RoboCoop project

Robot Navigation

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Robot Navigation

Abstract: Introduction to the robot navigation techniques. Various mathods for robot localization, sensors used for obtaining relevant position estimation, mapping, planning, control.

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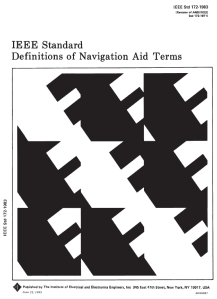
1879 illustration of Babes in the Wood by Randolph Caldecott. Source: Wikimedia Commons.

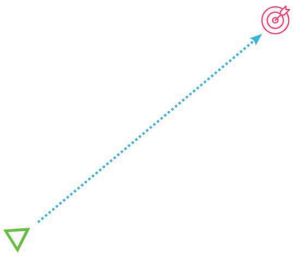
Navigation

„The process of directing a vehicle so as to reach the intended destination“

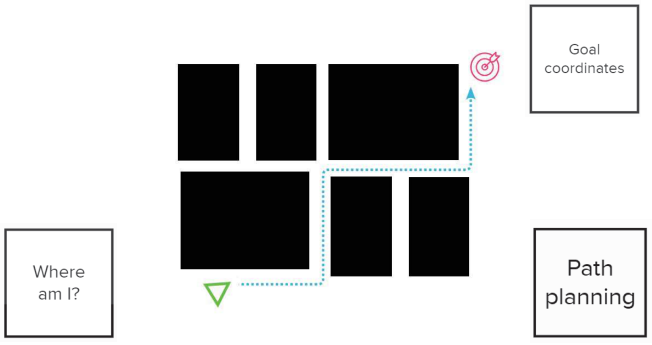

IEEE Standard
Definitions of Navigation Aid Terms

IEEE Standard Definitions of Navigation Aid Terms, in IEEE Std 172-1983, vol., no., pp.1-34, 22 June 1983, doi: 10.1109/IEEESTD.1983.82384.

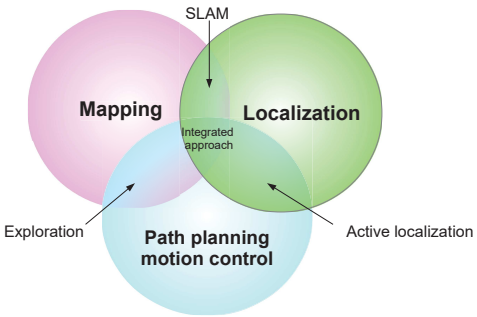
Navigation is easy...

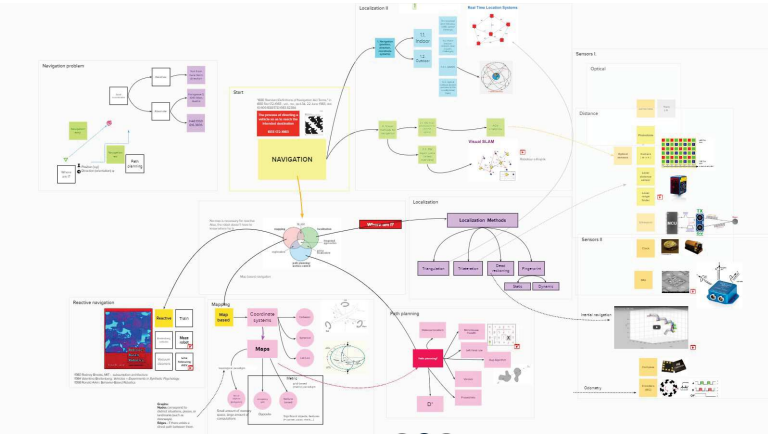


...or not?



Navigation is complex task



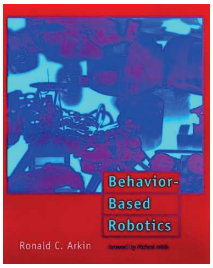


1: Mapping

1.0 Reactive navigation

Reactive	Train
Breitenberg vehicles	**Maze robot**
Vacuum cleaners	**Line following AGV**

No map
No internal representation
Not required to know Where am I



1980 Rodney Brooks, MIT - subsumption architecture
1984 Valentino Breitenberg: Vehicles – Experiments in Synthetic Psychology
1998 Ronald Arkin: Behavior-Based Robotics

