateration

Differential (dWi-Fi) should solve

(1) spatial and temporal signal variations and fluctuations,

(2) influences from outside, e.g. due to shielding by persons, etc.

(3) no continuous transmission, e.g. due to fault hardware, interrupted power supply, etc.

Position
= center of gravity of all six intersections
(for RSS min/max from 3 anchors)

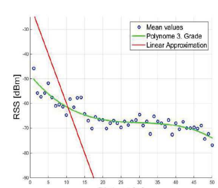


Fig. 4. Linear approximation of the relationship between RSS and range.

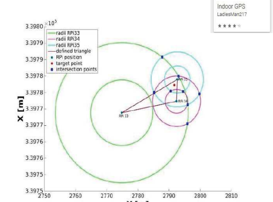


Fig. 2. Resection and determination of the center of gravity.

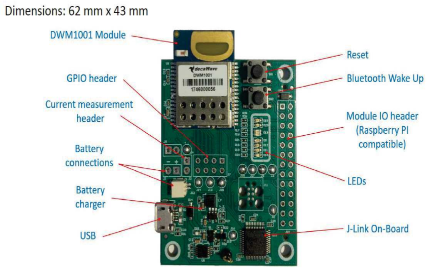
Retscher, Guenther & Kleine, Jonathan & Whitemore, Lisa. (2018). Trilateration approaches for Wi-Fi indoor positioning. AVN Allgemeine Vermessungs-Nachrichten. 125. 264-273. 10.1051/e3sconf/20199402002.

Ultra Wideband (UWB) transceiver
Decawave DW1000

Decawave

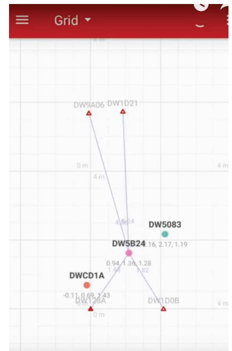
Key Features

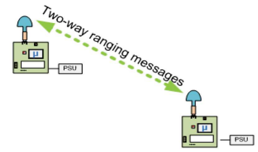
- Ranging accuracy to within 10cm
- UWB Channel 5 PCB antenna (6.5 GHz)
- 6.8 Mbps data rate
- 60 m line-of-sight range typical
- IEEE802.15.4-2011 UWB compliant
- Nordic Semiconductor nRF52832
- Bluetooth®connectivity with antenna
- Motion sensor: 3-axis accelerometer
- Current consumption sleep mode: <15μA
- Supply voltage: 2.8 V to 3.6 V
- Size: 19.1 mm x 26.2 mm x 2.6 mm



Ultra Wideband (UWB) transceiver
Decawave DW1000

Decawave





Fiducial markers

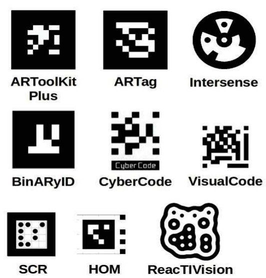


photo: (c) Bostin Dynamics
markers: Garrido-Jurado, Sergio & Muñoz-Salinas, Rafael & Madrid-Cuevas, Francisco & Marín-Jiménez, Manuel. (2014). Automatic generation and detection of highly reliable fiducial markers under occlusion. Pattern Recognition. 47. 2280–2292. 10.1016/j.patcog.2014.01.005.

WhyCon

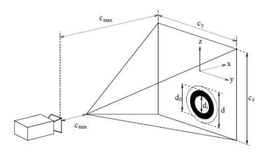


Table 5: Required image processing time

CPU	Processing time [ms]					
	Measured			*Predicted*		
Dataset:	small	large	fast	small	large	fast
i-5 2450M	0.04	0.10	0.37	0.04	0.12	0.35
Atom N270	0.30	0.72	3.25	0.33	0.89	2.68
Pentium M	0.20	0.45	1.44	0.17	0.48	1.45
Odroid U2	0.27	0.89	2.76	0.29	0.79	2.86
Raspb. Pi	1.10	4.00	15.8	1.34	3.66	11.0

Table 6: Localization accuracy of a moving target

Mode	Abs. [cm]		Rel. [%]	
	ϵ_{avg}	ϵ_{max}	η_{avg}	η_{max}
2D	1.2	4.2	0.4	1.5
3D	3.1	11.2	1.2	4.4

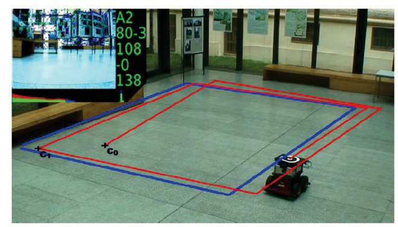


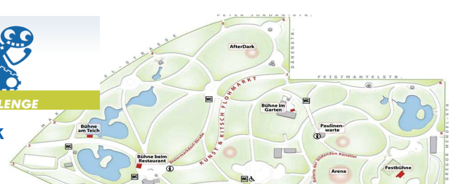
Fig. 11: Reconstructed trajectory of a mobile robot.

