Modeling and understanding LiDAR data for absolute and relative positioning

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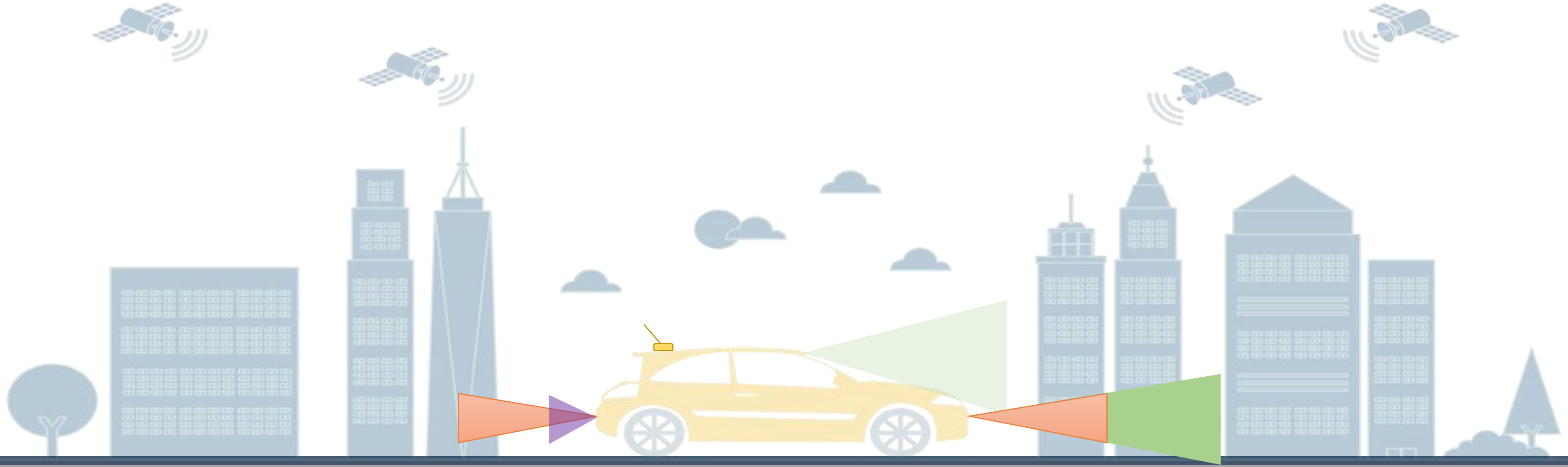
Outline

- Introduction
- Absolute positioning
- Relative positioning
- Practical case
- Conclusions
- Future work

Introduction I

Precise localization in autonomous driving

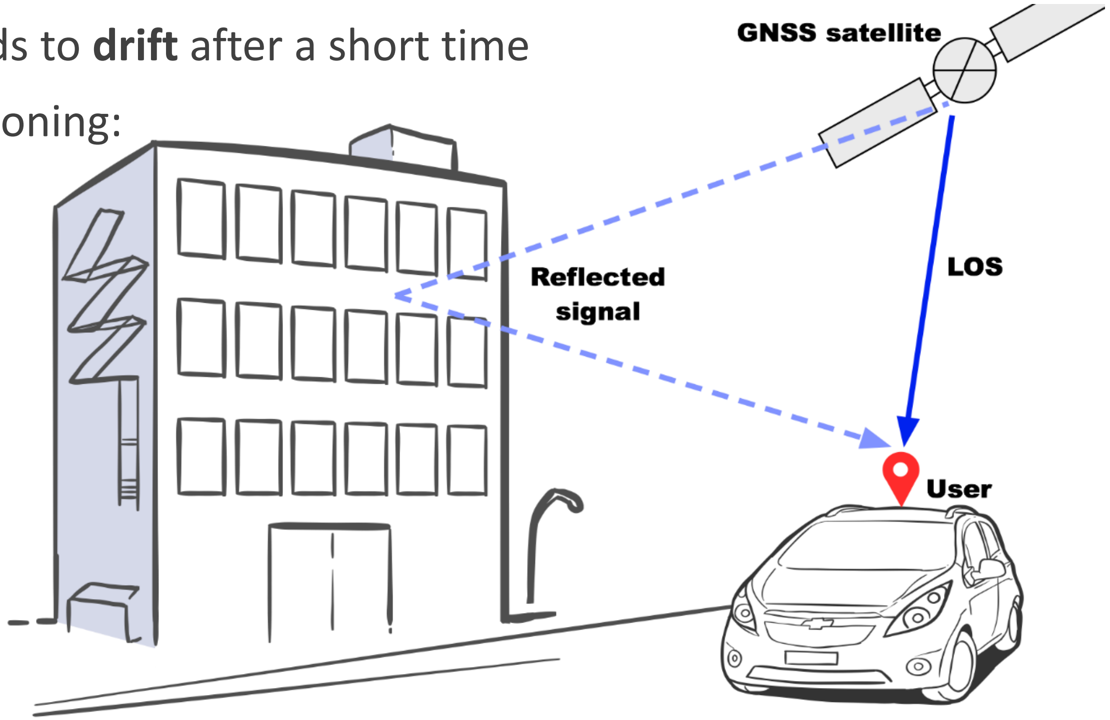
- Robustness to driving assistance functions (adaptive cruise control, intelligent speed adaptation)
- Aids safety features as collision avoidance
- Intended to be used for controlling and improving traffic conditions
- Opens the possibility to offer position based services (road tolling, fleet management)



Introduction II

GNSS-INS systems

- **Error sources**: satellite clocks, orbit errors, tropospheric delays, multipath.
- Mitigation of errors through **correction data services** (fee based)
- Problems that cannot be avoided: **Line of sight**
- **IMU** may support the navigation, but the solution tends to **drift** after a short time
- One must rely on other sensors that can provide positioning:
  - Cameras
  - RADAR
  - **LiDAR**
  - among others



Introduction

III

LiDAR

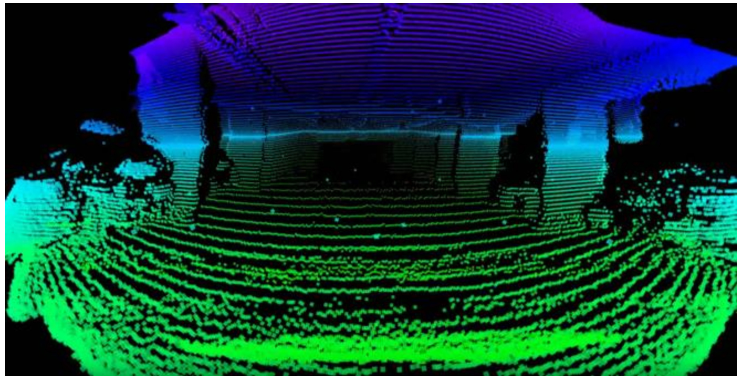


Image taken from Blickfeld

Advantages
- Direct range measurements to work with
- Independent of light conditions
- Solid state LiDARs are starting to be available to the market :
  - ✓ Cheaper
  - ✓ No moving mechanical parts (no offsets)
  - ✓ Smaller, suitable for autonomous cars as they can esthetically be integrated.

Weaknesses
- It has a low resolution in the vertical component, which is not favorable for object detection as few lines may intercept an object. Unless a bulky LiDAR is being used that supports several channels.
- It is important to notice that this is changing as new startups are emerging offering new solutions.
- Storage requirements
- Weather can impact data collection

Camera

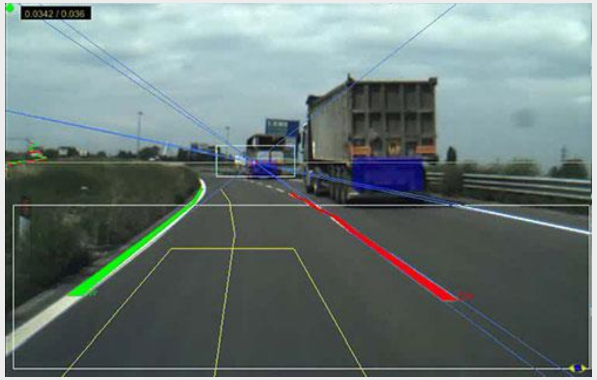


Image taken from FLIR machine vision

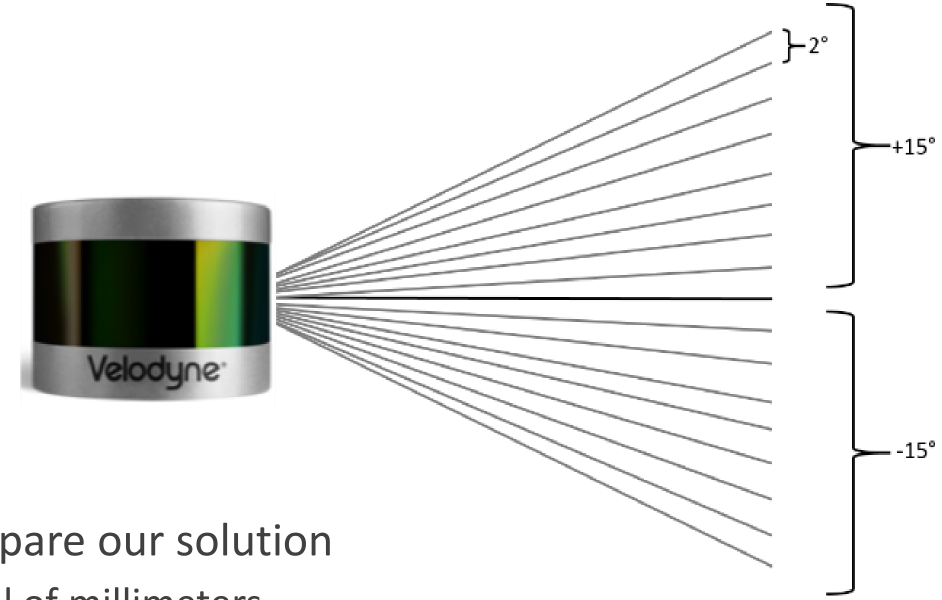
Advantages
- It is a pretty mature technology as well as the algorithms developed for its data
- Cheap