Material transport from point A to B

conveyor belt

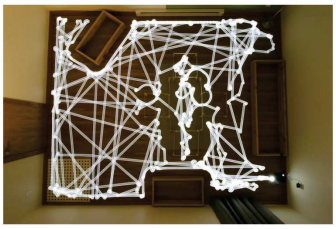
rope car

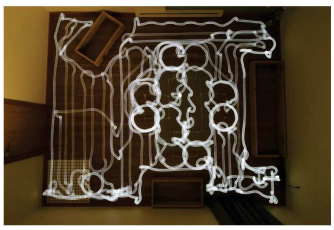
pipeline

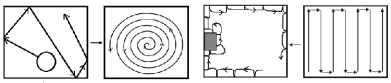
railways

Photo: VW Bratislava Annual Report 2017

Reactive navigation



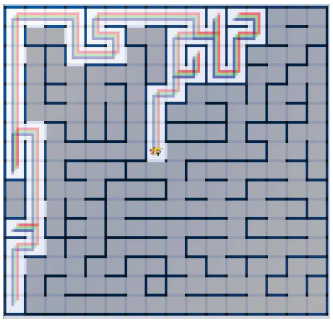


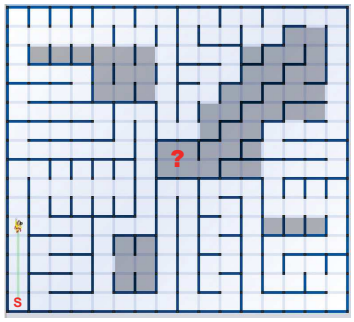


Mi Robot Vacuum: Cleaning Path Comparision

https://youtu.be/SusPRqU2W4M

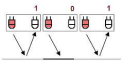
Micromouse: wall follower (left hand rule)





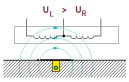
https://code.google.com/archive/p/maze-solver/

Autonomous Guided Vehicles (AGV)



Optical

Reflection of the signal from the color surface



Inductive

Induced voltage in pair of coils from the wire in ground

Laser ranging

Distance from the reference high reflective points

Magnetic

magnetic tape e.g. **1300L-A tractor AGV**

CEIT AGV

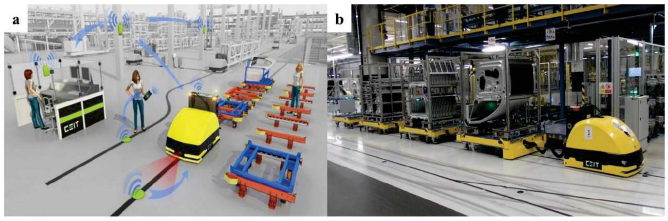


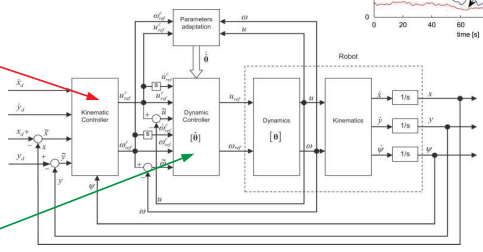
Fig. 2. (a) CEIT Internal logistics concept; (b) CEIT AGV in VW Slovakia 0

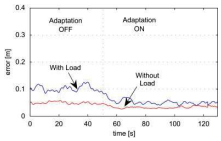
Tomáš Gregor, Martin Krajčovič, Dariusz Więcek: Smart Connected Logistics. Procedia Engineering, Volume 192, 2017, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2017.06.046.

2: Path planning

2.1. Path planning note:

Path ≠ Trajectory ≠ Controller

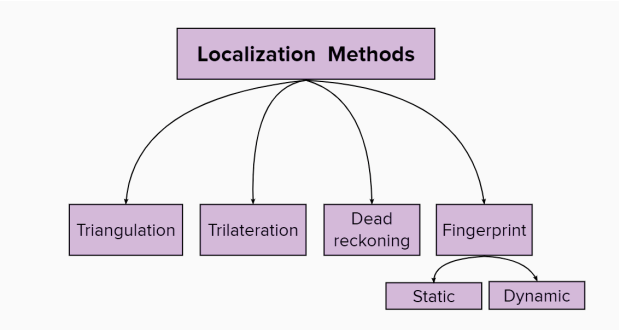




Felipe N. Martins *et al.*: An adaptive dynamic controller for autonomous mobile robot trajectory tracking, Control Engineering Practice,Volume 16, Issue 11, 2008, https://doi.org/10.1016/j.conengprac.2008.03.004