T. Krajník, M. Nitsche et al.: A Practical Multirobot Localization System. Journal of Intelligent and Robotic Systems (JINT), 2014.

Robotour

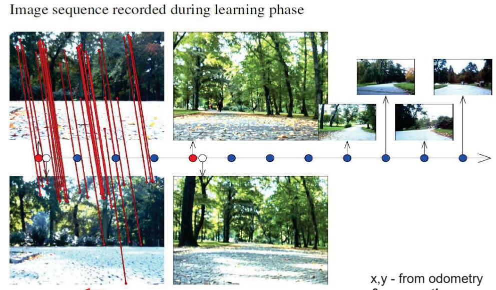
ROBOTIKA.CZ OUTDOOR DELIVERY CHALLENGE

2011: Wien, Türkenschanzpark
2021: Bratislava
...you are welcomed!



STRoLL BearNav: Teach and Replay

Image sequence recorded during learning phase

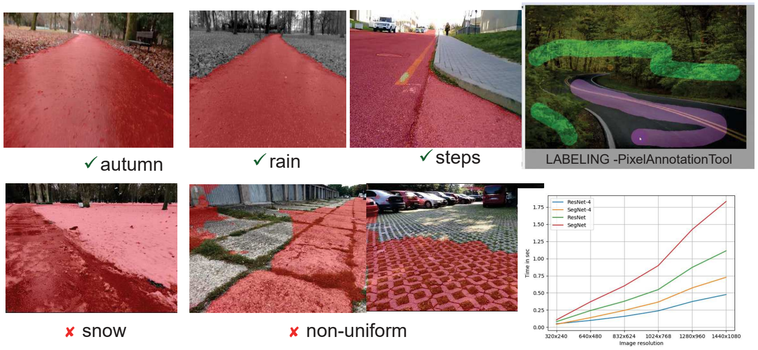


x,y - from odometry
θ - correction

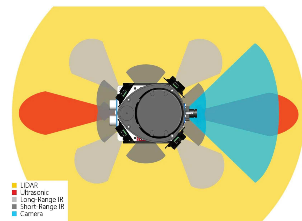
Image perceived by the robot during autonomous repeat

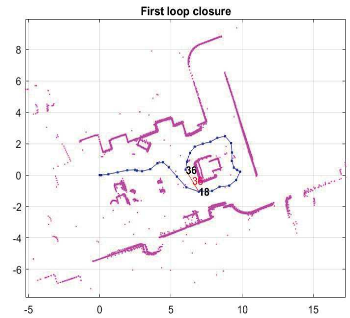
Krajnik, Faigl, Vonasek et al.: **Simple, Yet Stable Bearing only Navigation**. Journal of Field Robotics, 2010

Robotour: Istrobotics team (DNN approach)



Simultaneous Localization and Mapping (SLAM)





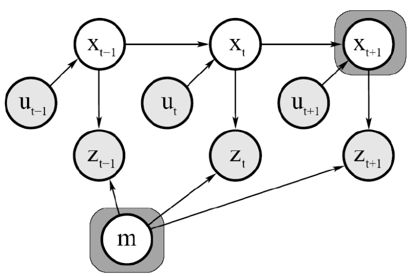
Graphical Model of Online SLAM

Given:

- The robot's controls $U_{1:k} = \{u_1, u_2, \ldots, u_k\}$
- Relative observations $Z_{1:k} = \{z_1, z_2, \ldots, z_k\}$

Wanted:

- Map of features $m = \{m_1, m_2, \ldots, m_n\}$
- Path of the robot $X_{1:k} = \{x_1, x_2, \ldots, x_k\}$



$$p(x_t, m \mid z_{1:t}, u_{1:t}) = \int\int \cdots \int p(x_{1:t}, m \mid z_{1:t}, u_{1:t})\, dx_1 dx_2 \ldots dx_{t-1}$$

Wolfram Burgard, Cyrill Stachniss, Kai Arras, Maren Bennewitz: SLAM - Simultaneous Localization and Mapping Introduction to Mobile Robotics, Uni Freiburg course materials

