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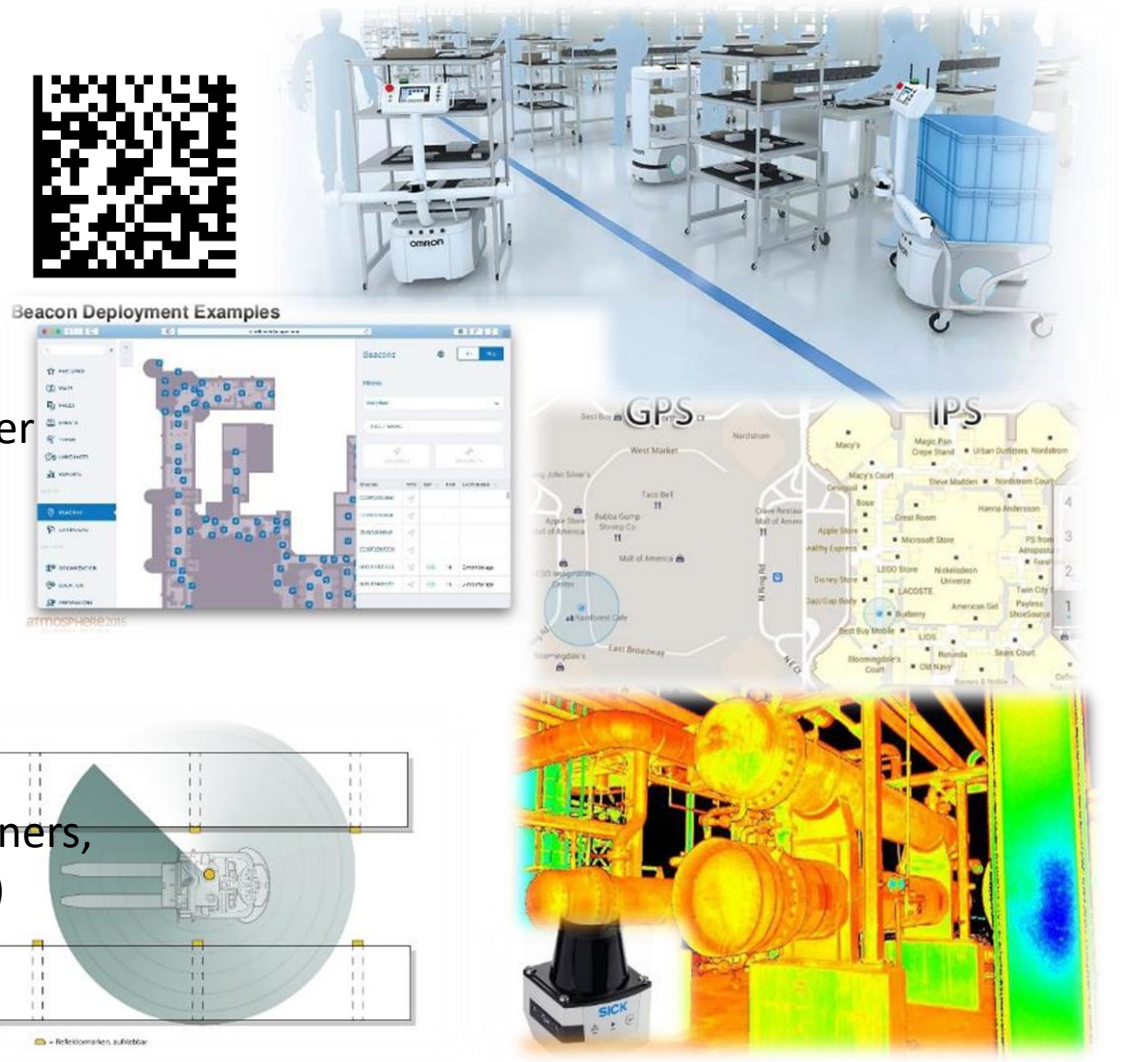
AGV vision

Jakub Musiał, Aiut Sp. z o.o. (Ltd.)

jakub.musial@polsl.pl

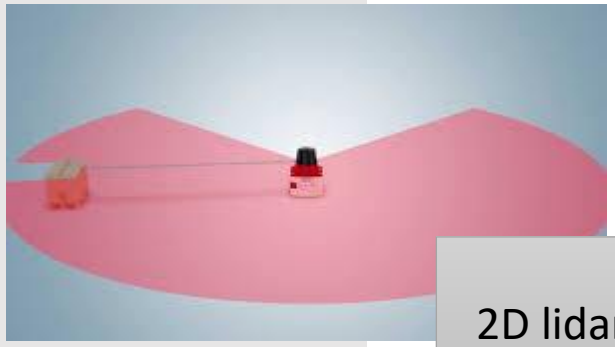
Navigation possibilities

- Line following:
  - Magnetic (Hall effect, contractron, magneto-resistive)
  - Colour (optical)
  - Metal (inductive)
- Beacon/anchor localistaion:
  - Mirrors and rotating laser,
  - Passive or active RFID tags,
  - DMX (readers) or symbols (computer vision)
  - BLE or UWB tags
  - GPS
- Natural navigation
  - Signal strength(Wi-Fi)
  - Environment mapping (2D/3D scanners, lidars, radars, 3D or stereocameras)

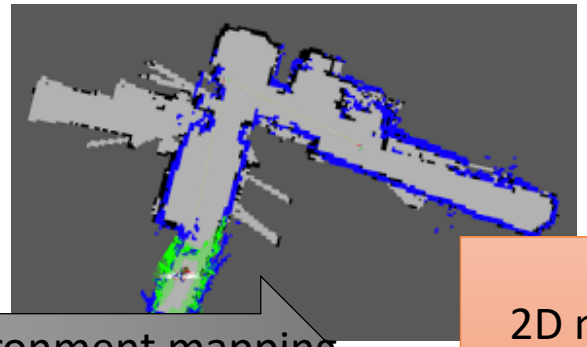


Automatykab2b.pl, Slideshare.net/AtubaNetworks, Jungheinrich.com, sick.com, aamgroup.com, extremetech.com

Natural navigation



2D lidars



Environment mapping

2D map

Odometry

Reference points

Encoders

Odometry

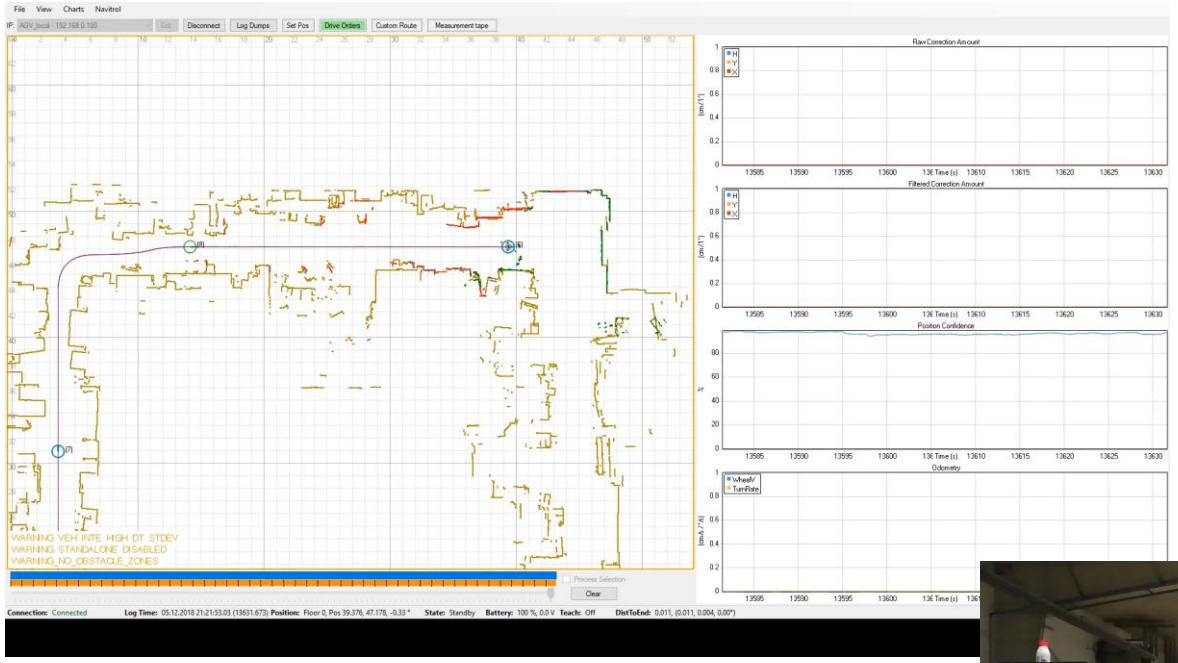
Localistaion

Possibilities to enhance the localisation:

1. Using inertial measurement units (IMU): gyroscope and accelerometer
2. Using received signal strength (RSSI) for reflectivity indication and using objects as positioning mirrors (anchors)
3. Reinitialisation of position through automatic coordinate refreshing (global points used as position reference)
4. Using Simultaneous Localisation and Mapping approach (SLAM) for dynamic environments

Natural navigation commissioning

- Gathering of measurement data in teaching mode
- Construction of a reference map using dedicated software
- Determination of trajectories and navigation points
- Initialisation of robot's position
- Calculation of position and using odometry for determination of shifting within map coordinate system
- Navigation through following of virtual lines



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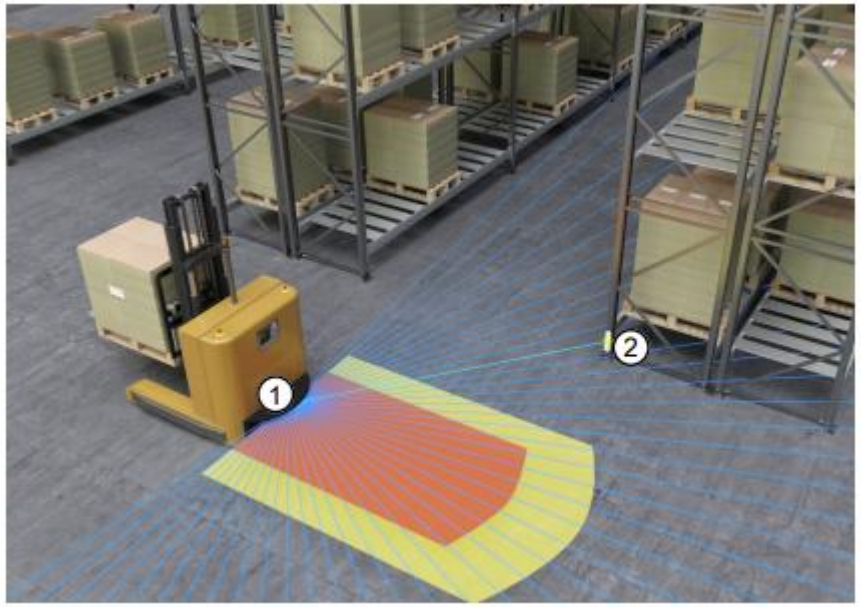
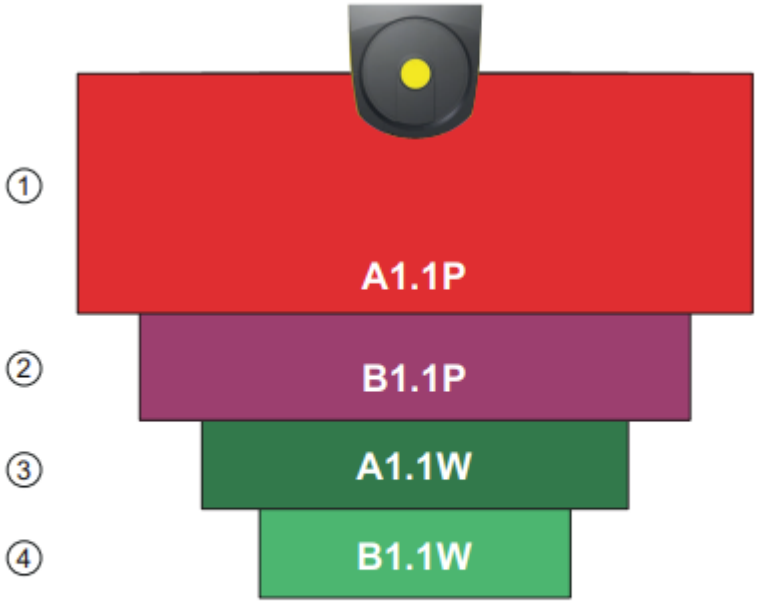
LIDAR 2D

Leuze scanner model RSL420-M/CU416-10

Scanning angle	**270 °**
Distance resolution	1 mm
Detection range	0 ... 50 m
Measuring accuracy	± 20 mm
Angular resolution	0.1 °
Scans per second	25/s

Protective fields





1 Protective function A: protective field
2 Protective function B: protective field
3 Protective function A: warning field
4 Protective function B: warning field

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Data frames

Basic design

For internal processing purposes, each UDP data package is preceded by Header 1 (H1) and Header 2 (H2).

Table 3.1: UDP data package design

8 bytes	**4 bytes**	**2 bytes**	**2 bytes**	**4 bytes**	
Header 1	Header 2	ID	Block	Scan	<data>

- The first four bytes of Header 1 specify the total length of the transferred UDP data package.

Table 3.2: Header 1 design

Total length				**Header size**	**Follow flag**	**Request ID**	
[Lo byte]	…	…	[Hi byte]	8		[Lo byte]	[Hi byte]

- The ID identifies the type of UDP data package.
- The safety sensor may only send UDP data packages up to a maximum size which is sufficient for most information. If the amount of data exceeds this size, each UDP data package is designated with an additional block number (0 … 65535).
  This ensures that the UDP data packages can be reconstructed in the correct chronological order.
- A complete system profile consists of multiple UDP data packages. Every UDP data package contains the scan number. This ensures that the UDP data packages of a system profile are coherent.
  The scan number increases after every scan cycle. After 4294967296 (2^{32}) cycles, the scan number starts again at 0.

Scanner signals

UDP data packages for system profile

The system profile shows the following process data:

- Extended status profile: status profile plus measurement contour description
- Measurement data

The safety sensor normally sends the UDP data packages as follows:

H1/H2	ID	Block	Scan	Extended status profile

Optional UDP data packages:

H1/H2	ID	Block	Scan	Measurement data, 1st fragment
H1/H2	ID	Block	Scan	Measurement data, 2nd fragment
...				
H1/H2	ID	Block	Scan	Measurement data, nth fragment

Status profile

Table 3.3: Status profile design

Byte	Bit	Signal	Value "0"	Value "1"	Default	Description
	-	-	-	-	1	Type (model) of status profile. Extensions require a new type of status profile.
		OP-MODE	-	-	1	Operating mode • 1: Safety mode • 2: Simulation mode
		SDs				
		ERROR	off	message	0	Collective message: Error with switch-off
		ALARM	off	message	0	Collective message: Warning without switch-off (also window warning)
		SCREEN	off	message	0	Contamination display for optics cover: Warning or switch-off
	4	EDM	off	message	-	EDM collection error
	3	FIELD PAIR	off	message	-	Collective message: Fault detected by field pair selection monitoring
	2	E-STOP	off	message	-	Error with OSSD linkage / E-Stop monitoring
	1	A-OSSD	off	on	0	OSSD state, protective function A
	0	B-OSSD	off	on	0	OSSD state, protective function B

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Measurment data

Measurement contour description

Table 3.4: Measurement contour description design

Byte	Bit	Value range	Description
0 … 1	15 … 0	0 … 2699 0 ≤ **Start index** < Stop index	Start index
0 … 3	15 … 0	0 … 2699 Start index < **Stop index** ≤ 2699	Stop index
4 … 5	15 … 0	1 … 8	Index interval
6 … 7	15 … 0	-	Reserved

The total number of scanning beams is calculated according to the following formula:

$$n = 1 + \text{ceil}\left(\frac{\text{Stopindex} - \text{Startindex}}{\text{Indexinterval}}\right)$$

n- total number of scanning beams

The ceil(x) function determines the smallest integer that is greater than or equal to the value x.