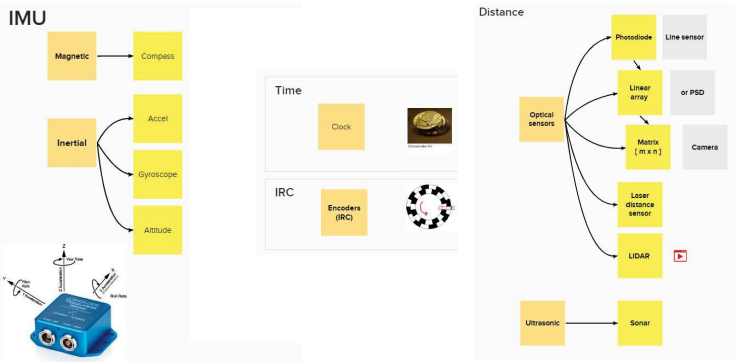
3.1 Localization methods I

Part III: Localisation



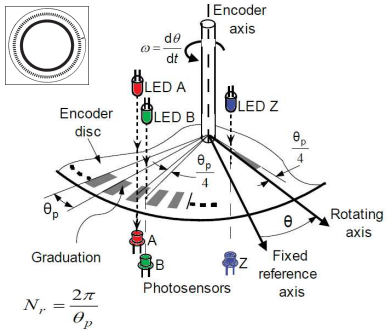
3.2 Sensors for Localization

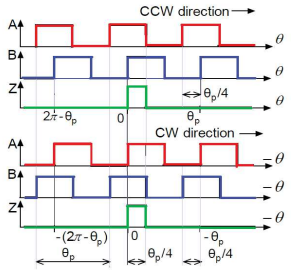
Sensors



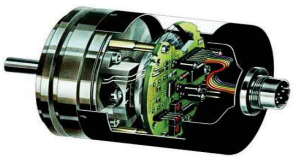
3.2.1. Optical sensors

Incremental Rotary enCoders – IRC

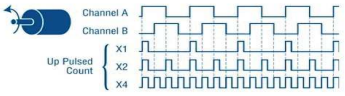


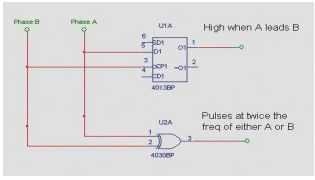


IRC incremental rotary encoder



4x multiply





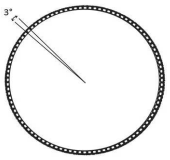
IRC incremental rotary encoder

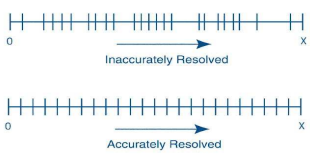
How to Calculate Minimum Required Encoder Resolution:

Resolution (PPR) = 360° / Smallest Increment of Measurement Required

If 3° Required:

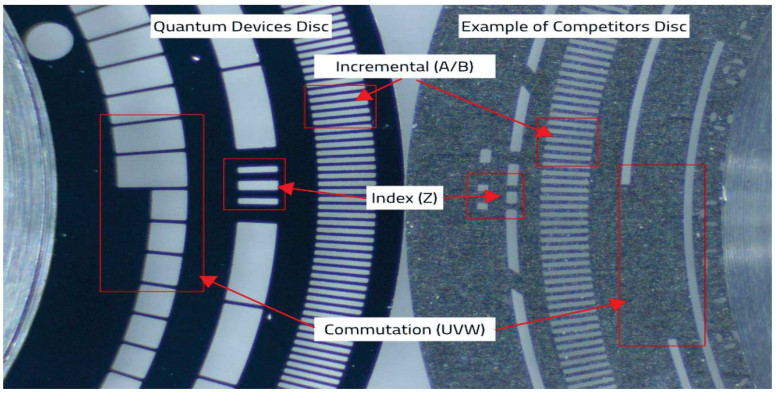
360° / 3° = 120 PPR





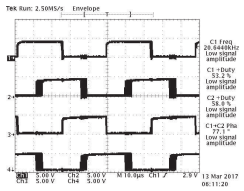
Example: *high resolution does not always improve accuracy.*

IRC: encoder disc

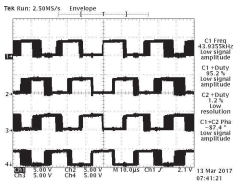


IRC: real signal

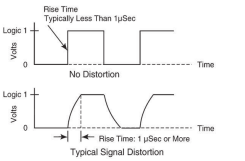
IRC troubleshooting



Signal jitter: decentered encoder disk



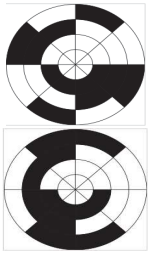
Extended pulses : loose encoder mounting



Shark fin: too long wires, missing pull-up

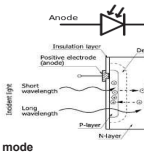
Source: https://www.dynapar.com/knowledge/encoder_issues/

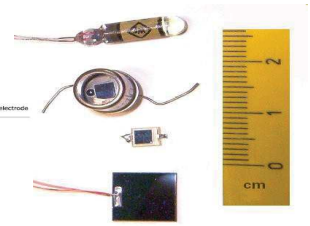
Absolute position encoders



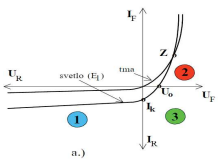
Optical sensors: photodiode

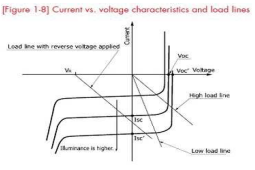
fast, less sensitive

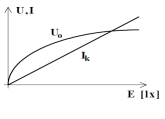




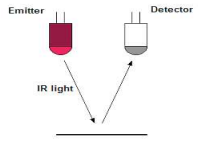
1 - reverse biased: photoconductive mode
2 - forward biased
3 - photovoltaic mode (solar cell)
Z - operating point not sensitive to light





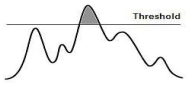


Optical line sensor principle



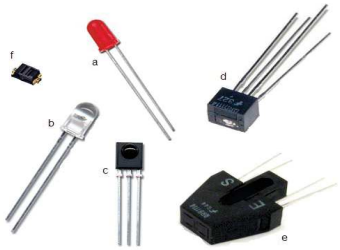
Black = no reflection (0)
= reflection (1)

Output
DIGITAL 0 and 1
ANALOGUE 0-100%



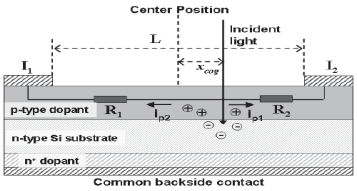
Sources of failures

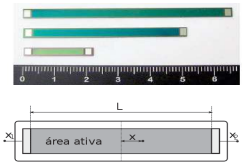
- Ambient light
- Shadows
- Sun, lamps
- Sources of IR
- Dust, dirt
- Distance!
- Speed