Weaknesses
- It may be cheap but also requires a lot of effort in the algorithms to obtain something.
- The processing time is important to consider in RT applications.
- Dependent of light conditions

Absolute positioning

Approach

- Give the LiDAR point clouds an absolute position and the correct orientation
- Sensors used in this process: GNSS receiver antenna Trimble R10, MEMS IMU Xsens Mit-G-710, Velodyne Puck VLP-16
- Main outcome: High precise 3D reference models

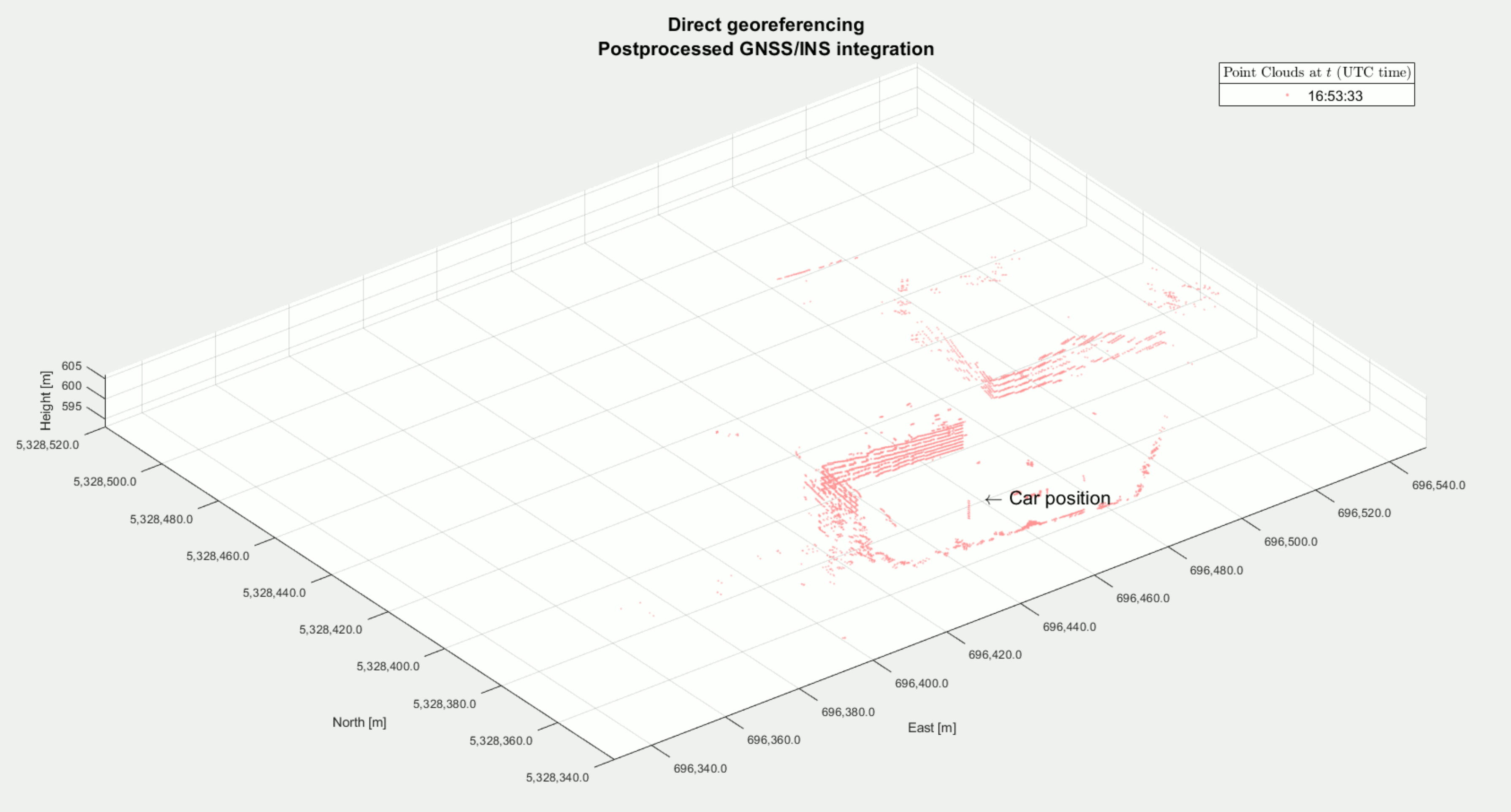


Assess the quality of the results

- Use a reference system like a Multistation MS60 to compare our solution
  - Precise long range scanning with range accuracy in the level of millimeters
  - Most precise solution for terrestrial scanning (e.g. Architectural modelling)

Absolute positioning II

Give the LiDAR point clouds an absolute position

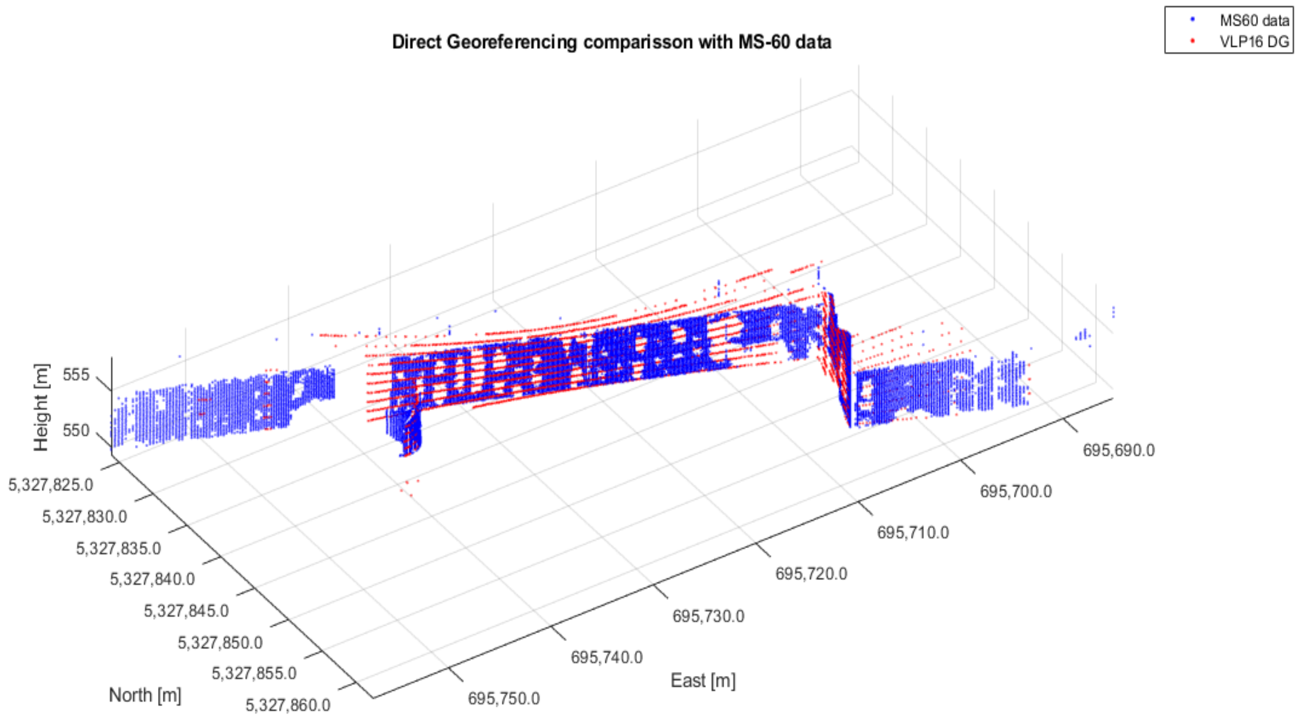


Absolute positioning III

How accurate is it?