Measurement data

The measurement data is transferred via multiple UDP packages according to the configuration.
The expected number of values can be calculated using the measurement contour description. The measurement contour can be reconstructed in its entirety and in the correct chronological order with this result and the block number.

H1/2	ID	Block	Scan	Measurement data, (nth fragment)

- ID: 6: Distance measurement data type
  3: Distance + signal strength measurement data type
- Block no.: Continuous (0 - 65535)
- Scan no.: Continuous (0 - 4294967295)

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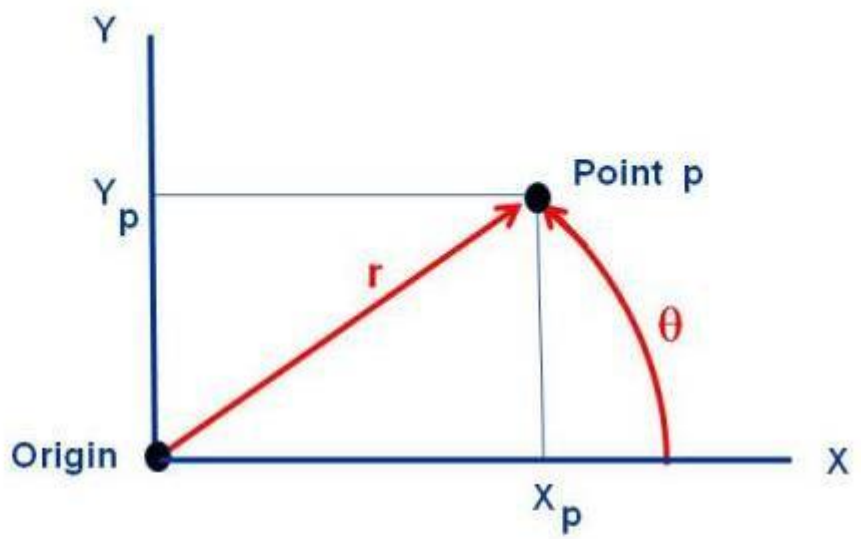
Polar to cartesian coordinates



Point p can be located relative to the origin by Rectangular Coordinates (X_p, Y_p) or by Polar Coordinates (r, θ)

$$X_p = r \cos(\theta) \qquad r = \text{sqrt}\left(X_p^2 + Y_p^2\right)$$

$$Y_p = r \sin(\theta) \qquad \theta = \tan^{-1}\left(Y_p / X_p\right)$$

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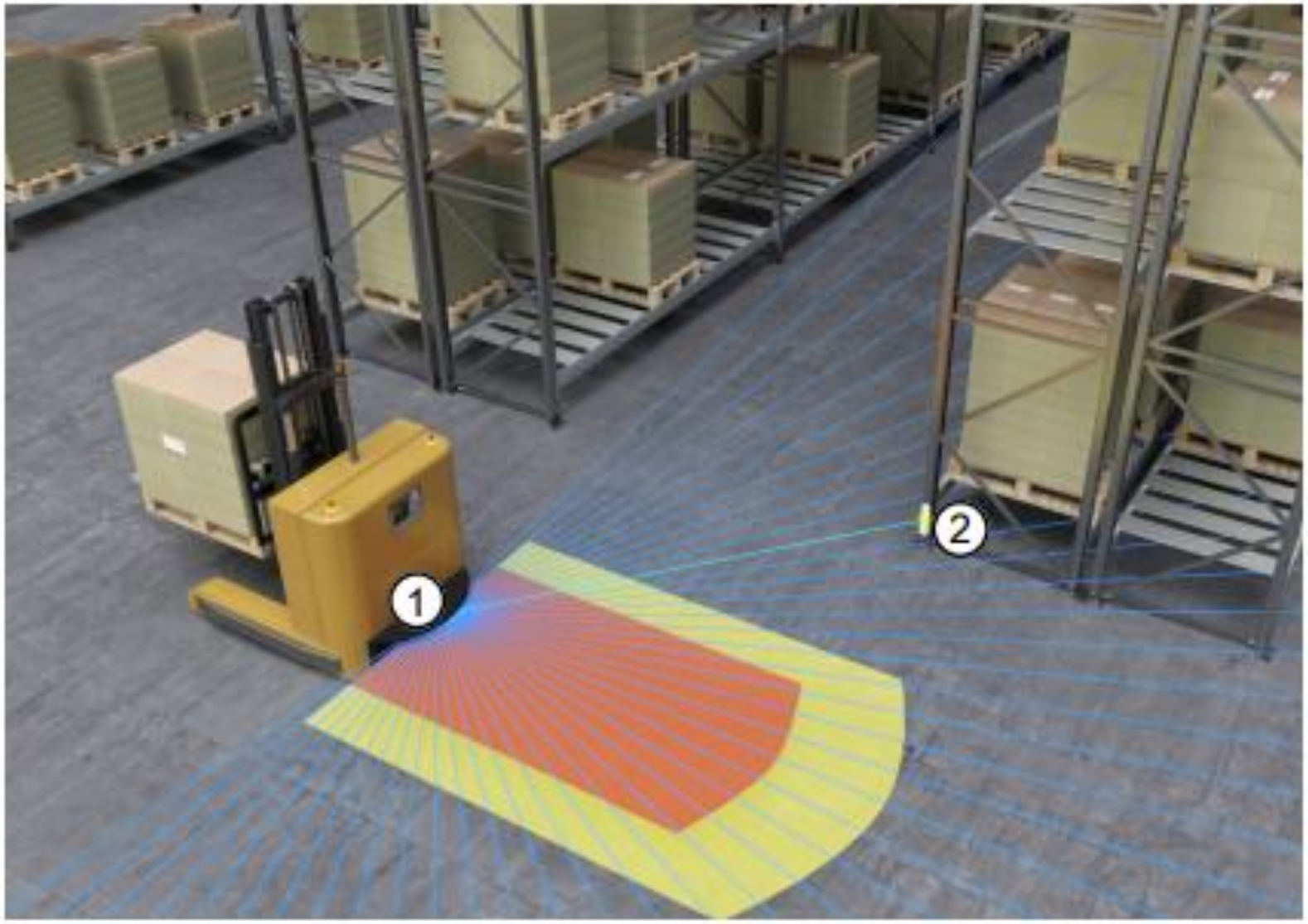
Signal strength