Sensors and detectors:
a) red LED b) Infra red LED c) Infra detector
d) combination emitter + sensor e) larger version
f) miniature SMD version of E+S

PSD (position sensitive device)

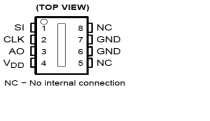


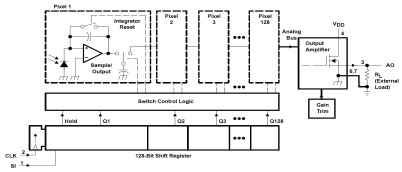


$$x = \frac{L}{2}\frac{I_2 - I_1}{I_2 + I_1}$$

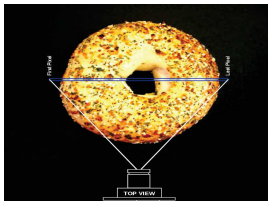
- information about POSITION, not intensity
- total current (common backside electrode) I_0 = 1µA!
- resolution 12 µm, error ±0,9%
- IR LED, more often laser,
- modulation for improved SNR

Line CCD sensor
TAOS TSL 1401 CL

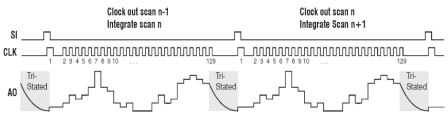




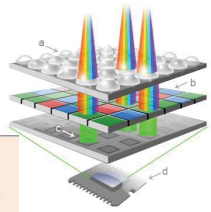
Line CCD sensor
TAOS TSL 1401 CL

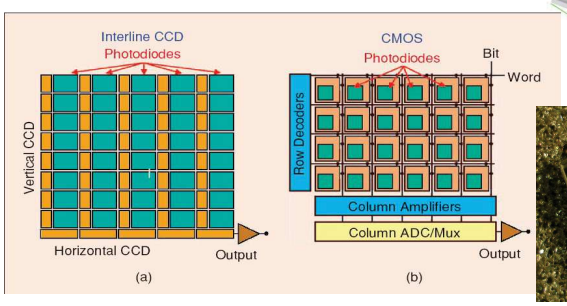


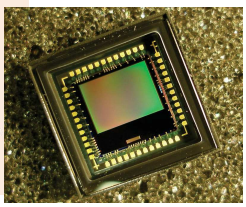
- 1 x 128 pixels
- 0 - 5 V output for each pixel
- 1 pixel / 1 clock pulse



Matrix - CCD and CMOS



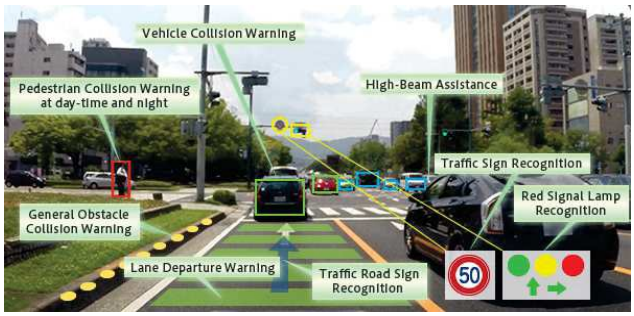




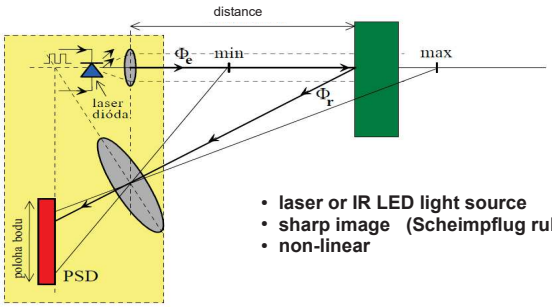
Automotive sensors

case study

Automotive visual sensor system



Optical rangefinder (triangulation)

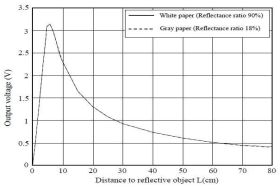


- **laser or IR LED light source**
- **sharp image (Scheimpflug rule)**
- **non-linear**

Triangulation rangefinder

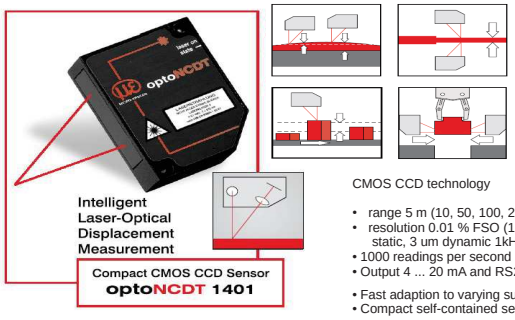
SHARP GP2Y0A21YK0F

GP2Y0A21YK0F Distance Measuring Sensor Unit
Measuring distance: 10 to 80 cm
Analog output type