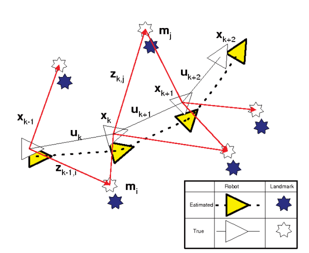
10. Lokalizácia a navigácia bez mapy

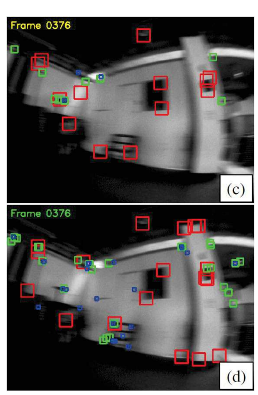
Simultaneous Localization and Mapping (SLAM)

a) Kalman Filter
b) Particle Filter
c) Graph-based

10. Lokalizácia a navigácia

Visual SLAM





Phollower 100

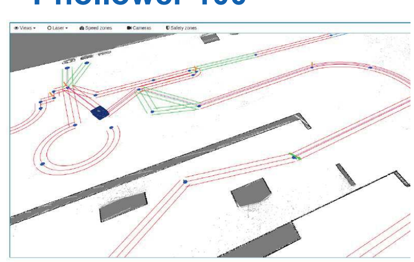


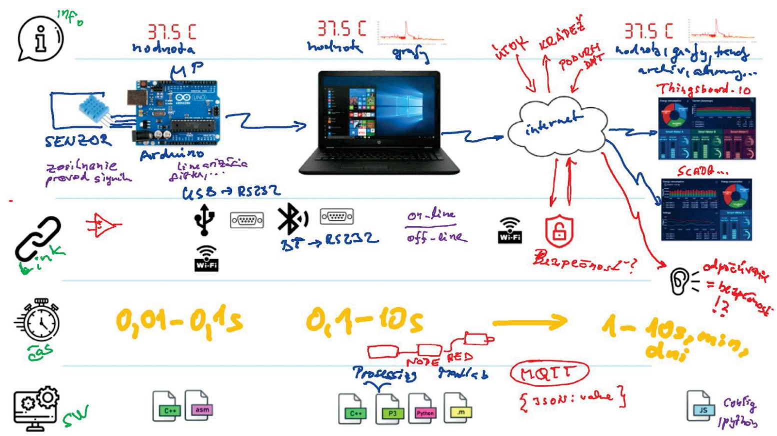
Figure 9. An example of a predefined trajectory

Figure 1. An overview of Phollower's base construction.

Bačík, J.; Tkáč, P.; Hric, L.; Alexovič, S.; Kyslan, K.; Olexa, R.; Perduková, D. Phollower—The Universal Autonomous Mobile Robot for Industry and Civil Environments with COVID-19 Germicide Addon Meeting Safety Requirements. Appl. Sci. 2020, 10, 7682. https://doi.org/10.3390/app10217682

MISA 2023

Zhrnutie



Rekapitulácia

Skúška

- 1. termín **19. mája** o **11:00 v D-101**
- 2. termín **12. júna** o 11:00 v D-101

Open book test

Papier, pero

Prineste si svoj počítač

60 min. čistého času

nutné získať min 1/2 bodov

Dovtedy:

- Odovzdať všetky cvičenia
- Odovzdať programovacie zadania
- Odovzdať projekt
- Vyskúšať si písomku v Classroome
- Malý deadline: **17. 5.**

Interreg Slovakia-Austria
European Regional Development Fund

ROBOCOOP

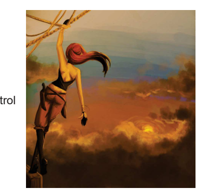
Thank you!

[1.] RYGER, I., BALOGH, R., CHAMRAZ, S., et. al.: Feedback Control of a Nonlinear Electrostatic Force Transducer. Sensors, 20(24), 2020.

[2.] BALOGH, R.: Practical kinematics of the differential driven mobile robot. Acta Mechanica Slovaca vol. 11, 2007.

[3.] CHAMRAZ, S. and BALOGH, R.: Two approaches to the adaptive cruise control (ACC) design. Cybernetics & Informatics (K&I), 1-6, 2018

[4.] BALOGH, R. and Tapak, P.: Modelling the driver assistance systems using an Arduino compatible robot. International Conference on Robotics and Education RiE 2017, 275-28



Richard Balogh

Slovak University of Technology in Bratislava

richard.balogh@stuba.sk

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