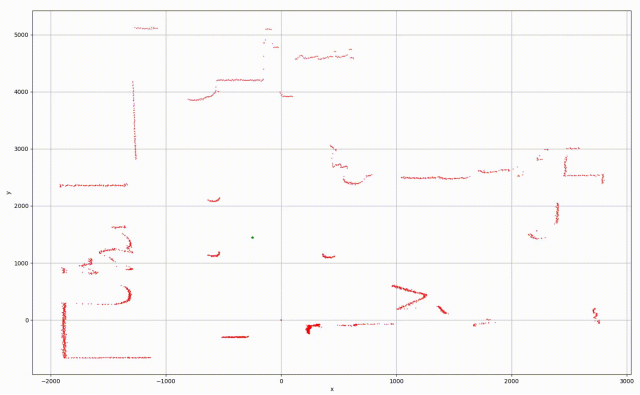


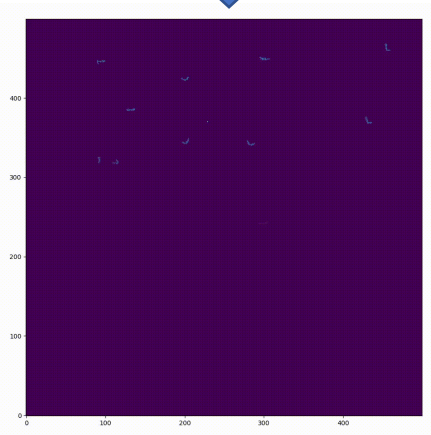
Sample algorithms

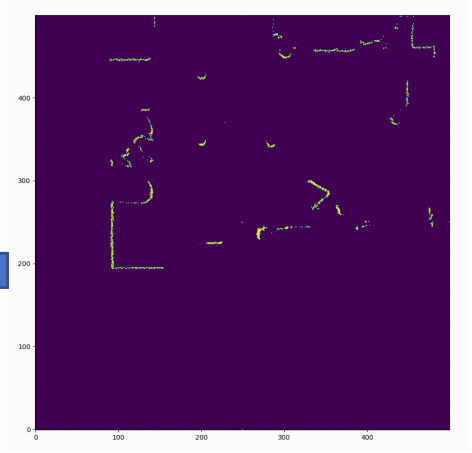
- Station detection
- Localization

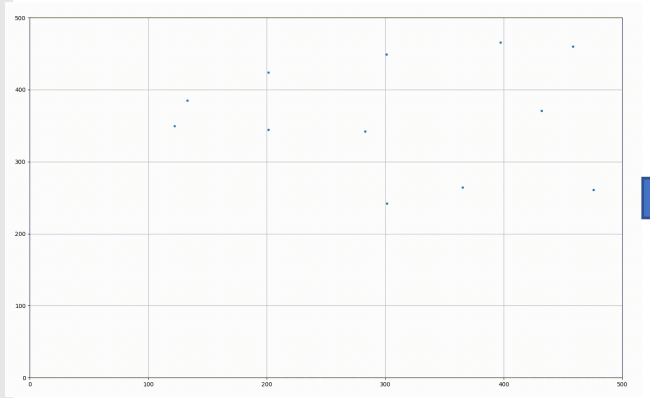
Station detection

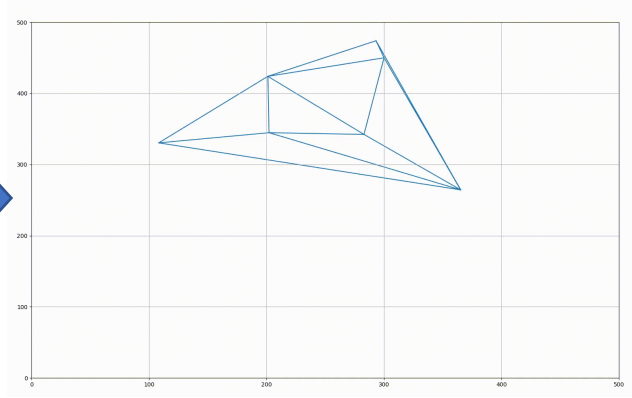
- Decoding frames
- X,Y map transformation
- Connected components labeling
- Filtration
- Calculating centroids
- Triangulation
- Station detction