6.2. Optické princípy

Triangulačný diaľkomer

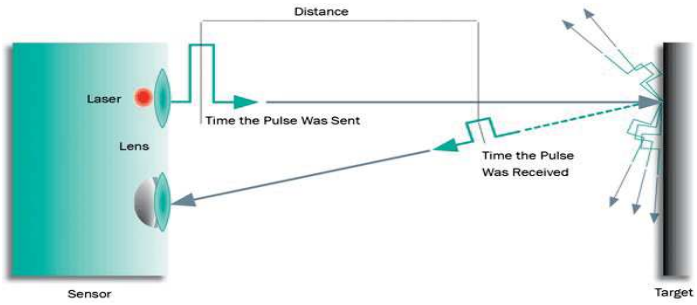


CMOS CCD technology

- range 5 m (10, 50, 100, 200 mm)
- resolution 0.01 % FSO (1 um static, 3 um dynamic 1kHz)
- 1000 readings per second
- Output 4 ... 20 mA and RS232
- Fast adaption to varying surface properties
- Compact self-contained sensor (IP67)

Laser systems

Time-of-flight



Need for speed!

Laser systems

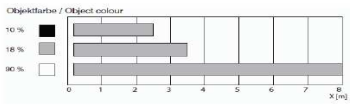
Laserový snímač vzdialenosti optoNCDT ILR 1030-8

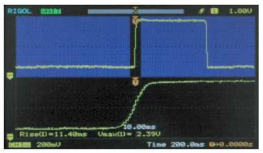
- time-of-flight technology

- Pulze 5 ns repeating frequency 250 kHz
- Class 2 laser diode
- wavelength 660 nm
- divergency 1 mrad

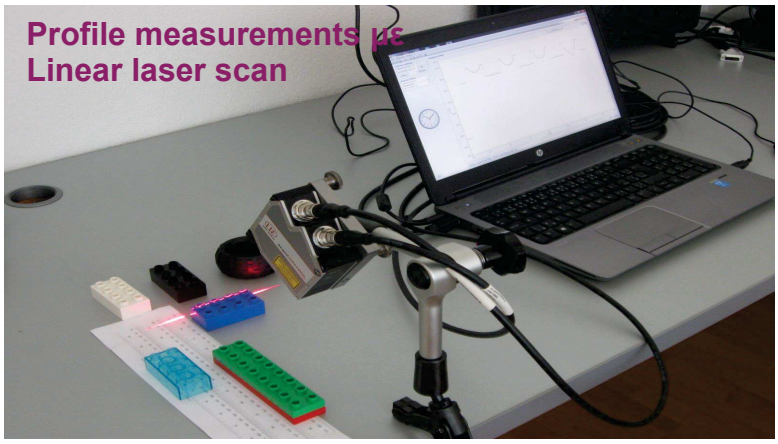
D = 100 cm	current
color	[mA]
white	6,62
yellow	6,62
red	6,62
green	6,61
blue	6,61
black	6,61
black foam	6,61
mirror	6,62

- analog output 4-20 mA
- 278 € (25x Sharp distance sensor)