Absolute positioning

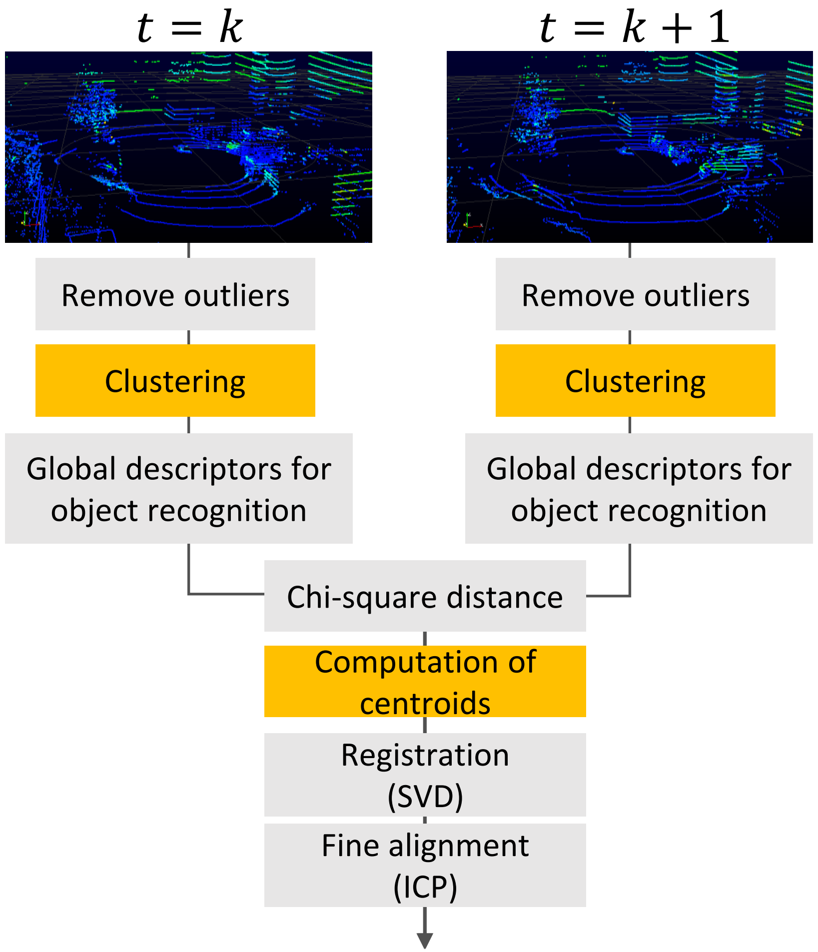
IV



Filtered point clouds belonging to the VLP-16 and the reference system MS60

Perspective	East error [cm]	North error [cm]	Roll [deg]	Pitch [deg]	Yaw [deg]
1	6.29	0.29	0.4762	0.5133	1.1443
2	2.44	5.24	0.7519	0.0129	1.7418
Mean error	**4.3**	**2.79**	**0.614**	**0.2631**	**1.443**

Relative positioning I



$t = k$

$t = k + 1$

Remove outliers

Clustering

Global descriptors for object recognition

Remove outliers

Clustering

Global descriptors for object recognition

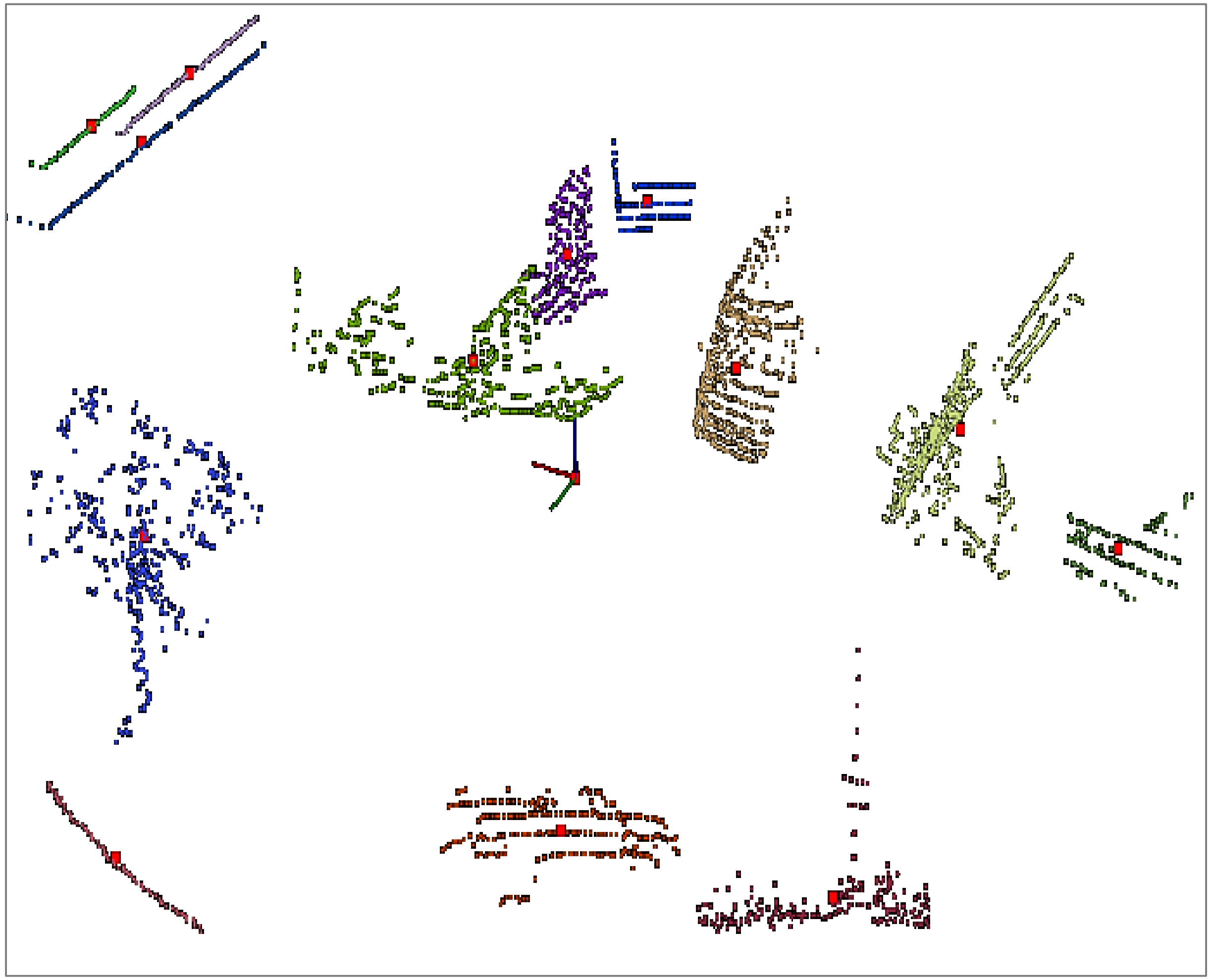
Chi-square distance

Computation of centroids

Registration (SVD)

Fine alignment (ICP)

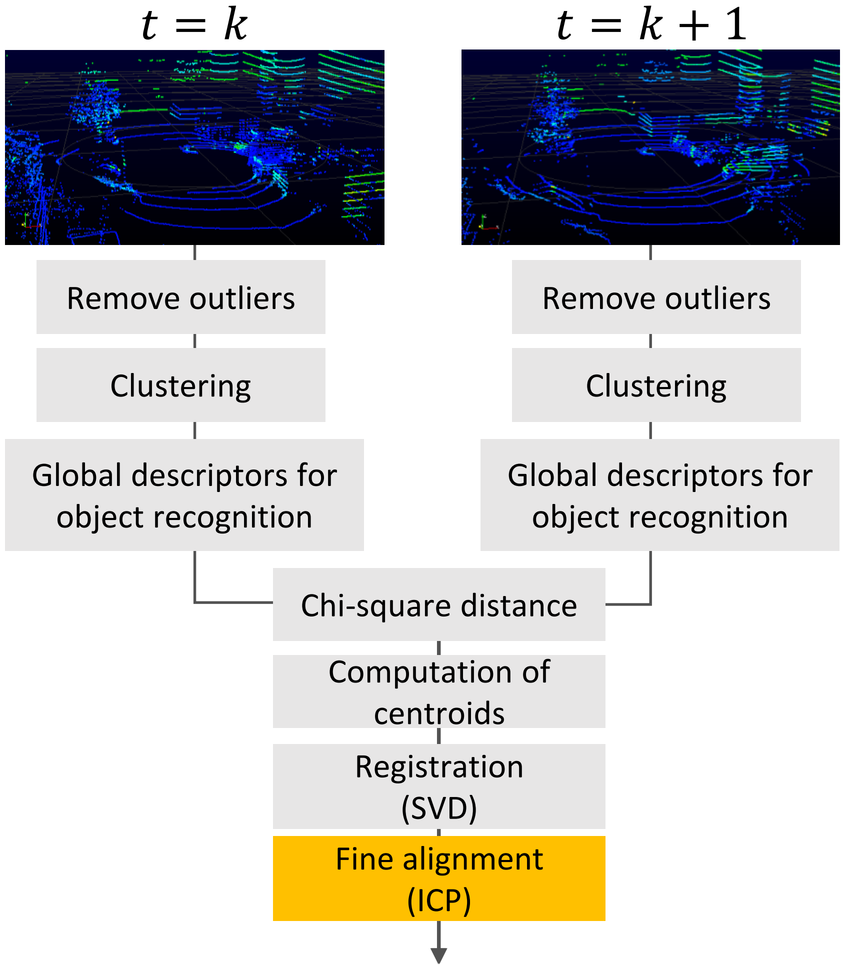
$$T = \begin{bmatrix} R_{ICP} R_{SVD} & R_{ICP} t_{SVD} + t_{ICP} \\ 0 & 1 \end{bmatrix}$$



Computed centroid (red dot) of each cluster. Each segmented object is shown in a different color

Relative positioning

II



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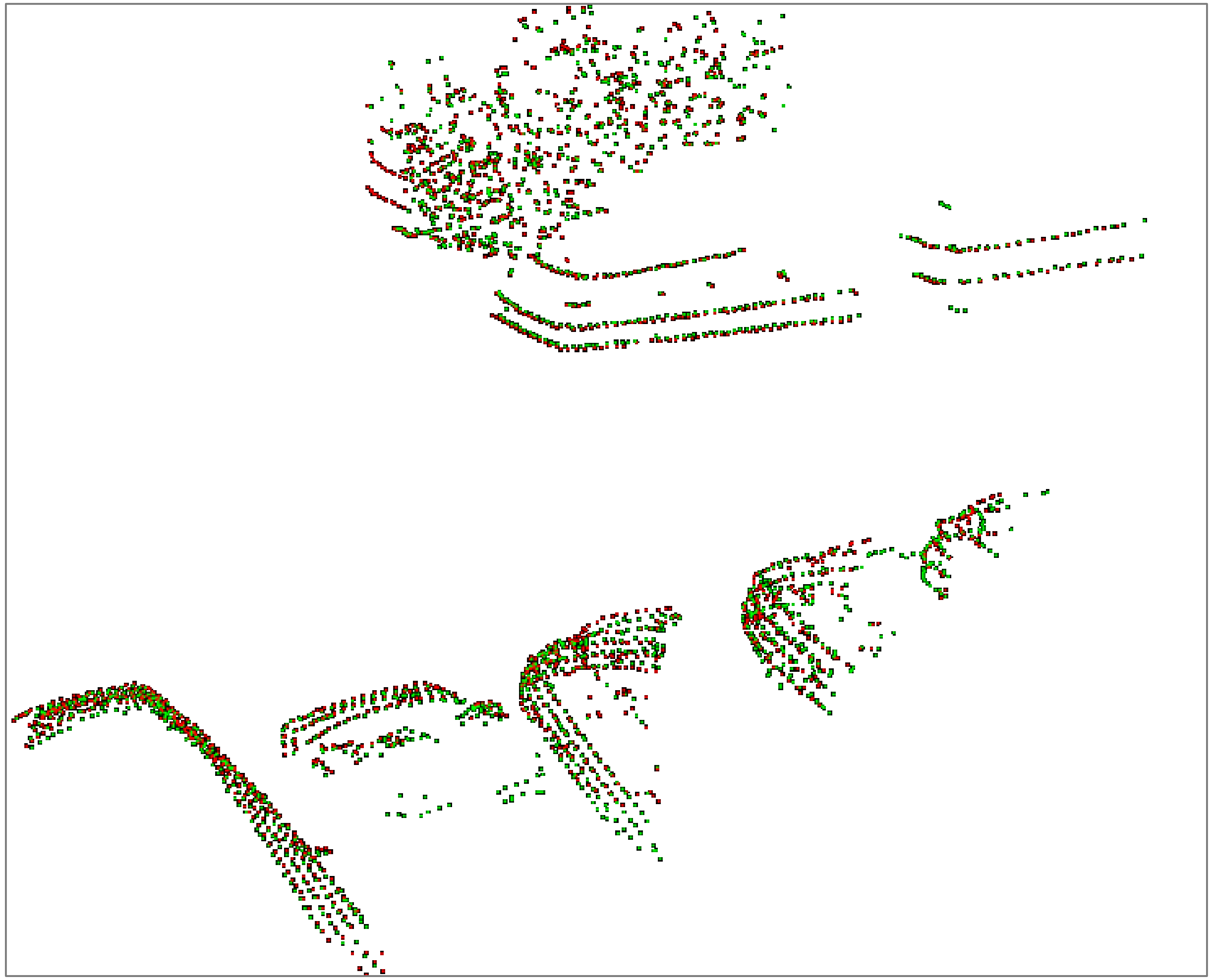
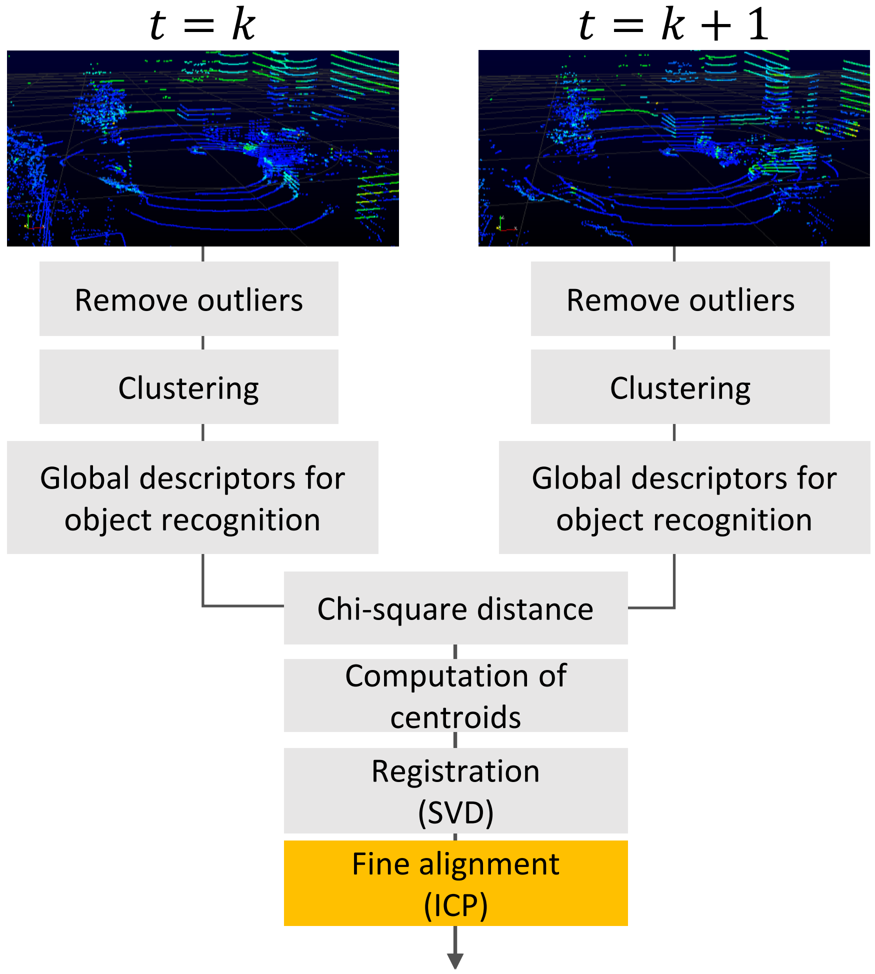


Point clouds final registration after coarse and fine alignments

Relative positioning III



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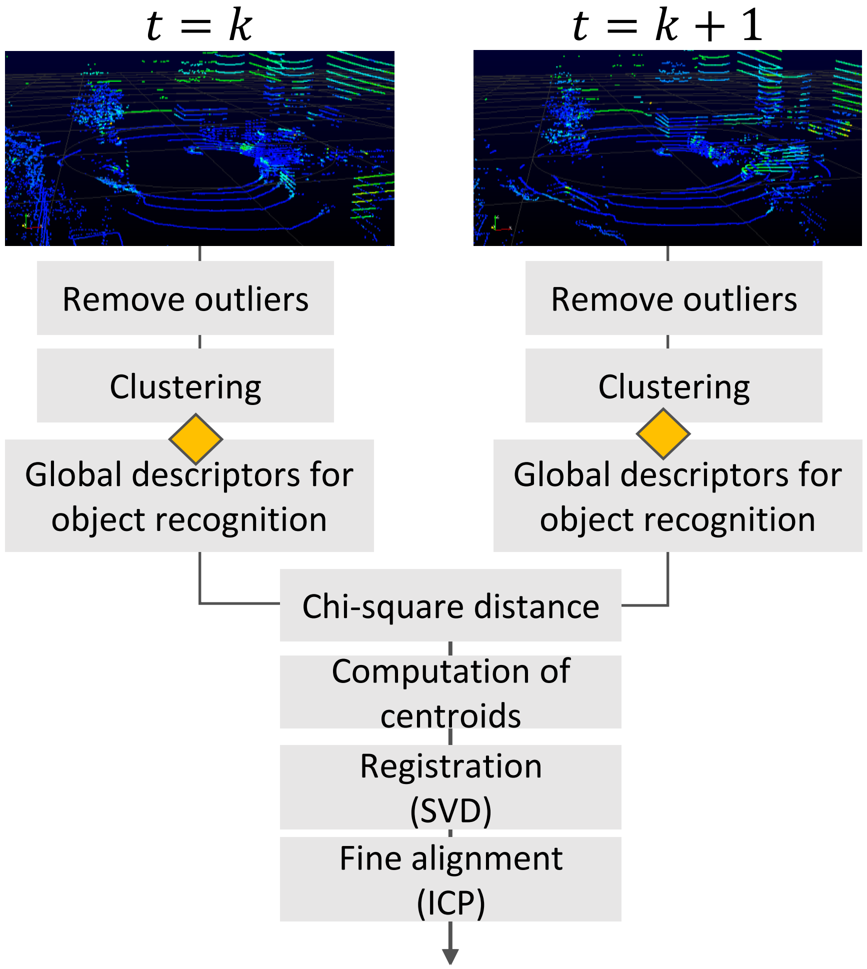
Sensor displacement between consecutive measurements

Relative positioning

IV



$t = k$

$t = k + 1$

Remove outliers

Clustering

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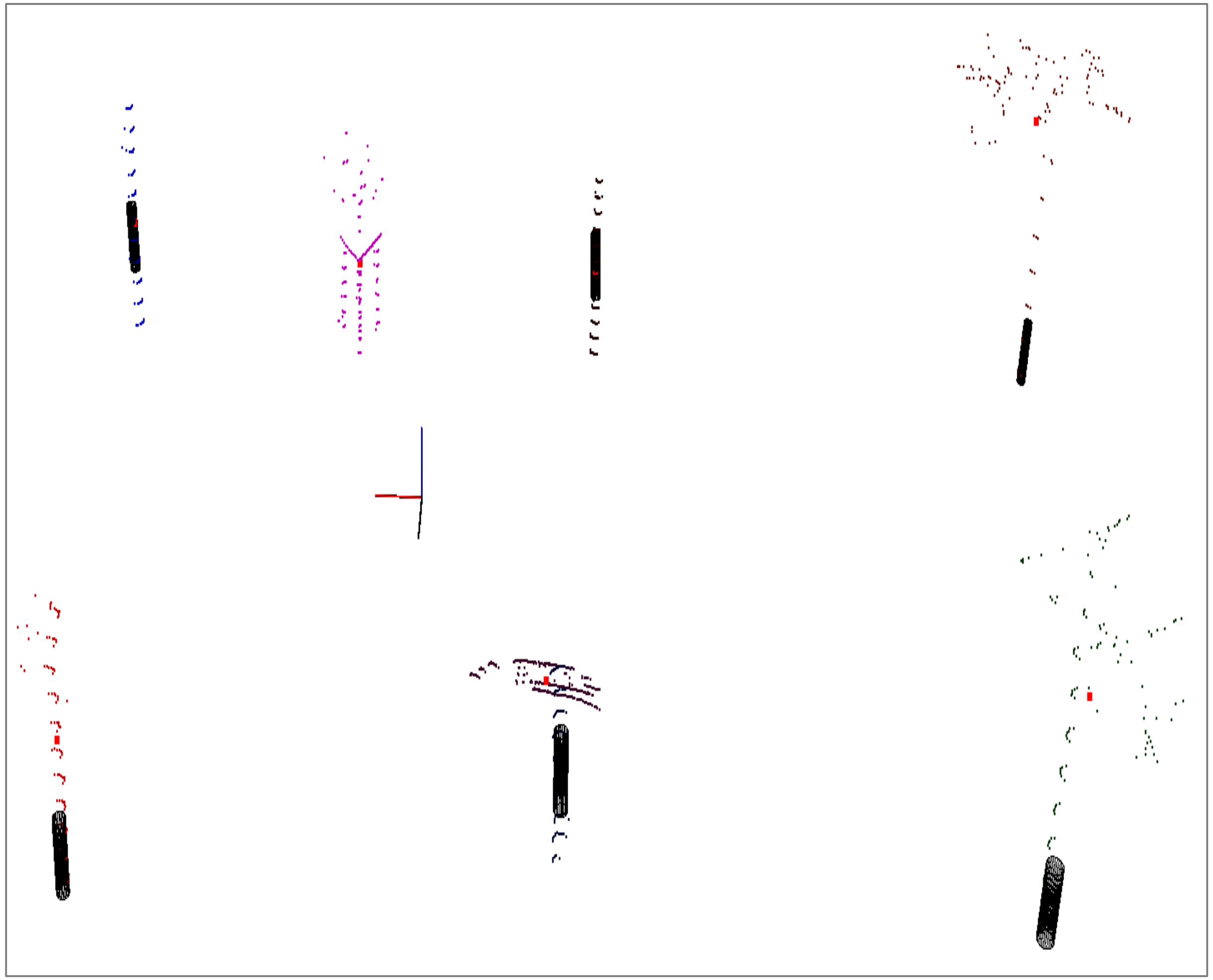
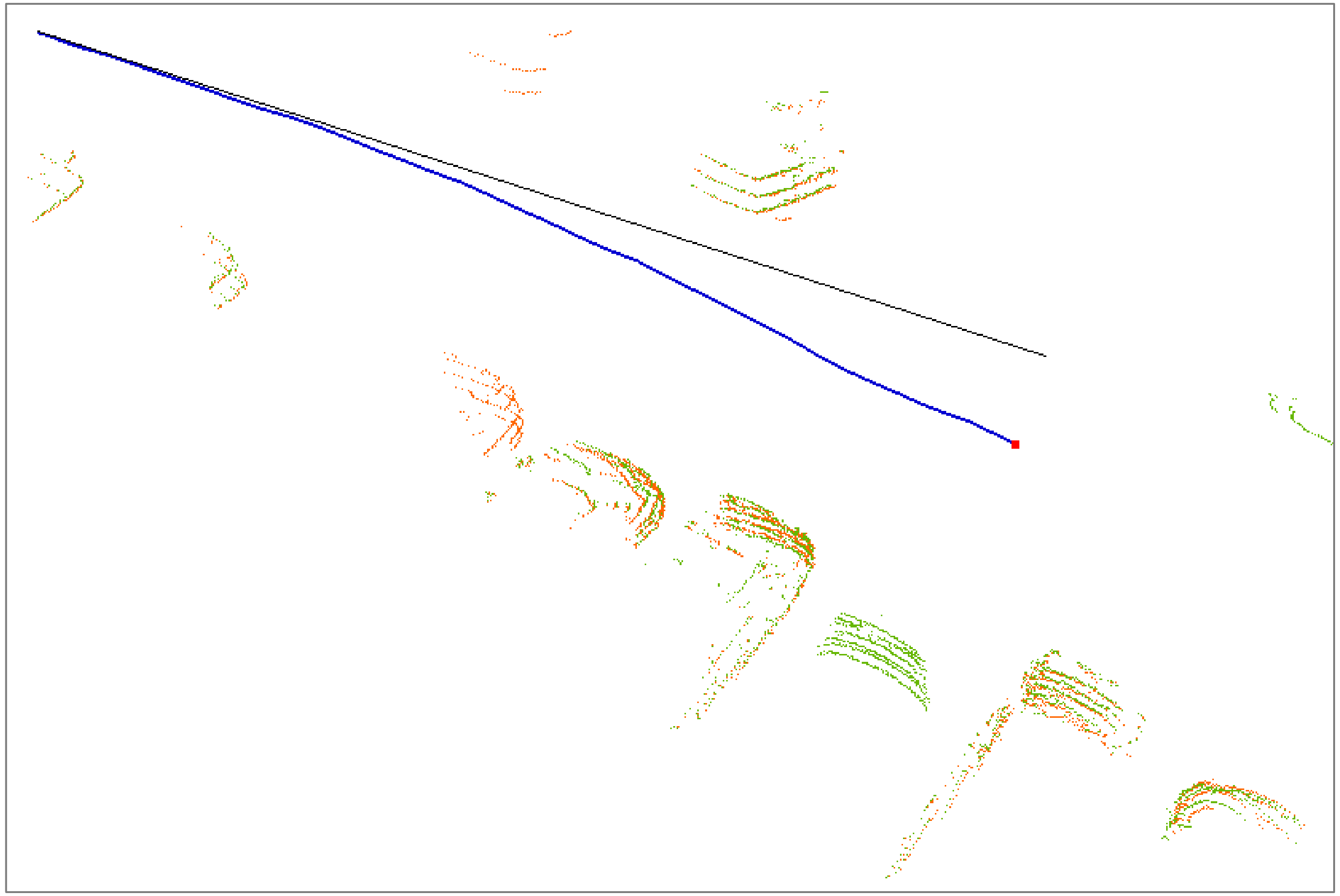


Detected cylinders from individual clusters

Relative positioning

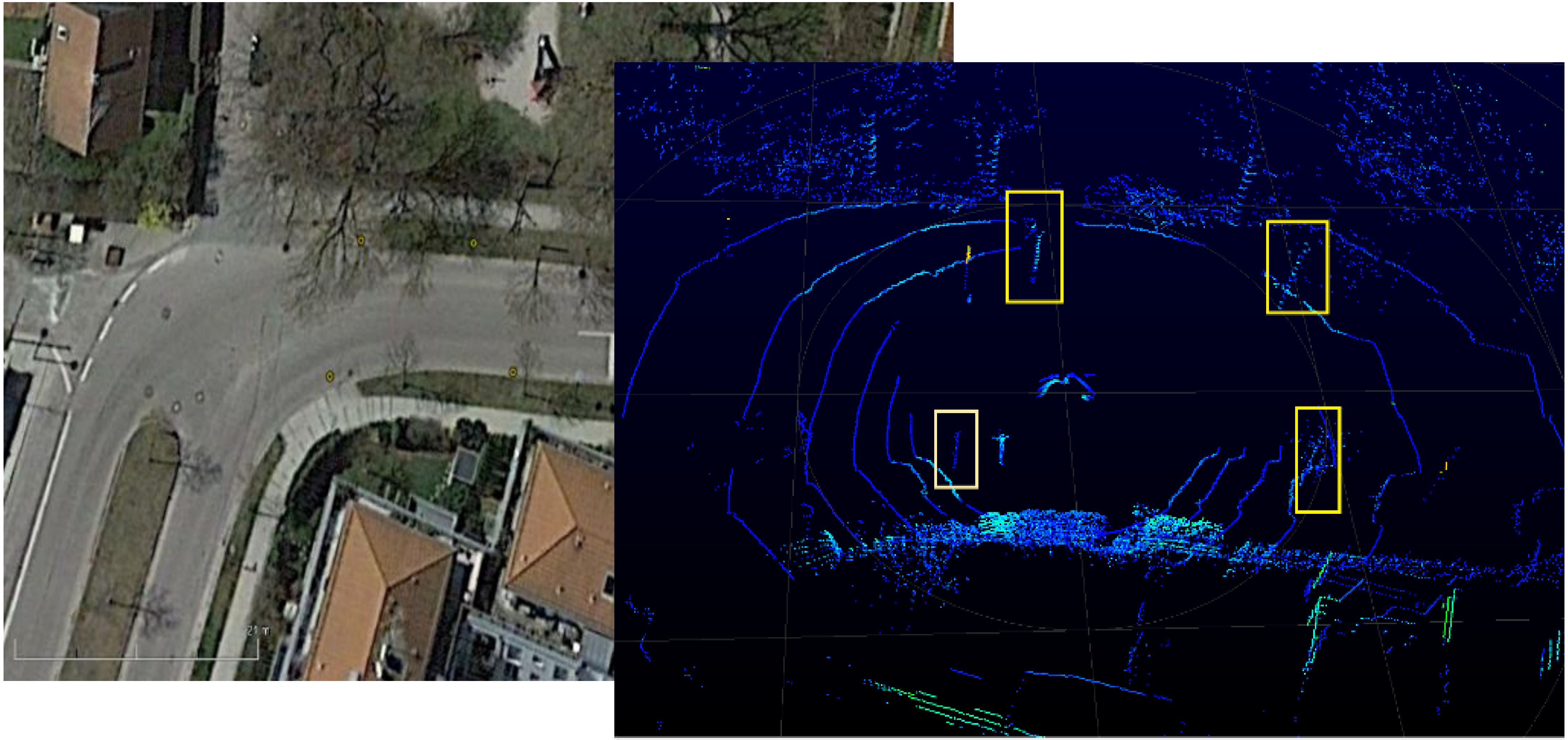
V

Vertical drift

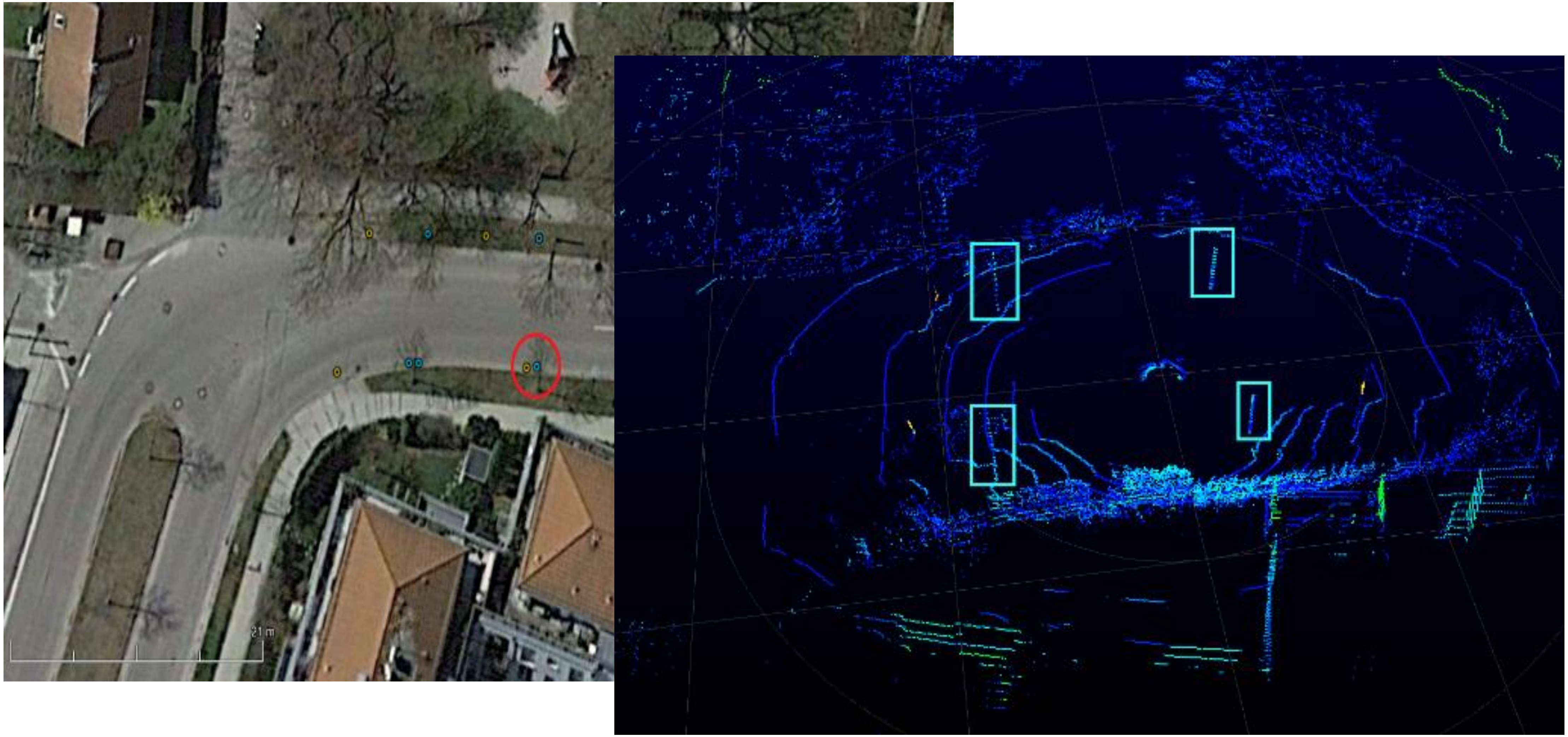


Vertical drift of LiDAR position after ca. 15-20 frames. The black line is the nominal path and the blue line is the actual path

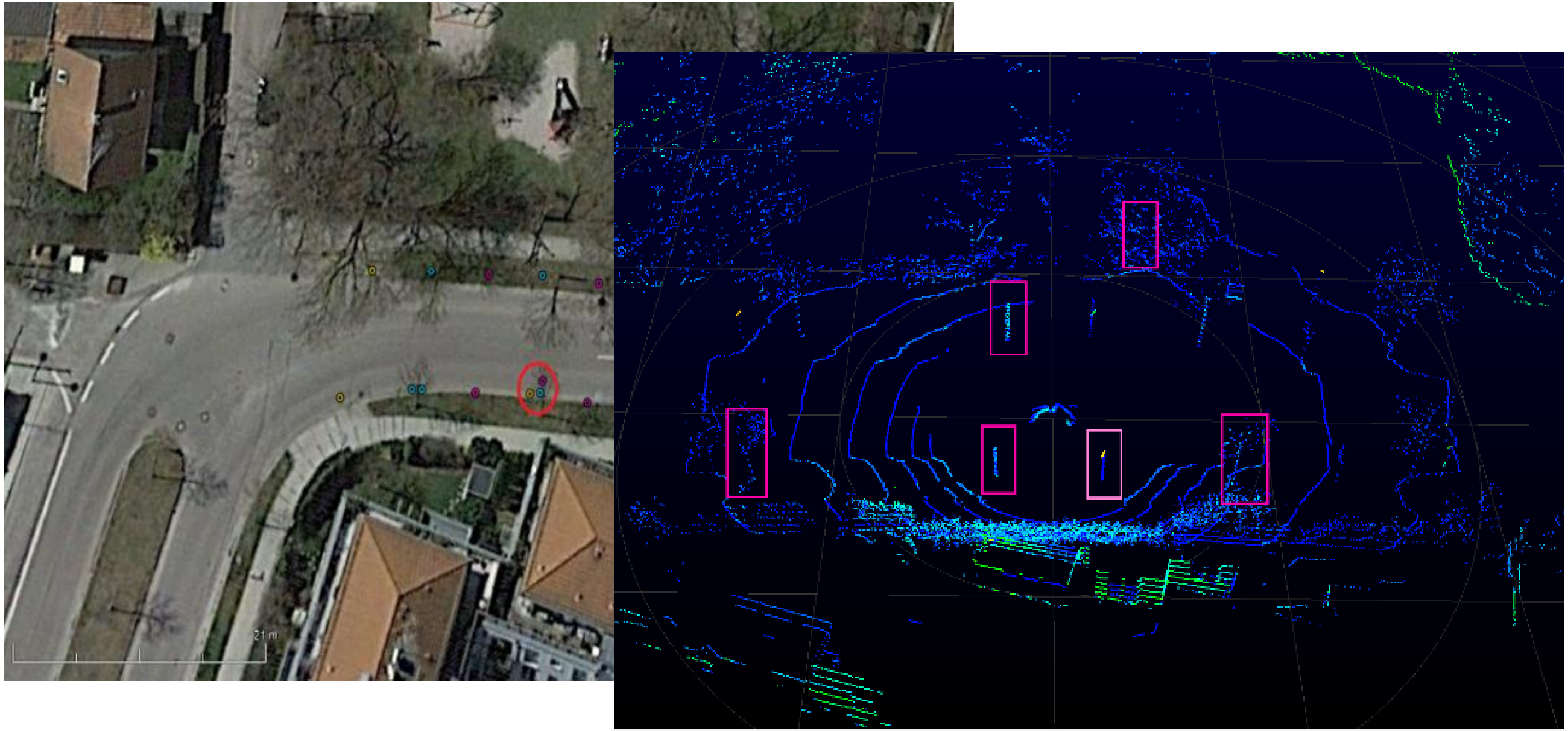
Practical case



Practical case II



Practical case



Conclusions

It has been proved a high accuracy of the geo-referenced point clouds when the conditions of the GNSS-INS system are advantageous.

- Geo-referenced data in RT offers unlimited services and possibilities (road quality information, accidents reconstruction, identification of damaged infrastructure, etc.)

When computing the displacement vector, a drift in the vertical component has been detected

It was possible to detect objects with cylindrical shape (trees, traffic signs, post lights)

A more intelligent approach to detect static objects that help the relative navigation algorithm must be inquired (i.e. machine learning with 3D data)

When the estimated error of the GNSS-INS position crosses certain threshold, one could use the displacement vector computed only from the LiDAR data to aid the computation of the car‘s absolute position.

Future work

Assess the quality of the computed car's absolute position using the displacement vector

Correction of the vertical drift by adding the floor detection

- through the same sensor or the close range LiDARs assembled in the front or the backside of the car

Interface development to our own developed GNSS-INS software receiver to test different integration architectures

Add mapping to our solution

Implement and test the new SS generation of LiDAR for autonomous driving

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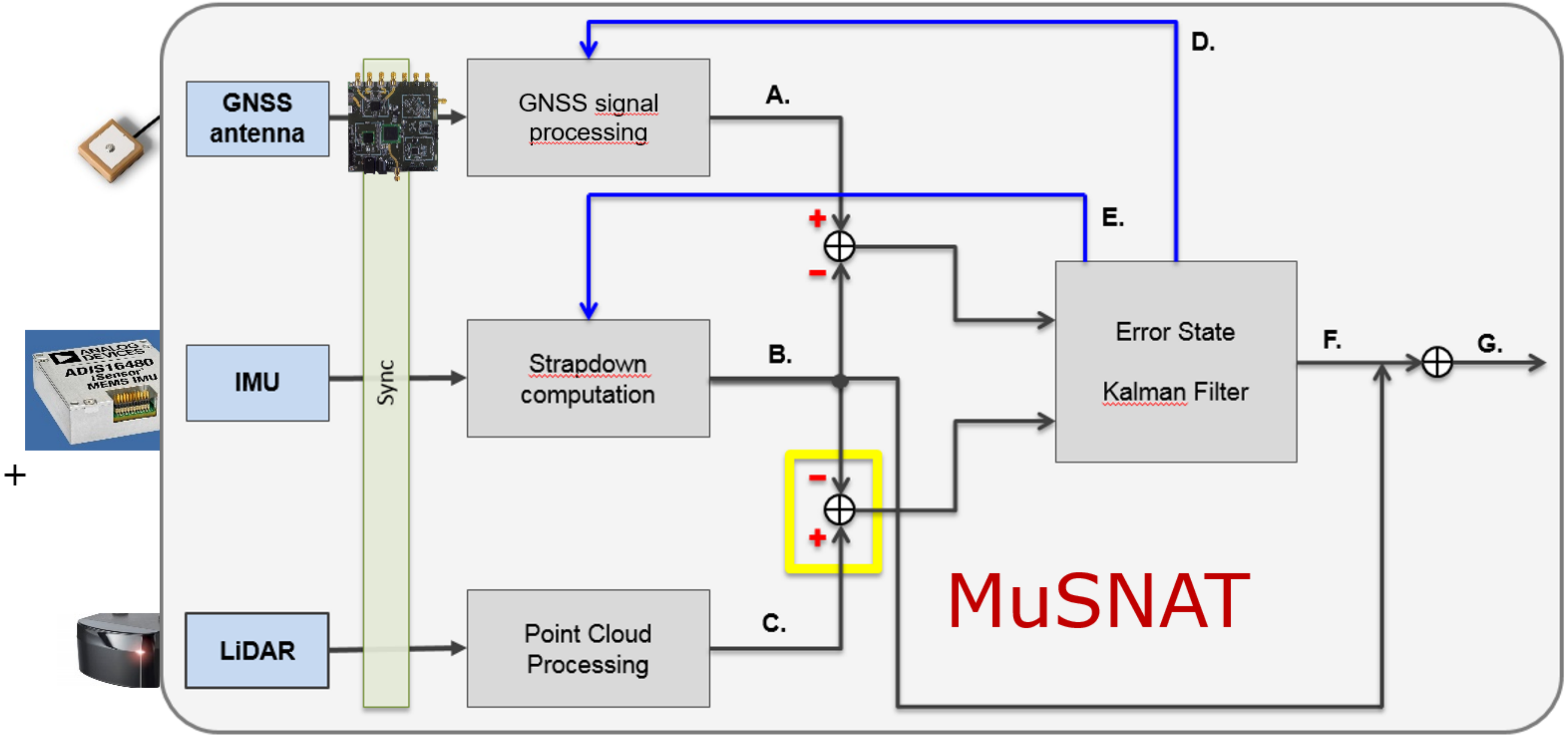
Additional material

GALILEO High Accuracy Service (HAS)

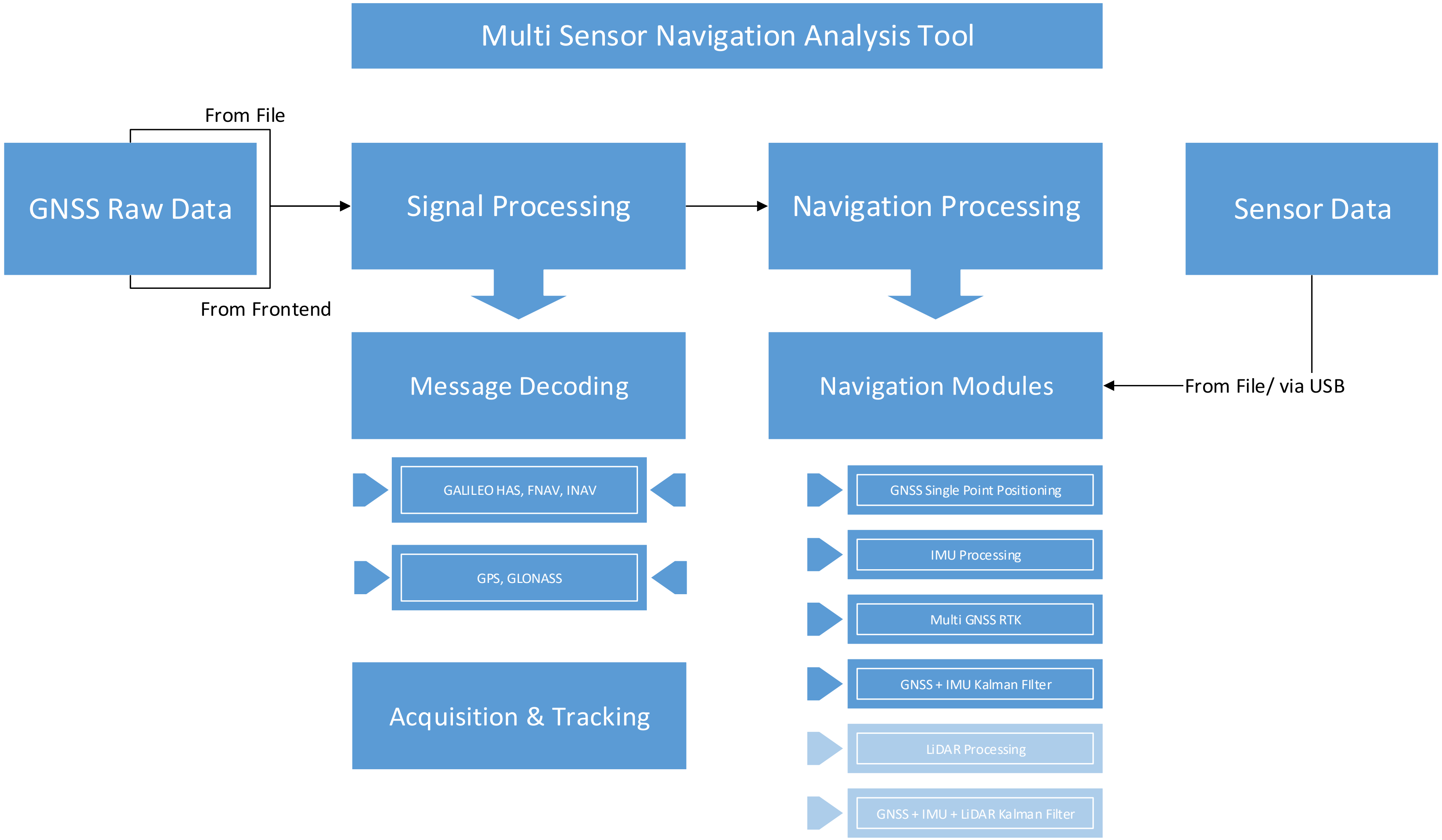
- **Service provided by GALILEO consisting of 2 channels E6-B and E6-C**
- **E6-B broadcasts correction data for Precise Point Positioning (PPP) for E1 and E5 open service signals**
  - Free of charge
- **E6-C will provide robust Position, Velocity and Time (PVT) by spreading code authentication**
- **High accuracy (below decimeter level) and high update rate (~30 secs) of correction parameters**
- **Currently under development, initial tests scheduled for early 2019**
- **Developed by ESA, overseen by the Working Group Commercial Service of the European Commission and the Member states (ISTA holds German mandate)**

Deep Sensor Fusion (GNSS, INS and LiDAR)



A. Position, code range, carrier and doppler; **B.** Position, velocity, attitude; **C.** Velocity, Dattitude**; D.** Feedback options: vector tracking, cycle slip corrections, synthetic aperture; **E.** Giro bias, acceleration

MuSNAT architecture



Multi Sensor Navigation Analysis Tool

GNSS Raw Data

From File

From Frontend

Signal Processing

Navigation Processing

Sensor Data

Message Decoding

- GALILEO HAS, FNAV, INAV
- GPS, GLONASS

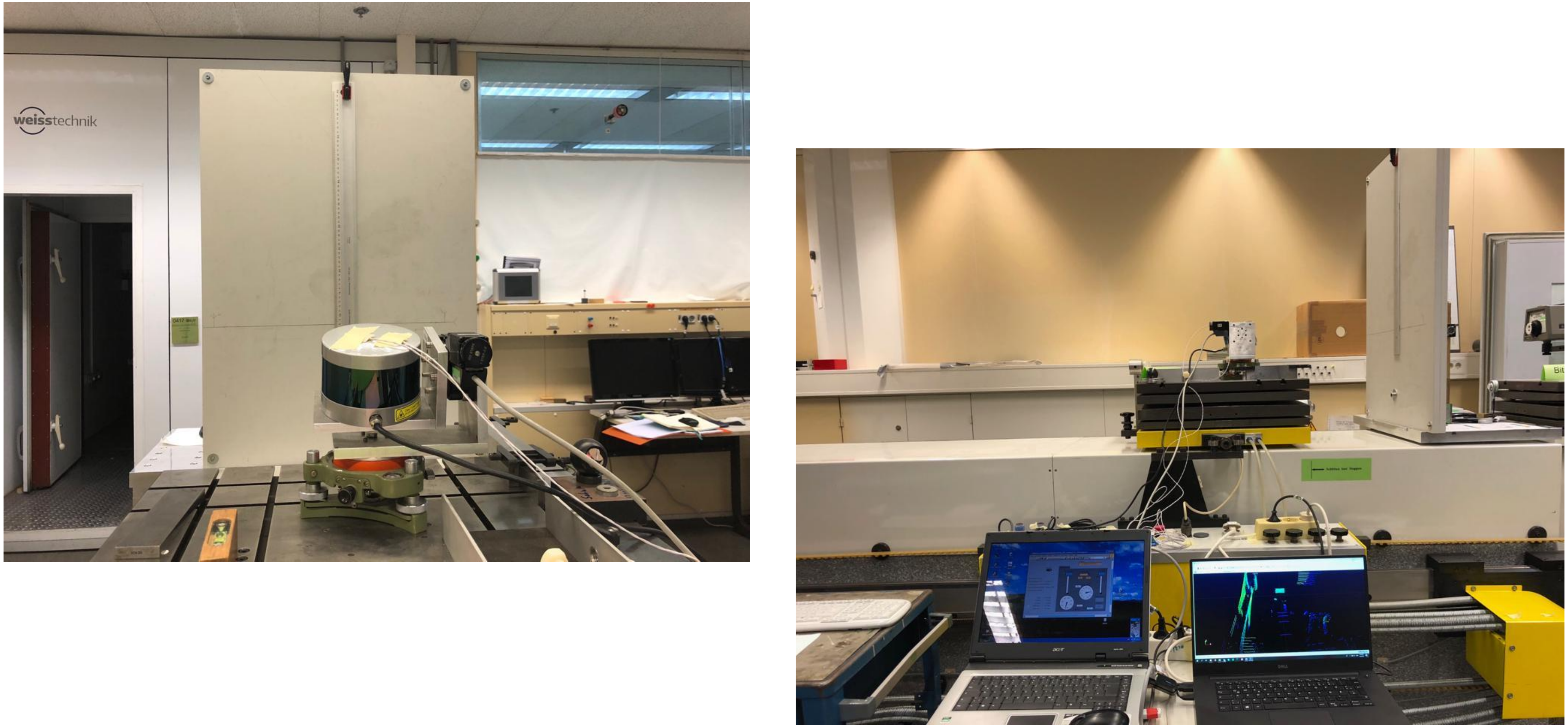
Acquisition & Tracking

Navigation Modules

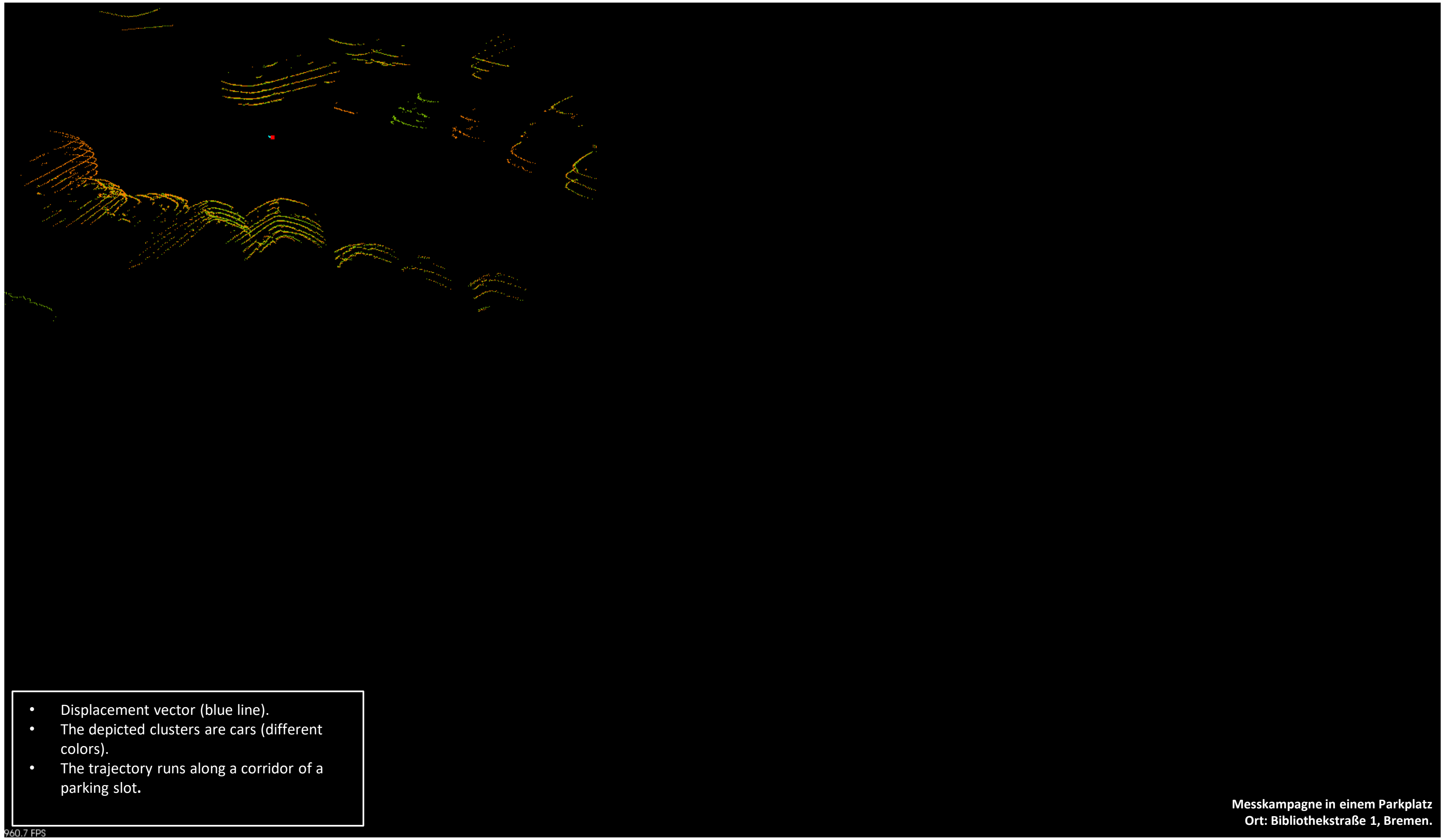
From File/ via USB

- GNSS Single Point Positioning
- IMU Processing
- Multi GNSS RTK
- GNSS + IMU Kalman FIlter
- LiDAR Processing
- GNSS + IMU + LiDAR Kalman Filter

VLP-16 Calibration



Relative navigation: displacement vector



- Displacement vector (blue line).
- The depicted clusters are cars (different colors).
- The trajectory runs along a corridor of a parking slot.

Messkampagne in einem Parkplatz
Ort: Bibliothekstraße 1, Bremen.

MS-60

Precise long-range scanning (up to 1000 m)

Millimeter scan precision

Wavelength 658 nm

Beam divergence 0.2 mrad x 0.3 mrad