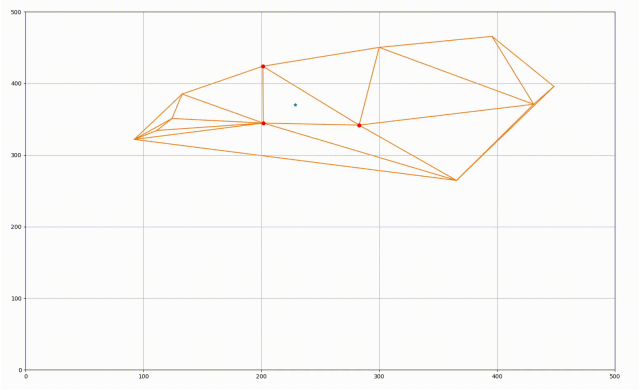








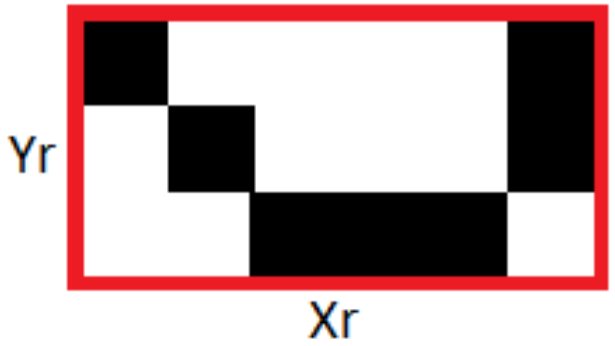


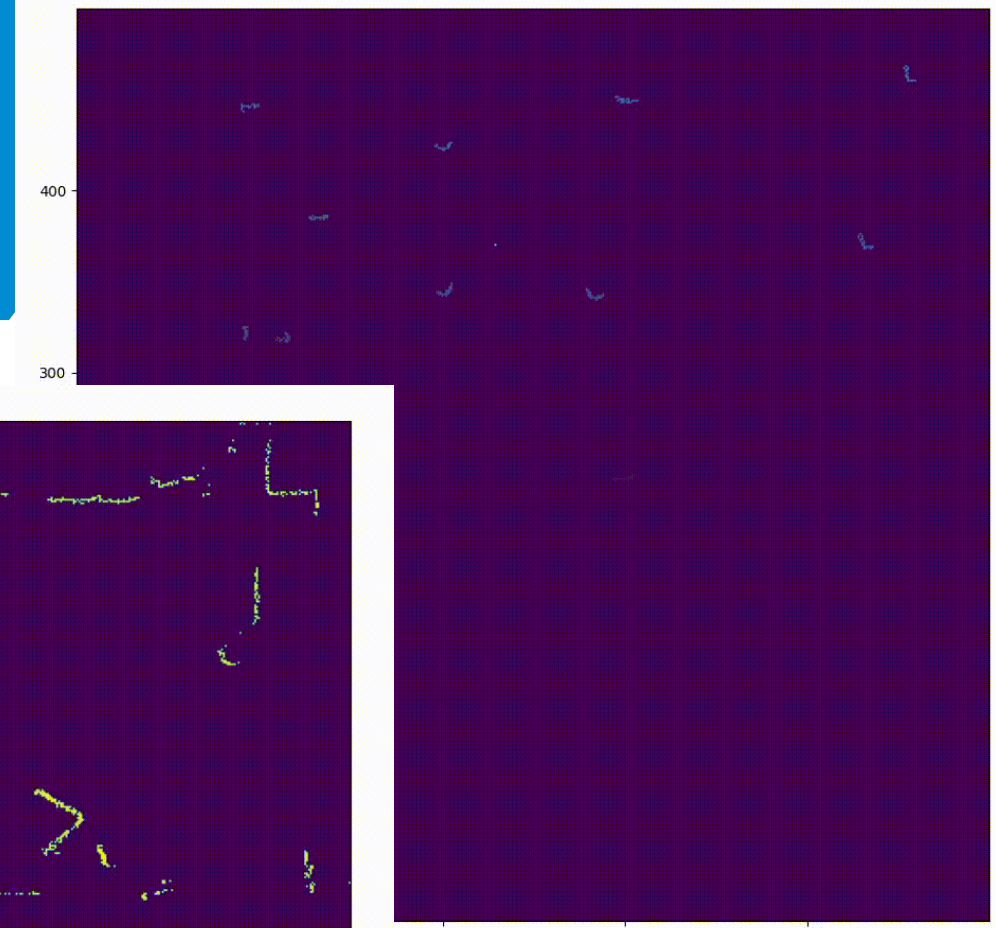


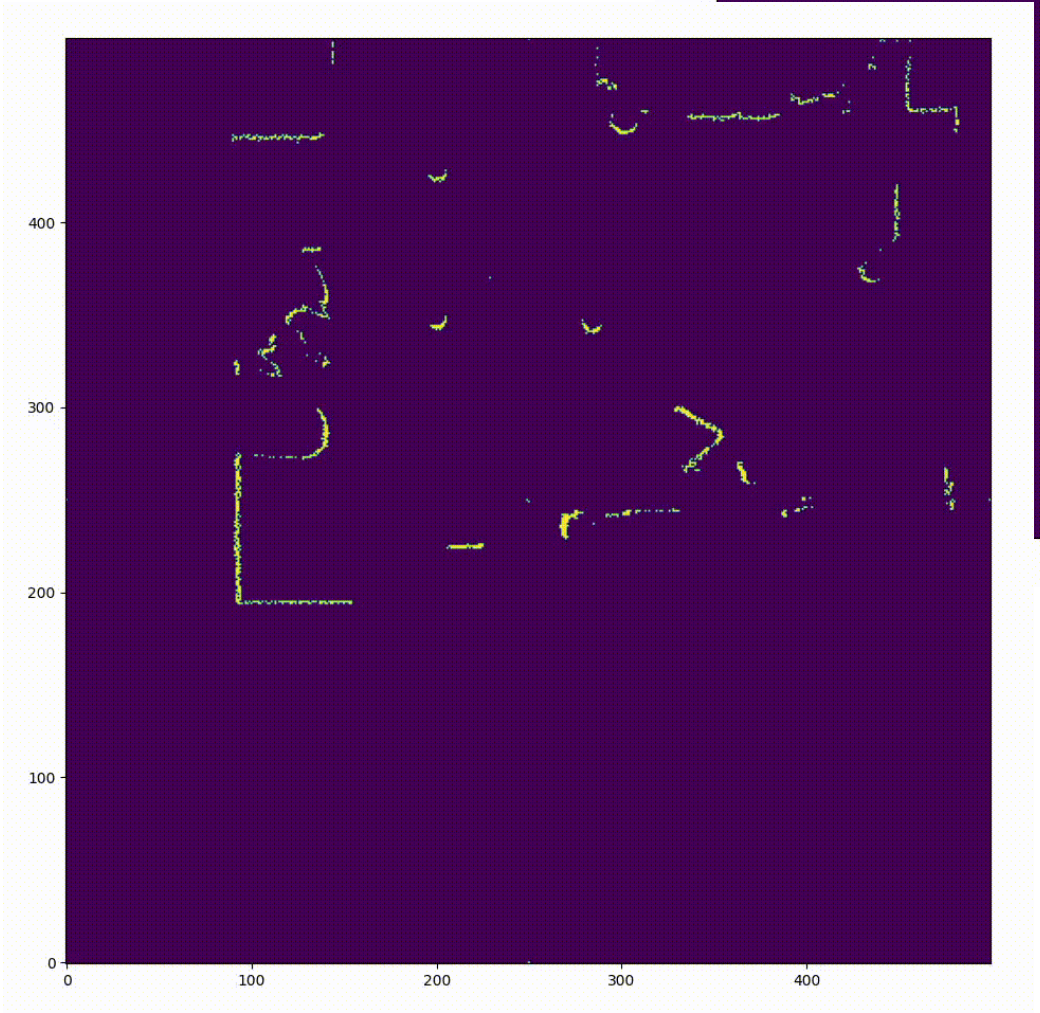
Binery map operations

Selcting criteria:

- Number of picxels
- Bourder ratio Xr/Yr

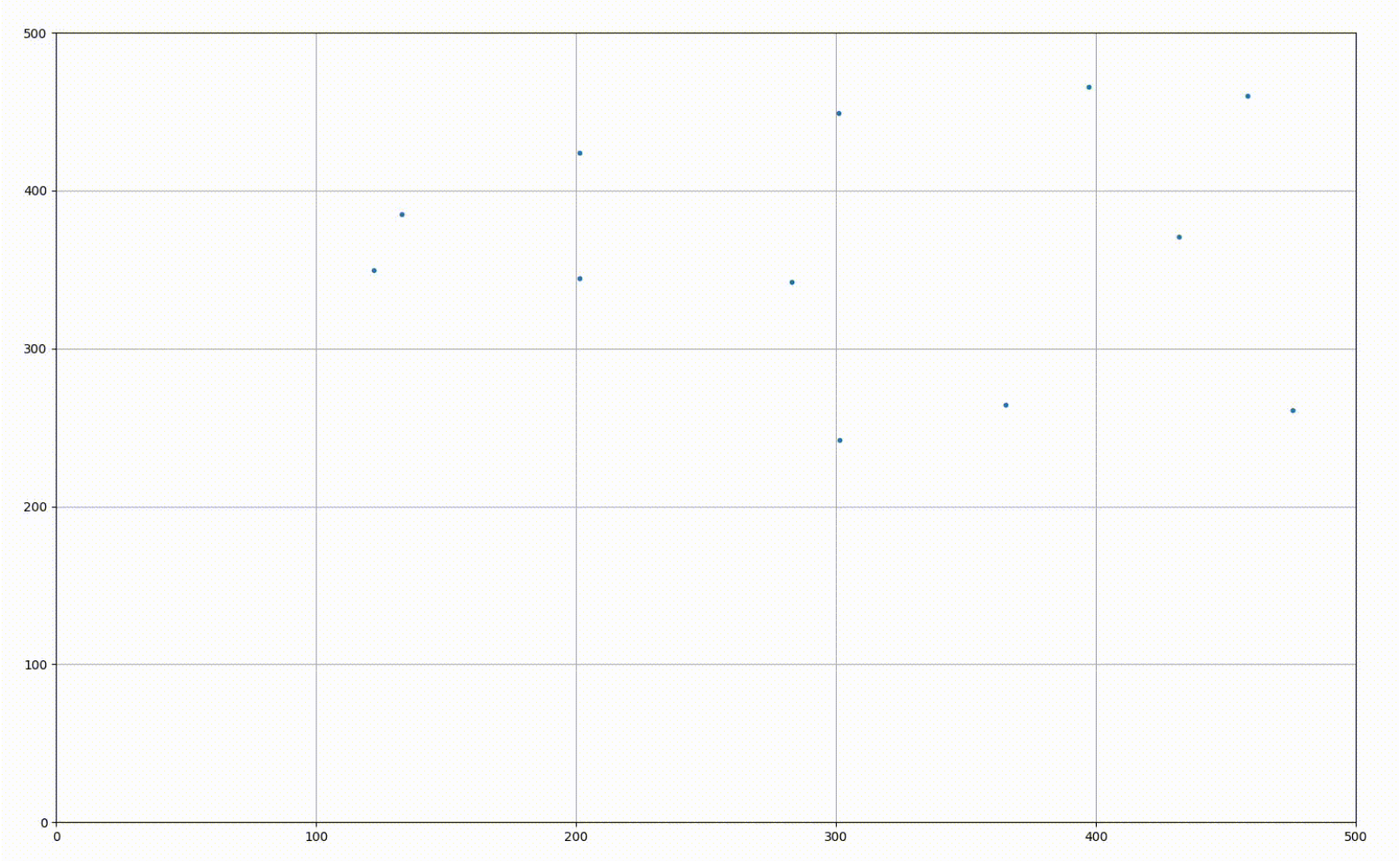






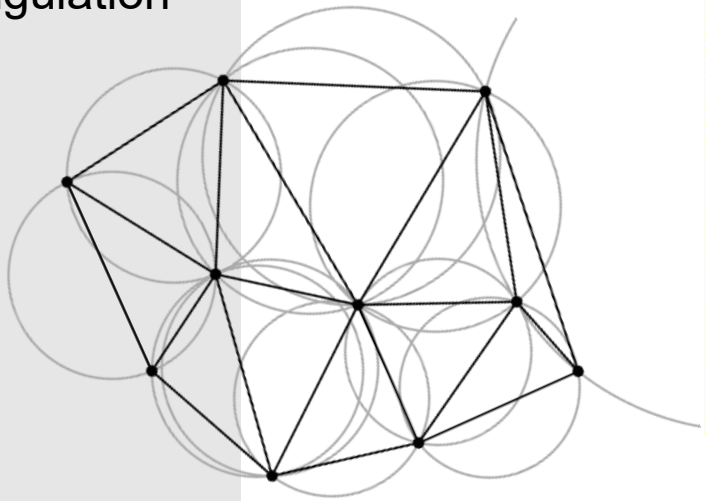
Calculating centroids

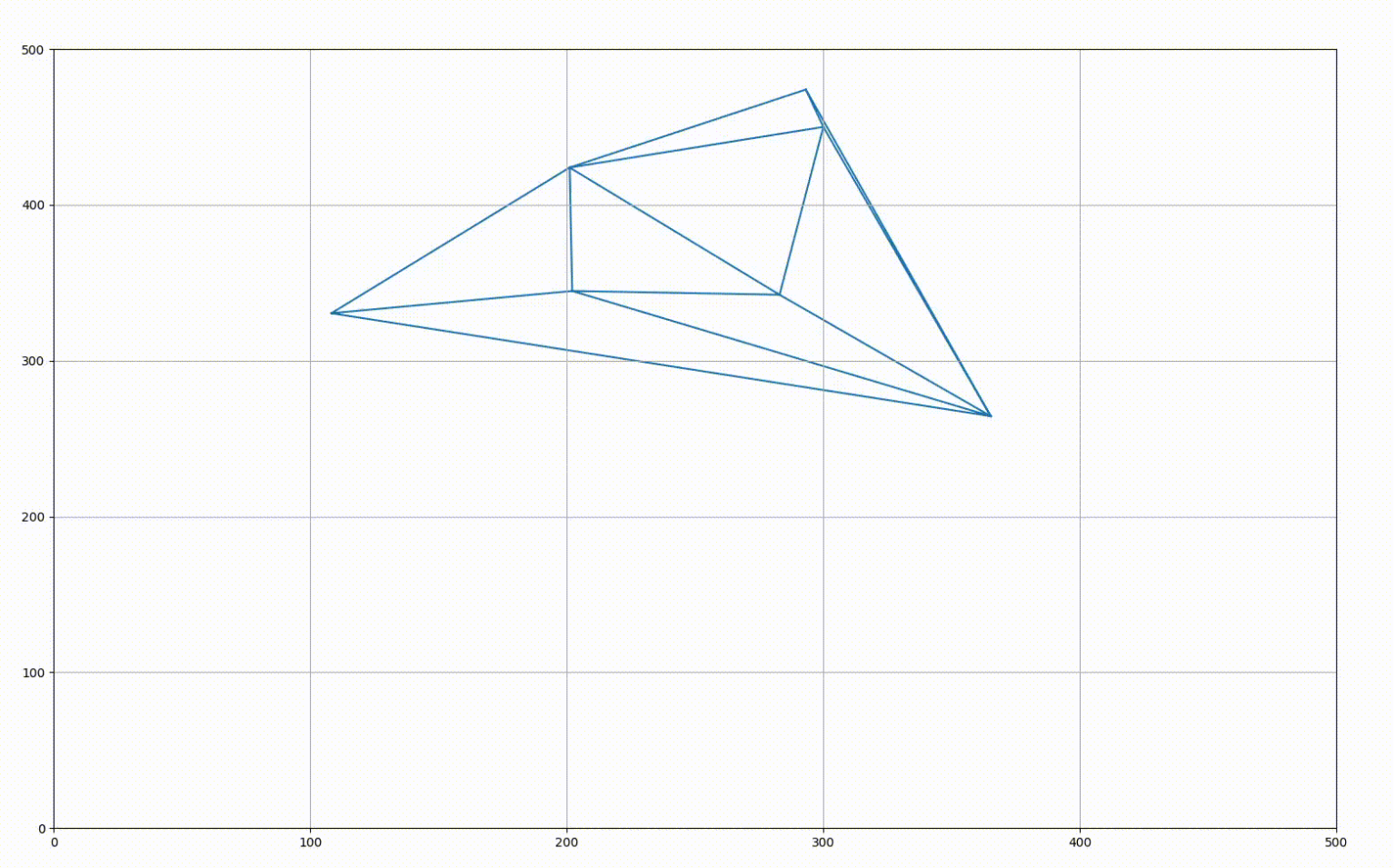
$$\begin{bmatrix} x_c \\ y_c \end{bmatrix} = \begin{bmatrix} \sum_{i=0}^{i=n} x_i/n \\ \sum_{i=0}^{i=n} y_i/n \end{bmatrix}$$



Delaunay Triangulation

- No point is inside the circumcircle of any triangle
- Maximize the minimum angle of all the angles of the triangles in the triangulation
- Tend to avoid sliver triangles
- For a set of points on the same line there is no Delaunay triangulation

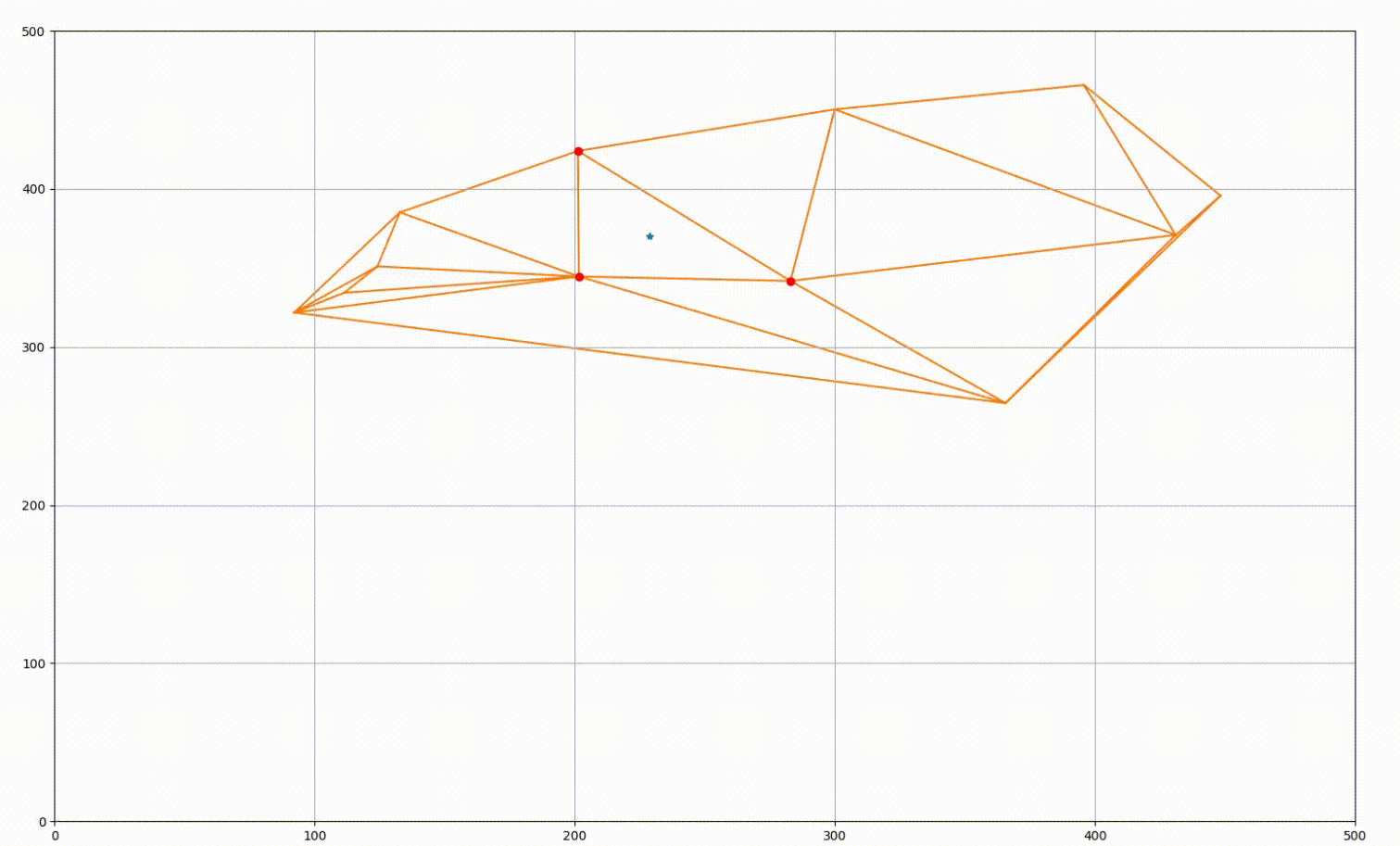




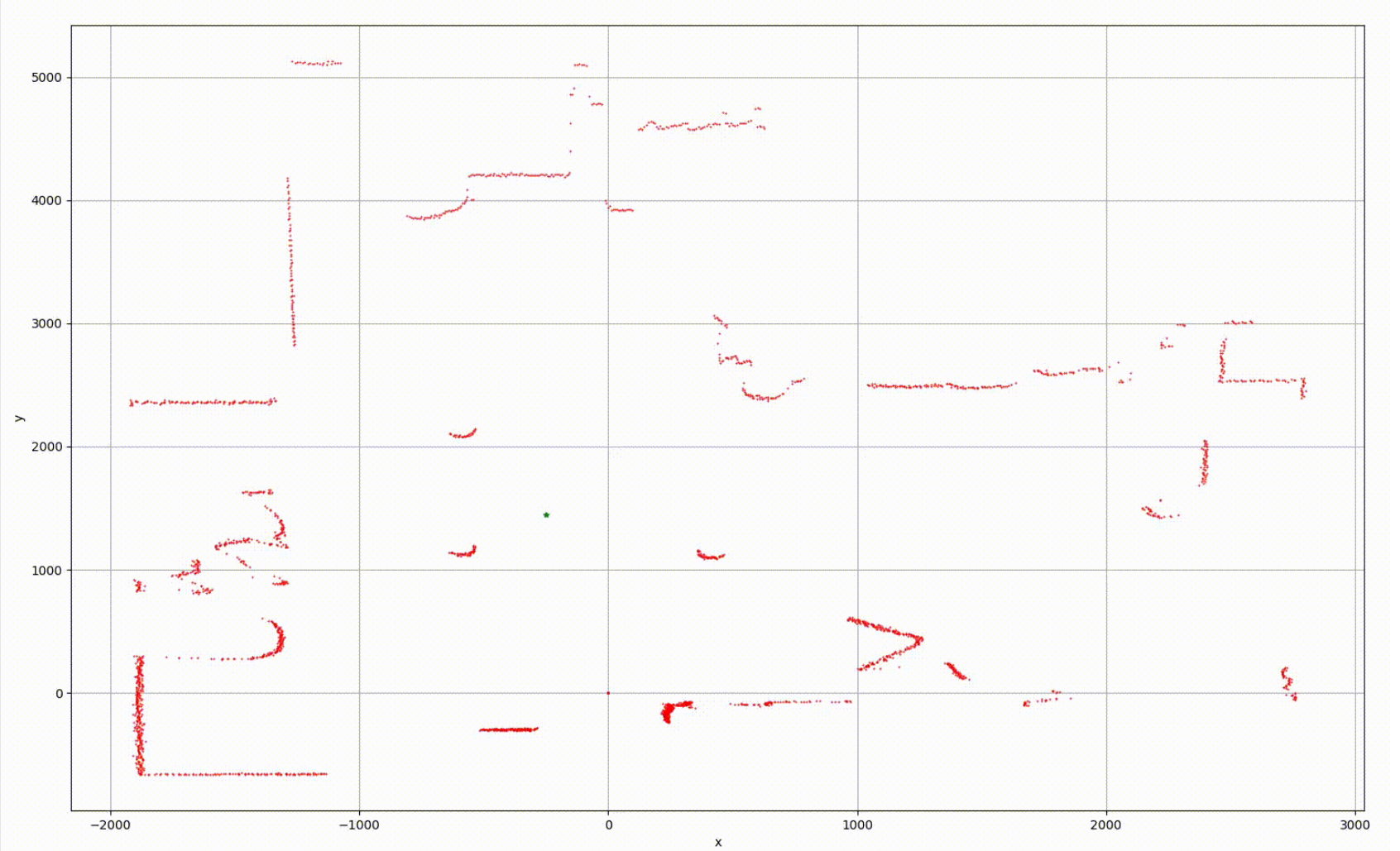
Detecting markers

- Selecting triangle with calculated edge lenght with selected accuary
- Calculeting station position

$$\left[\frac{x_0 + x_1 + x_2}{3}, \frac{y_0 + y_1 + y_2}{3}\right]$$



Final result



Rigid transformation

```
 RMSE: 55.74432756108732
Translation:
 [[ 2.65124334]
 [-1.21126795]]
Rotation:
 [[ 9.99999849e-01 -5.49895361e-04]
 [ 5.49895361e-04  9.99999849e-01]]
cos: 0.031506684933540016, sin: -0.031506684920149894, 0.0005498953882451662 , 0.00054989538
78730726

 RMSE: 56.12467558488027
Translation:
 [[ 3.36876696]
 [-1.60827462]]
Rotation:
 [[ 9.99999763e-01 -6.89087692e-04]
 [ 6.89087692e-04  9.99999763e-01]]
cos: 0.03948181962505932, sin: -0.03948181958828147, 0.0006890877464941048 , 0.0006890877468
135685

 RMSE: 71.69371630426298
Translation:
 [[ 1.42111127]
 [-3.23835918]]
Rotation:
 [[ 9.99999997e-01  7.89933902e-05]
 [-7.89933902e-05  9.99999997e-01]]
cos: 0.004525987696407521, sin: 0.00452598787270499, -7.899339028409043e-05 , 7.899338720706
477e-05

 RMSE: 56.80210352534091
Translation:
 [[ 2.16789014]
 [-2.92695004]]
Rotation:
 [[ 9.99999986e-01 -1.70132492e-04]
 [ 1.70132492e-04  9.99999986e-01]]
cos: 0.00974787371648765, sin: -0.009747873802155077, 0.0001701324929163834 7 , 0.00017013249
207388953

 RMSE: 70.76734489891864
Translation:
 [[ 2.27999421]
 [-3.49303503]]
Rotation:
 [[ 9.99999993e-01 -1.18979572e-04]
 [ 1.18979572e-04  9.99999993e-01]]
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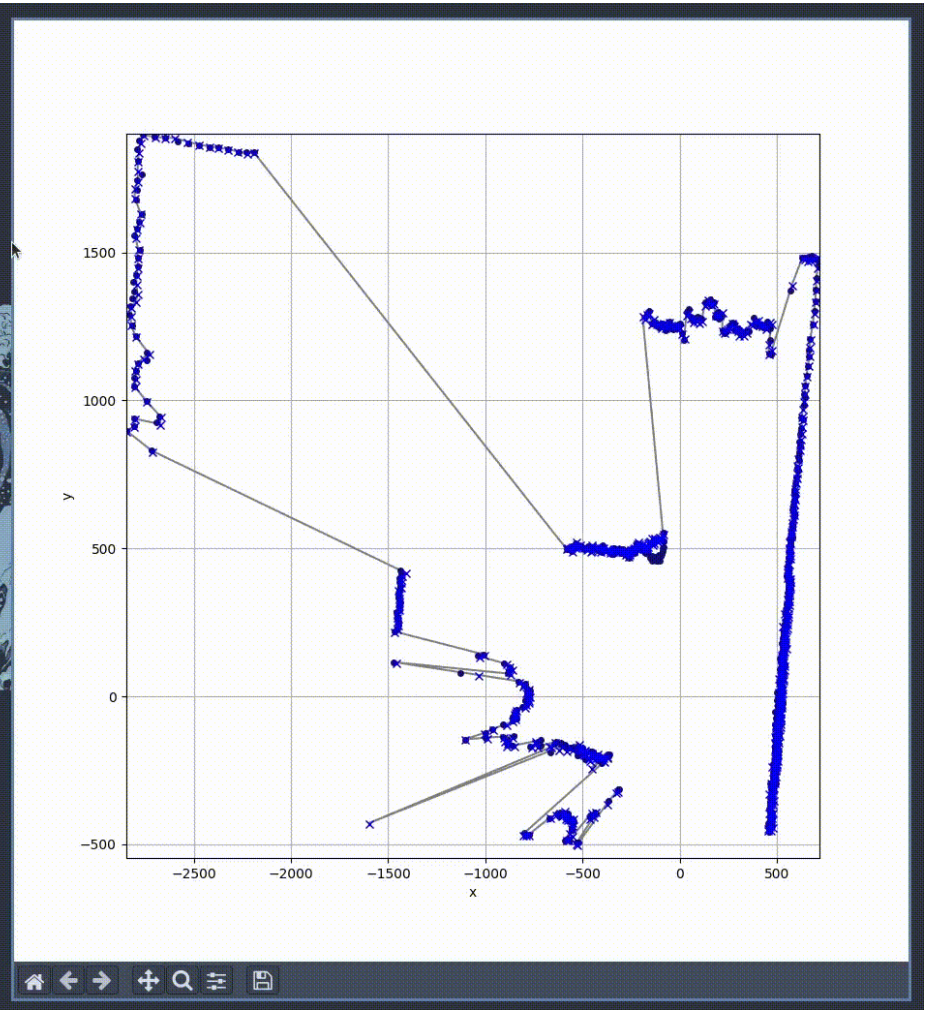
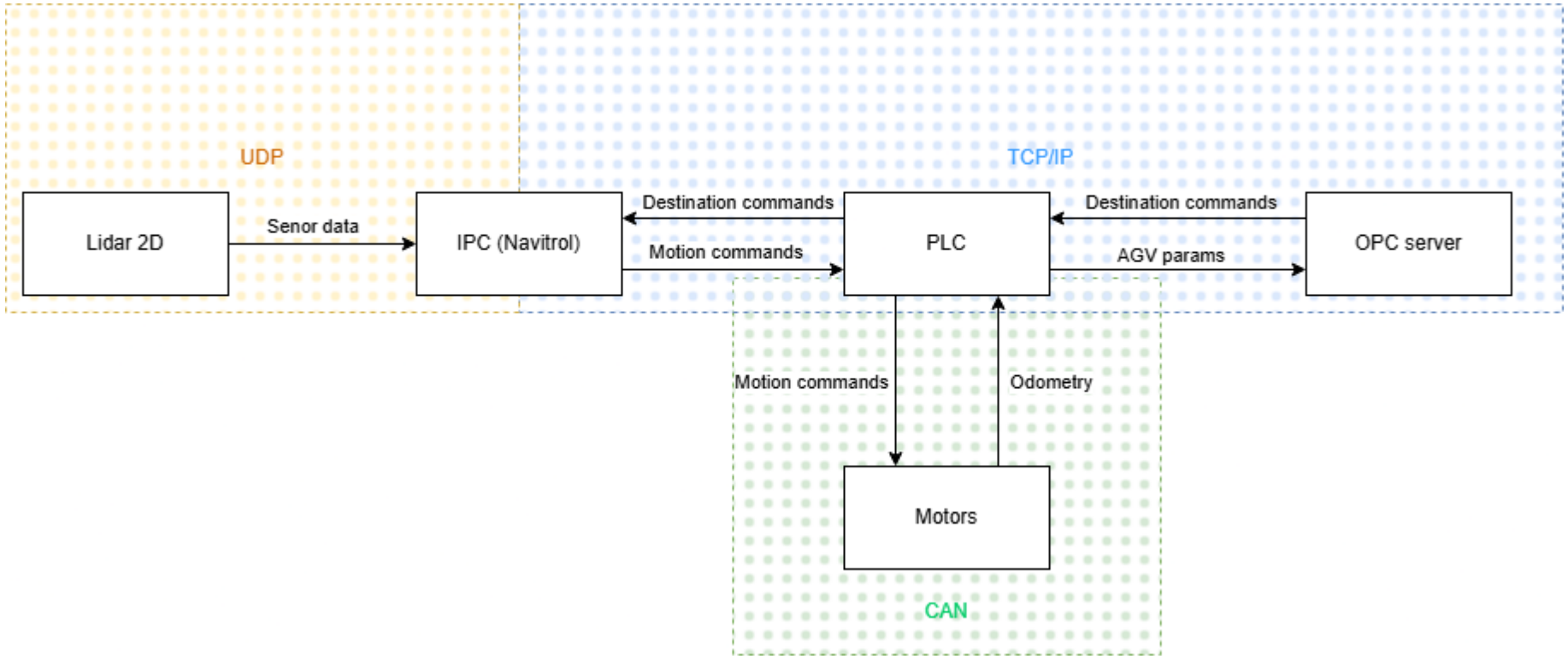


AGV data


UDP
TCP/IP
Lidar 2D
Senor data
IPC (Navitrol)
Destination commands
Motion commands
PLC
Destination commands
AGV params
OPC server
Motion commands
Odometry
Motors
CAN

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AGV Data

Operational Mode Indicators

Data Field	Description
Manual Mode Active	Indicates operator control
Automatic Mode Active	Machine runs autonomously
Docking Mode Active	System in docking procedure
PLC Fault Active	Fault detected in PLC
PLC Warning Active	Warning present but operation continues
Safety Circuit Closed	Safety circuit intact and closed

LED and Visual Indicators

Data Field	Description
LED Active	Master indicator light
LED RGB Strip left/right (red, green, blue)	RGB values for each LED strip
LED status – active mode	Which LED pattern corresponds to current mode

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Motion & Performance Data

Data Field	Description
ActualSpeed_L / ActualSpeed_R	Speed of left/right motor wheels
Momentary current consumption (mA)	Real-time current draw
Battery cell voltage	Current voltage per cell
Momentary energy consumption (mWh)	Energy usage snapshot
Total energy consumption (µWh)	Cumulative energy use
State Of Charge	Battery charge percentage

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Navigation and Route Data

Data Field	Description
On route status	Whether the vehicle is following a route
X-coordinate / Y-coordinate	Position on map or workspace
Heading	Orientation (in degrees/radians)
Position confidence	Reliability of localization
Speed	Linear speed of the vehicle
Going to ID	Identifier of current target destination
Target reached	Flag indicating arrival
Current segment	Path segment being traveled

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JAKUB MUSIAŁ

JAKUB.MUSIAL@POLSL.PL

aiut SP. Z O.O.