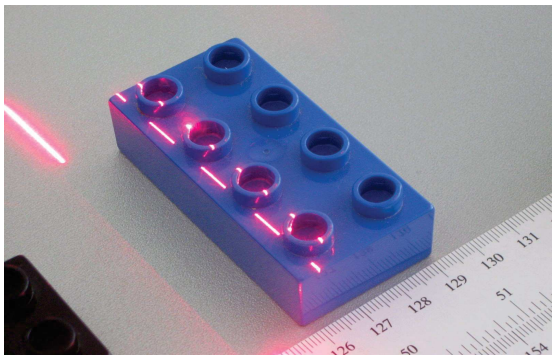




Profile measurements με
Linear laser scan

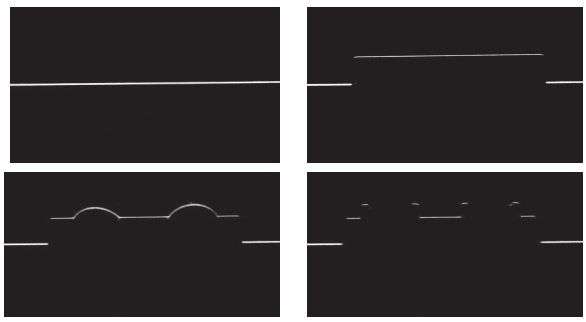


Profilemeter με

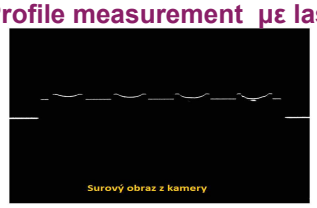


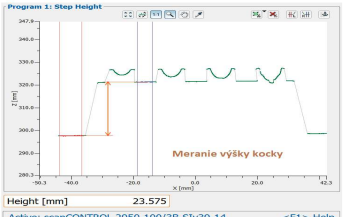
6.2. Optické princípy ToF

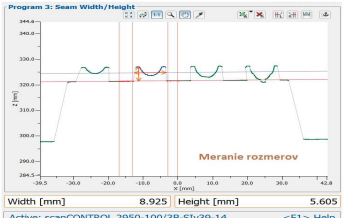
Profilometer με



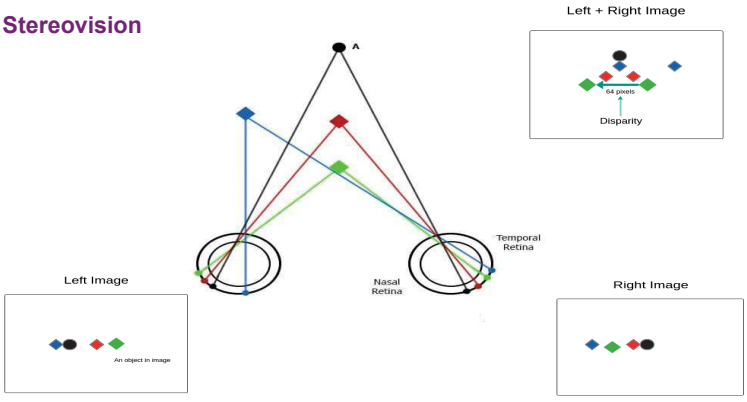
Profile measurement με laser



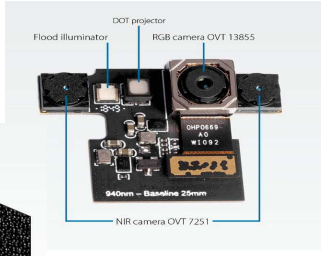


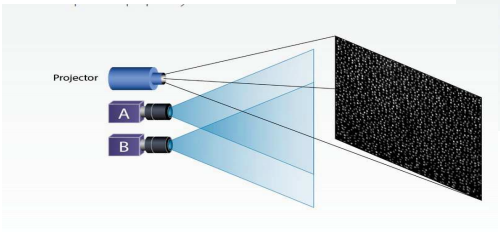


Stereovision



Active stereovision

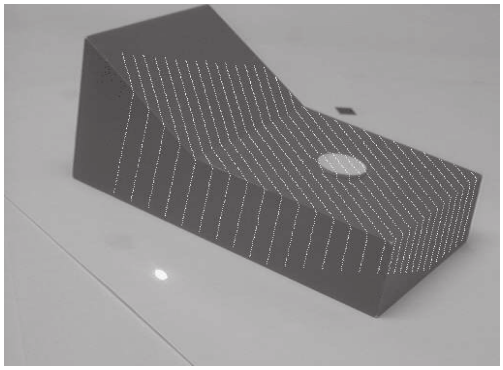




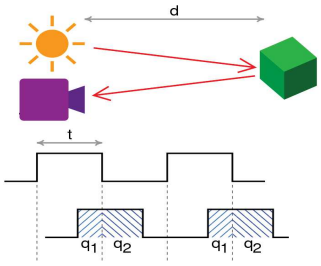
Inserting points into the image makes easier their identification and pairing

Source https://ams.com/stereovision

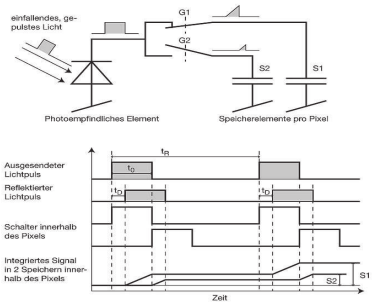
Active stereovision



Time of Flight camera



$$d = \frac{c\,t}{2}\,\frac{q2}{q1+q2}$$



Depth camera (Kinect)

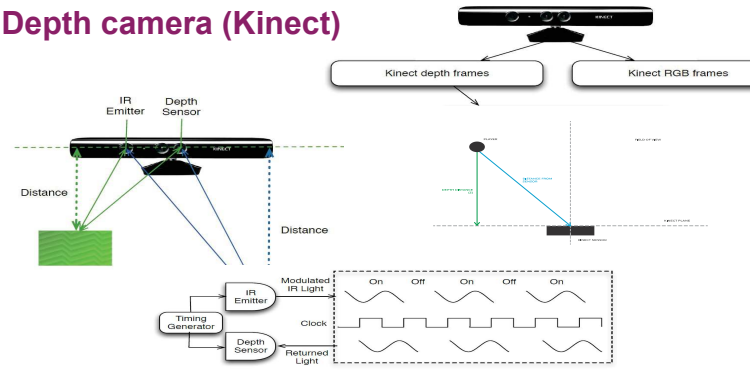
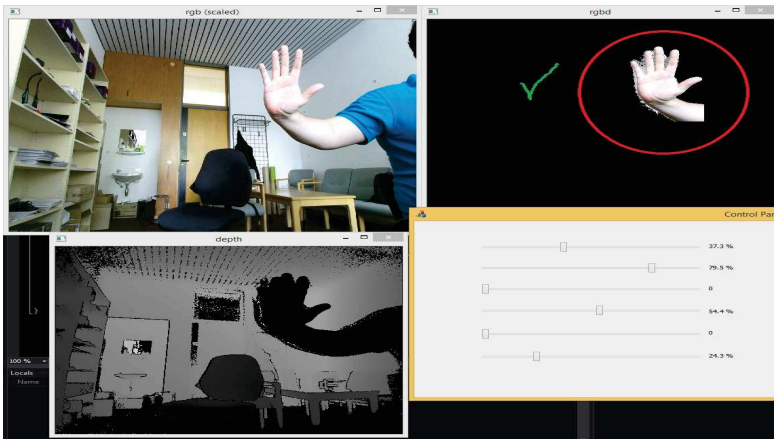


Fig. 3. Kinect v2 uses the time-of-flight method for depth sensing.



LIDAR

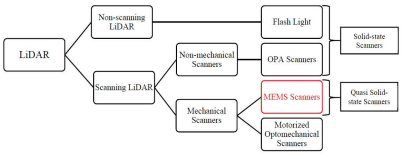
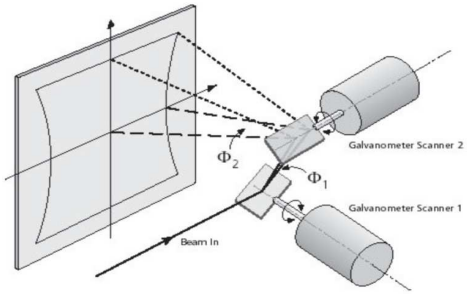
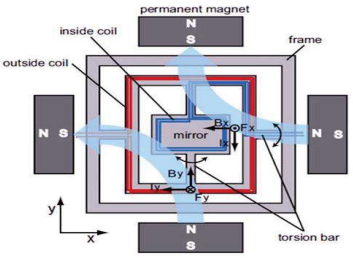


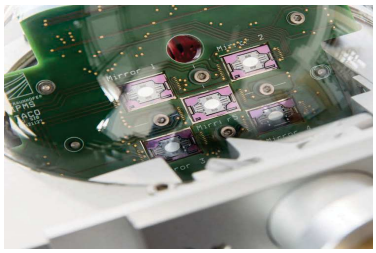
Figure 1. Different types of LiDAR scanners.



Dingkang Wang, Connor Watkins and Huikai Xie:
MEMS Mirrors for LiDAR: A Review. Micromachines 2020, 11, 456;
doi:10.3390/mi11050456

MEMS LIDAR





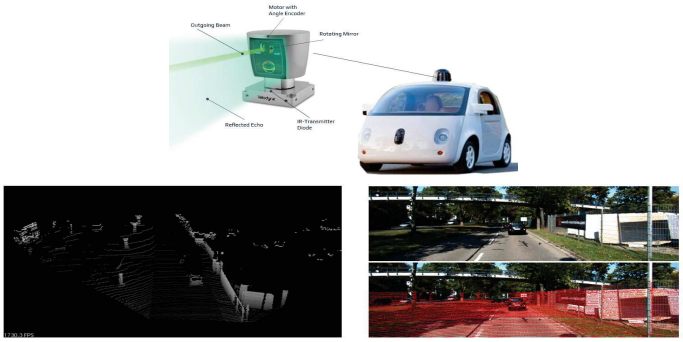
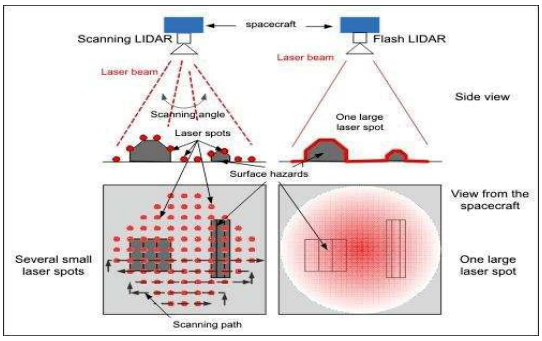
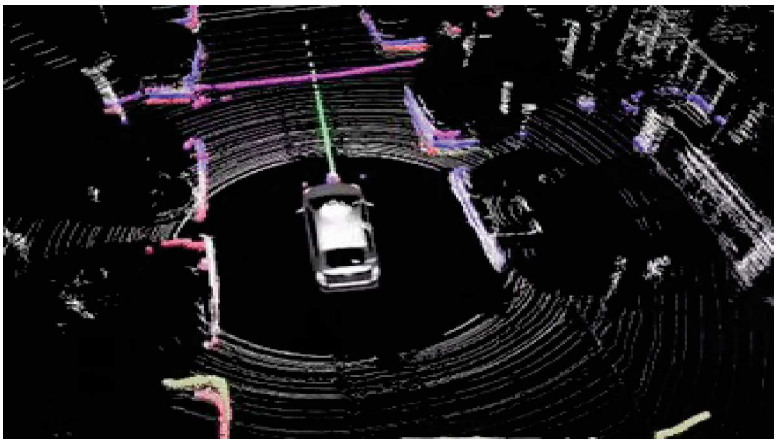


Figure 1: On the left is a LIDAR point cloud (only the data overlapped with the FOV of image are shown, grayscaled by height). On the top right is the corresponding image captu by camera. On the bottom right is the result of image and LIDAR point cloud fusion (r the well aligned tree trunks).

6.2. Optické princípy ToF

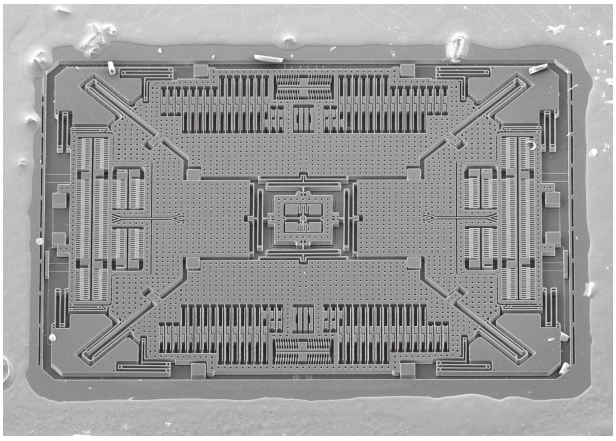
Flash LIDAR



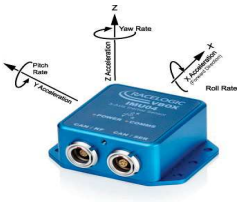


Photoneo
Focused on 3D

https://www.photoneo.com/videos3D/



IMU – Inertial measurement unit

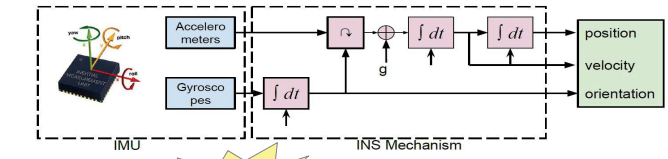


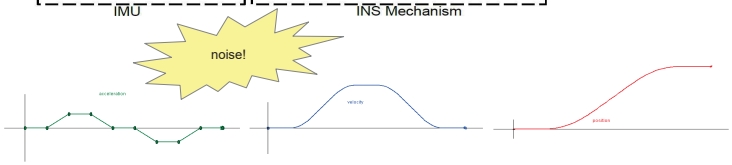
Racelogic's Inertial Measurement Unit (RLVBIMU04)

VN-100 Rugged Inertial Measurement Unit and Attitude Heading Reference System (IMU/AHRS)

MEMSIC Inertial Measurement Units (IMU)
IMU440CA-200/400

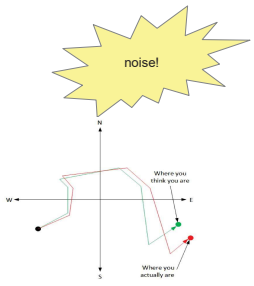
IMU – Inertial measurement unit

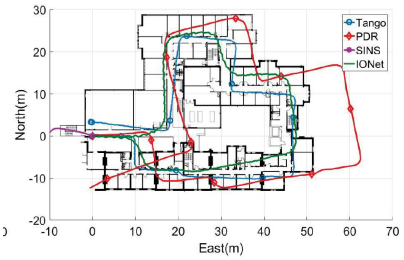




Michael R Gallis: Applets for Physics, Astronomy and Math available at http://phys23p.sl.psu.edu/simulations/

IMU – Inertial measurement unit

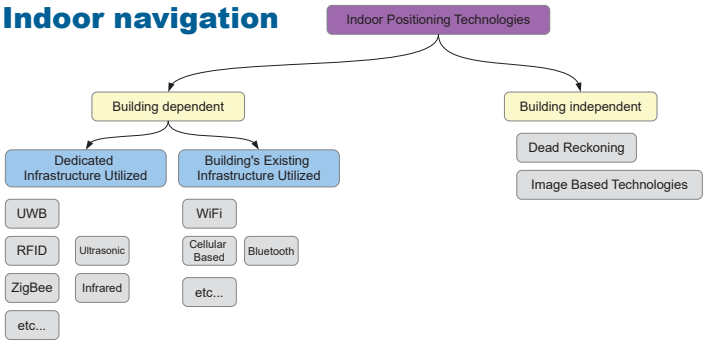




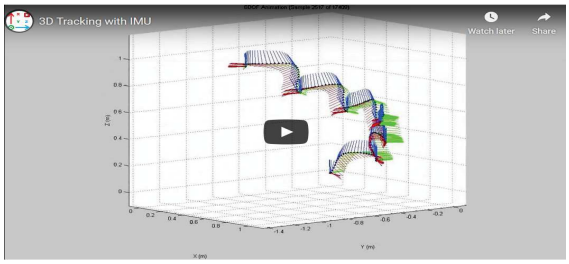
Chen, Changhao & Lu, Xiaoxuan & Markham, Andrew & Trigoni, Niki. (2018). IONet: Learning to Cure the Curse of Drift in Inertial Odometry. The Thirty-Second AAAI Conference on Artificial Intelligence (AAAI-2018)

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

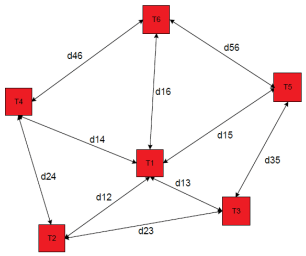


Figure 3: Relative location among a group of nodes

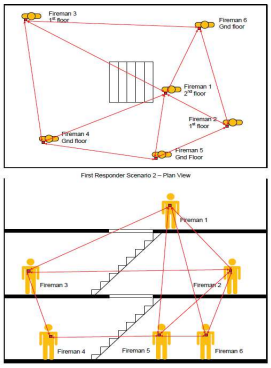


Figure 4: First responder scenario

Real Time Location Systems

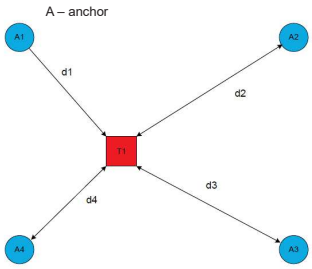


Figure 2: RTLS with fixed infrastructure

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.

Interreg Slovakia-Austria
European Regional Development Fund

ROBOCOOP

Thank you!

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STU FEI
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY