From Ego to Eco-System: Perception & Sensor Fusion for Autonomous and Connected Mobility

11.11.2025 | Simone Mentasti

Me, myself, and I

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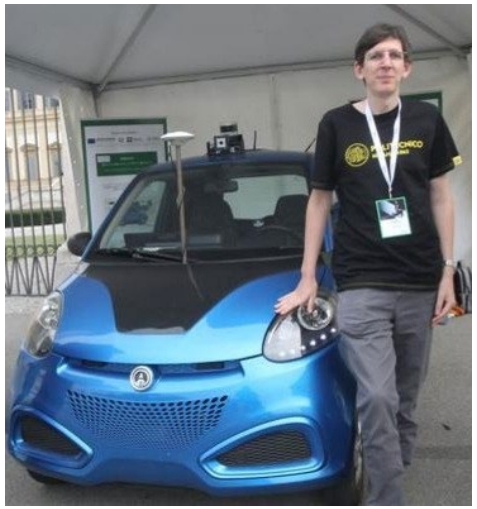


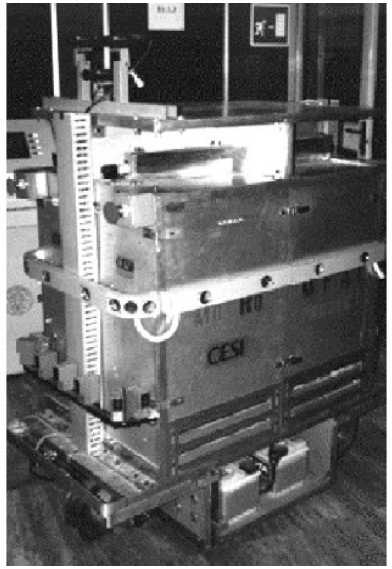
My research interests

- Mobile Robotics
- Autonomous Systems
- Computer Vision & Perception
- Deep Learning

Courses I tech

- Computer Science (BS)
- Robotics (BS + MS)

AIRLab @PoliMi



5 Full Professors
5 Ass. Professors
7 Researchers
44 PhD Students
18 Research Ass.

Contents

Autonomous Vehicles Perception

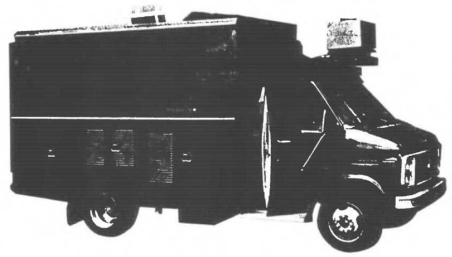
01

Autonomous Vehicles Perception

(Mostly line detection)

01

Autonomous vehicles timeline



ALVINN

1985

Darpa ALV

1988

1990

Sandstorm

2001

Sandstorm

2007

Stanford Racing Junior

2013

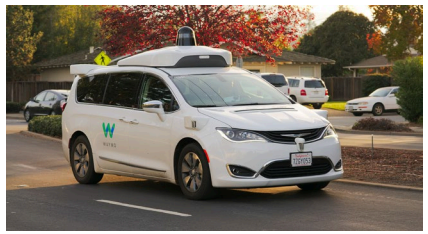
Nissan AV prototype

2015

Wyamo/google av

2020

Wyamo first public taxi

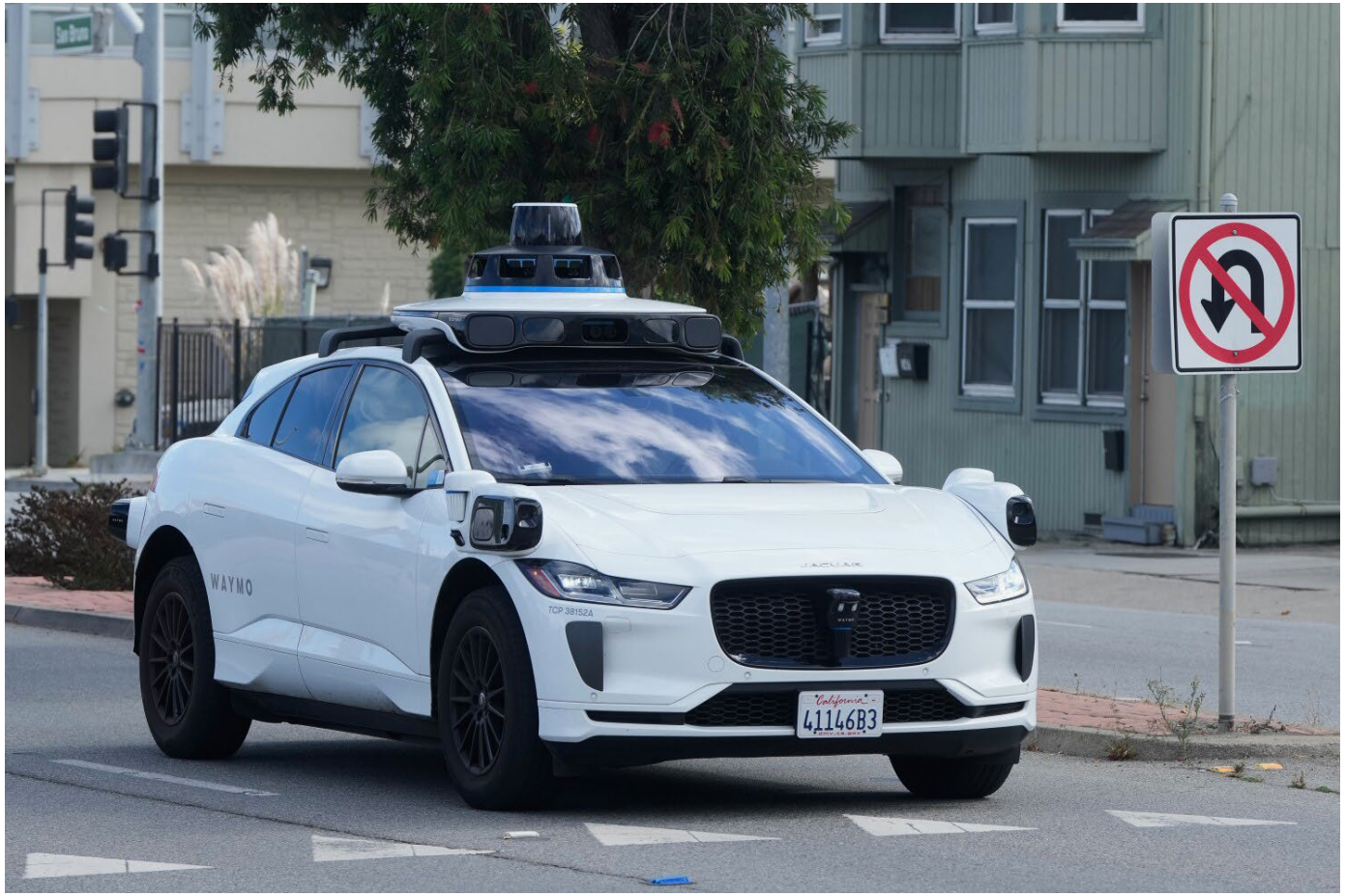


2021

Indy autonomous

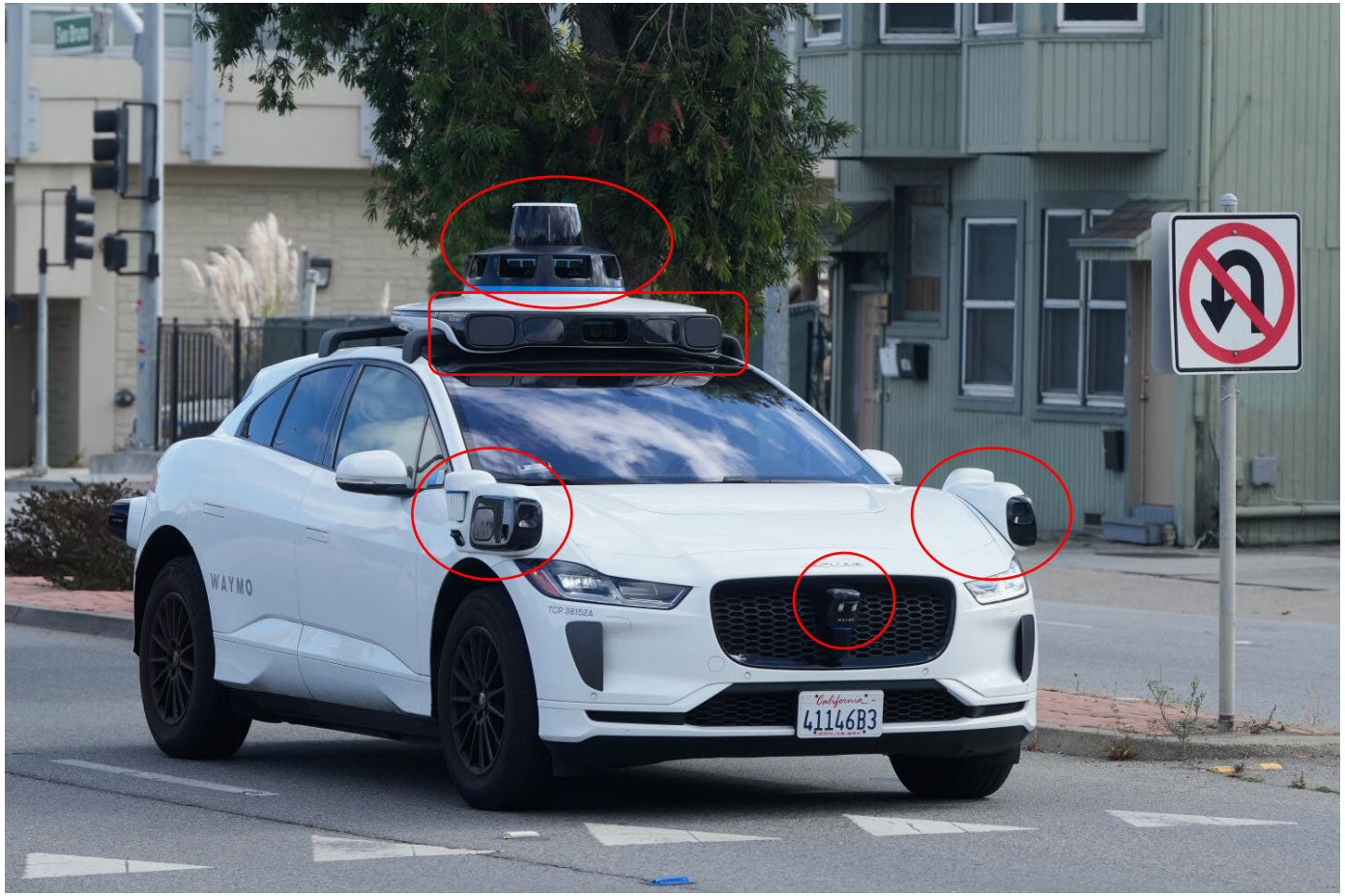
Sensor setup

Lots of sensors



Sensor setup

Lots of sensors



Sensor setup

Minimal setup

Sensor setup

Minimal setup

Ego vehicle state estimation

GPS is not enough:

- Tunnels
- Multipath
- Urban canyon

Combine other data

Leverage maps

Obstacle detection and tacking

Multiple sensors

- Different data
- Different accuracy
- Different reliability

Retrieve uniform representation of vehicle surroundings

Am I on the road?

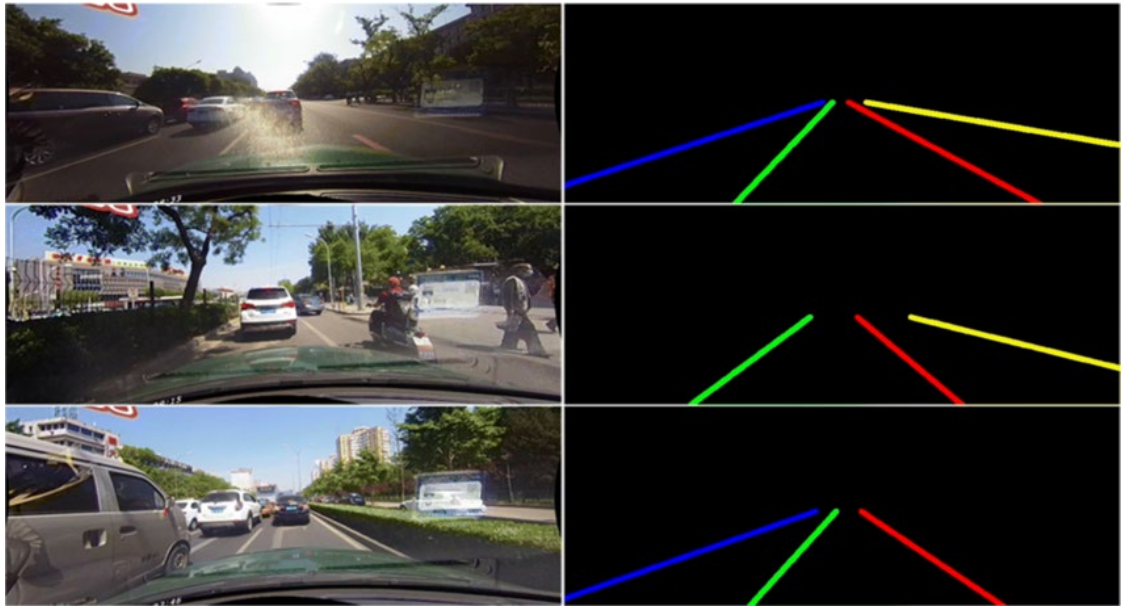
Road Line detection

512x512 RGB images from forward facing camera

Datasets

BDD100k

CULane



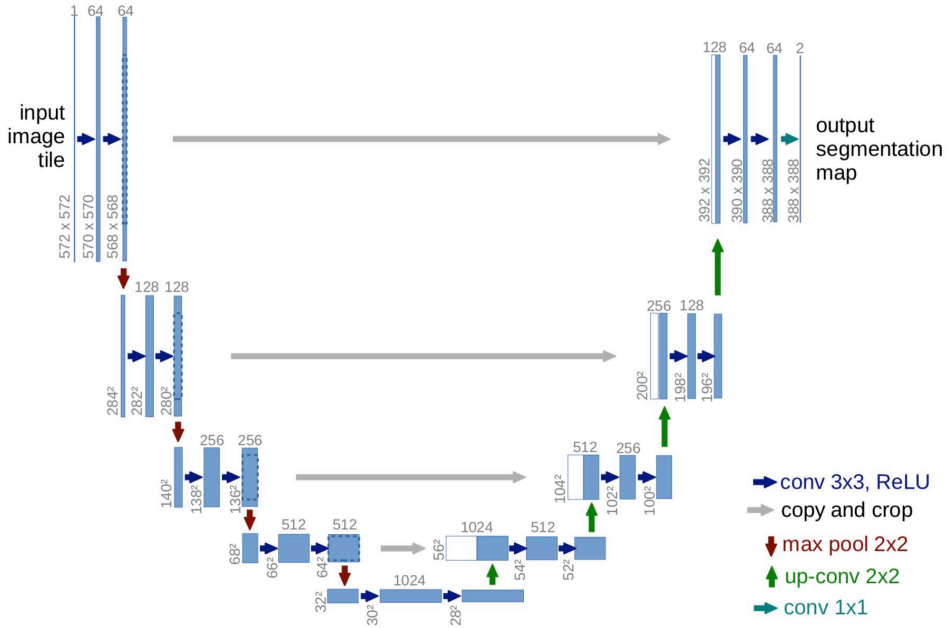
Pan, X., Shi, J., Luo, P., Wang, X. and Tang, X., 2018, April. Spatial as deep: Spatial cnn for traffic scene understanding. In *Proceedings of the AAAI conference on artificial intelligence* (Vol. 32, No. 1).
Yu, F., Chen, H., Wang, X., Xian, W., Chen, Y., Liu, F., Madhavan, V. and Darrell, T., 2020. Bdd100k: A diverse driving dataset for heterogeneous multitask learning. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition* (pp. 2636-2645).

Am I on the road?

Road Line detection

512x512 RGB images from forward facing camera

U-Net style segmentation model
Low-power optimized
100Hz on Jetson Xavier

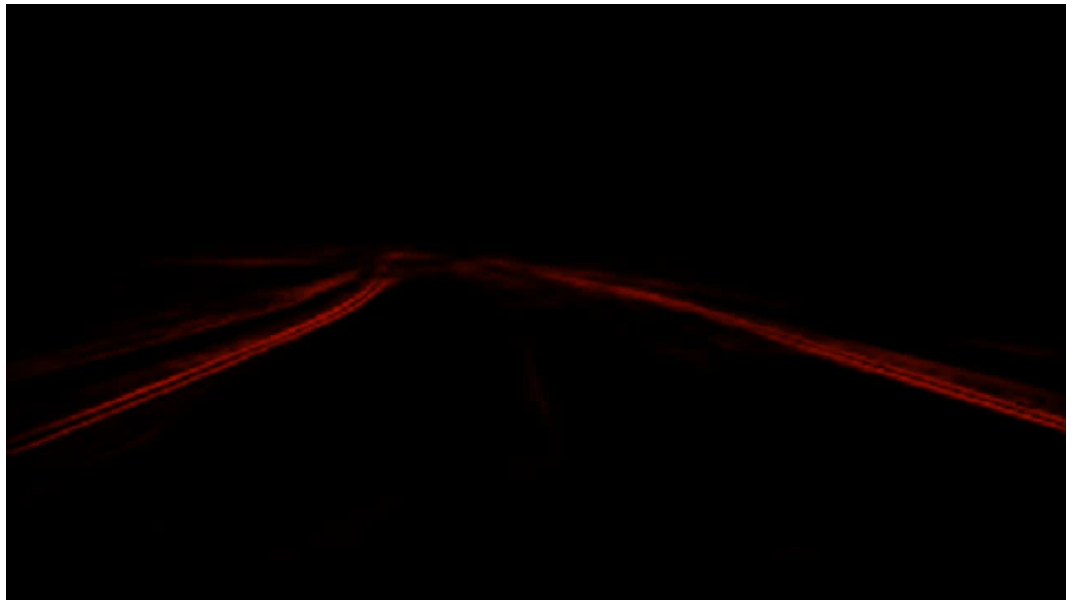


Cudrano, P., Mentasti, S., Matteucci, M., Bersani, M., Arrigoni, S. and Cheli, F., 2020, February. Advances in centerline estimation for autonomous lateral control. In *2020 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1415-1422). IEEE.

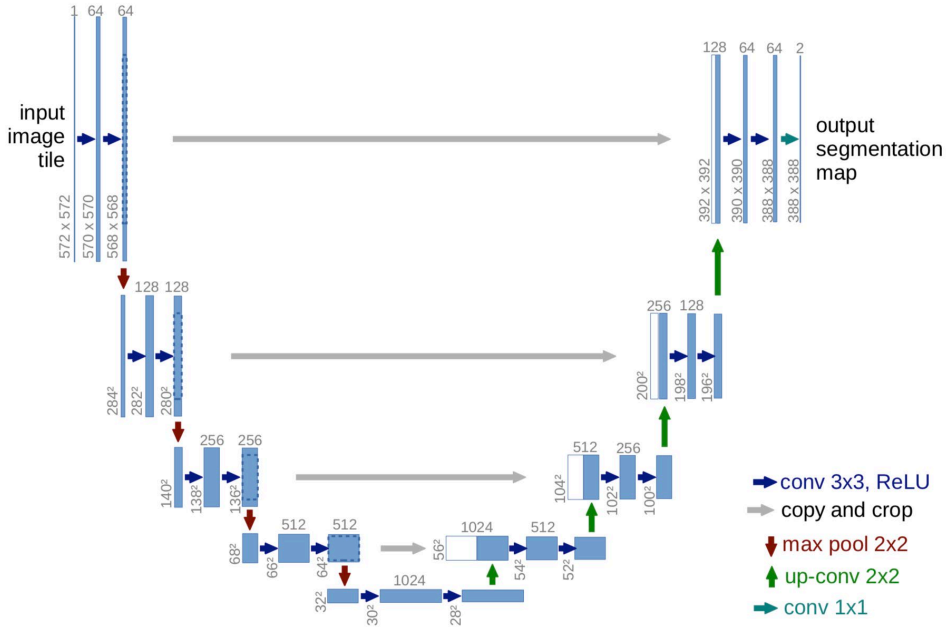
Road lines detection

Deep Learning Based

512x512 RGB images from forward facing camera



U-Net style segmentation model
Low-power optimized
100Hz on Jetson Xavier



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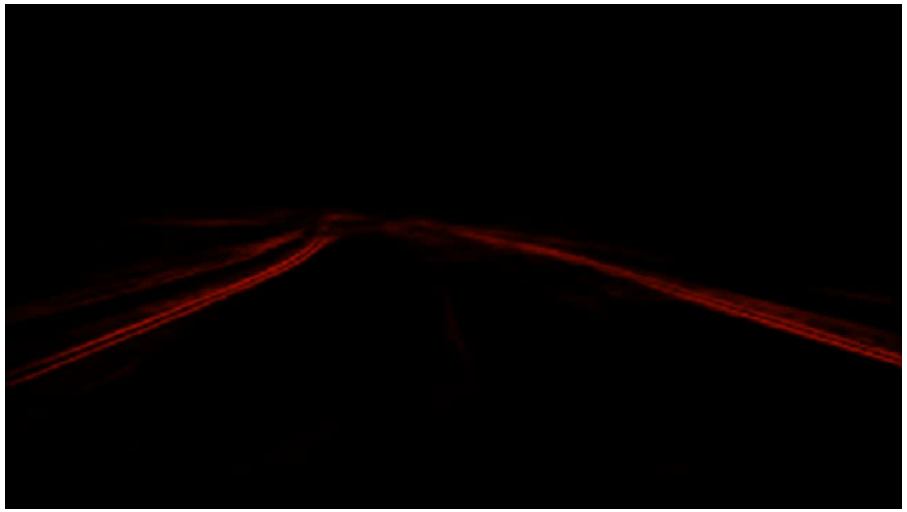
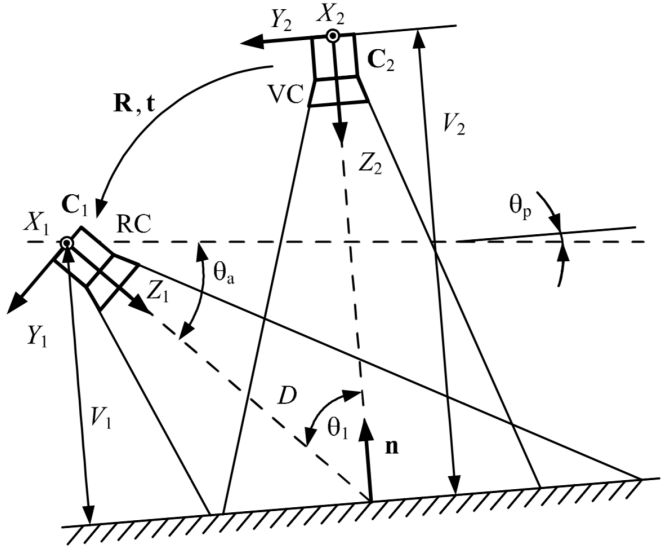
Road lines detection

BEV Reprojection

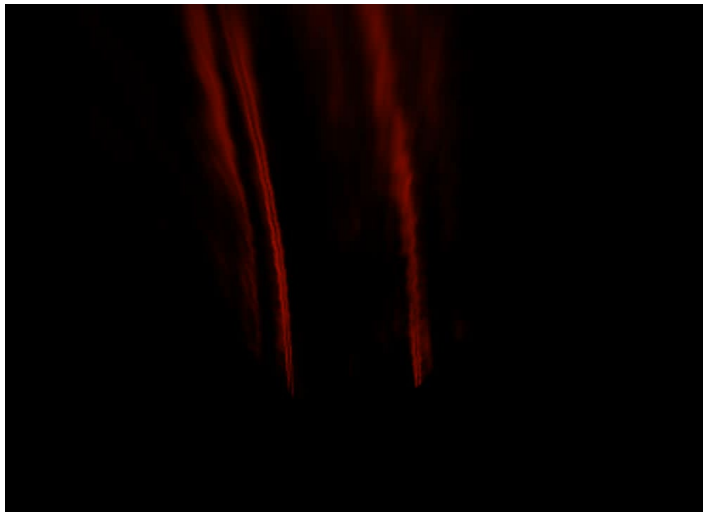
Segmented image



Calibrated Camera



Bird's eye view



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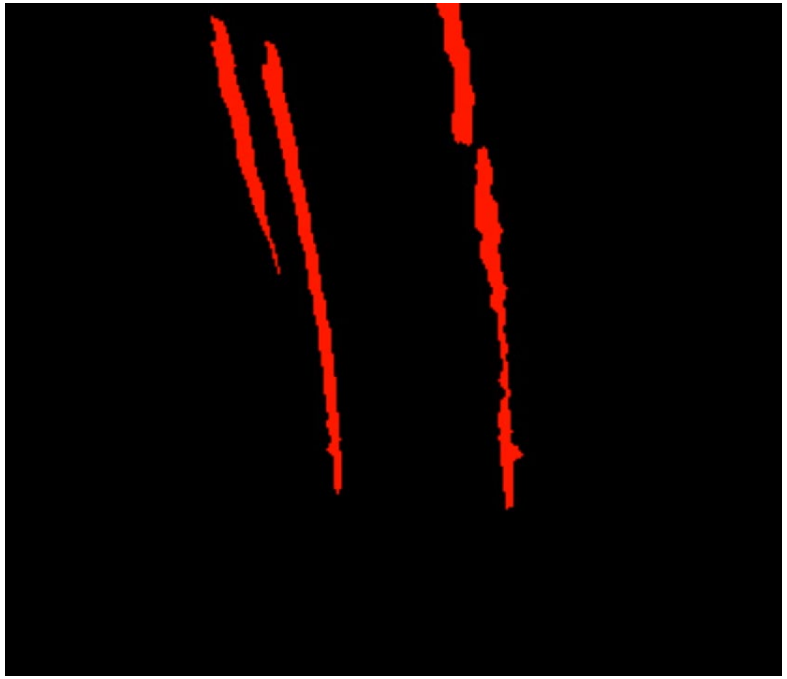
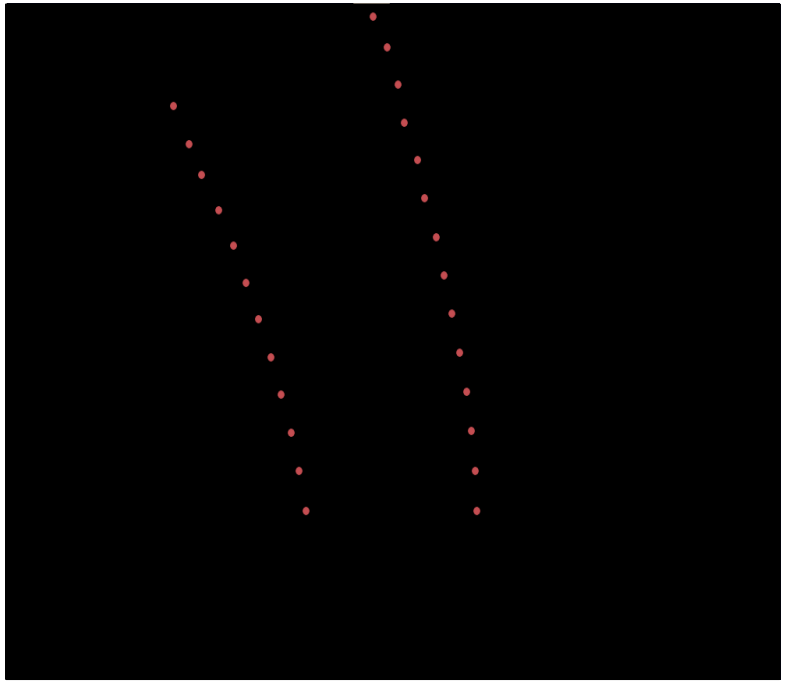
Road lines detection

Fitting

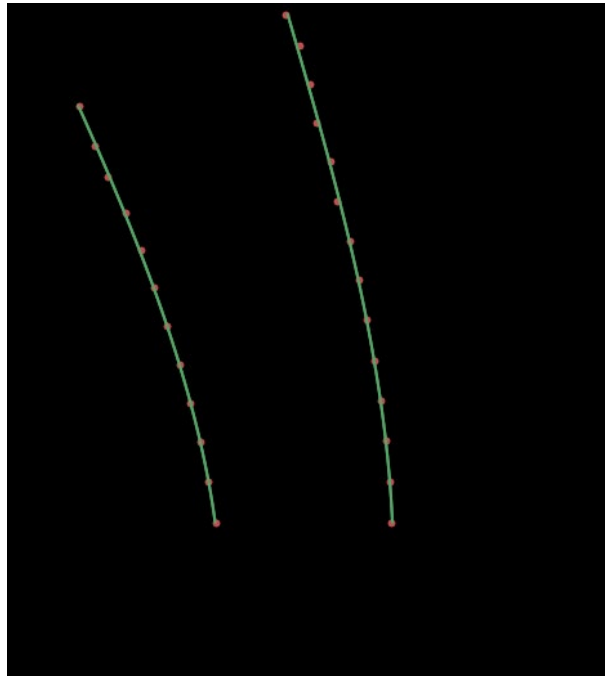
Thresholding (probability)



Point sampling



Line fitting



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Road lines position

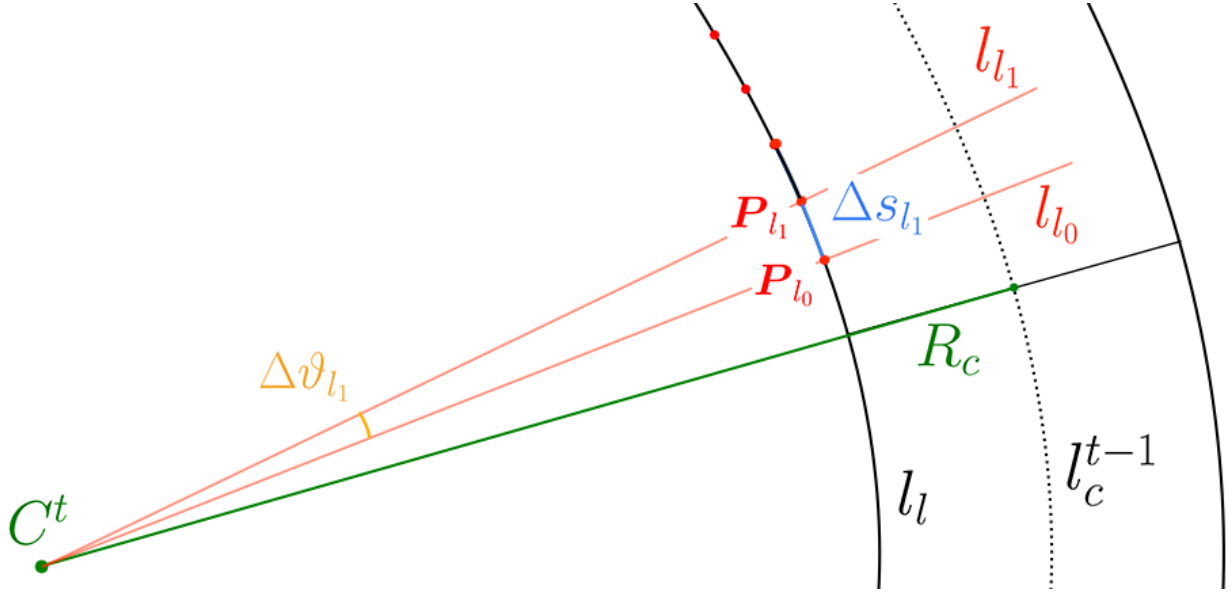
Locally constant curvature

The two lateral lines share the same center of curvature

Center of curvature varies smoothly

Under these assumptions it is possible to project lateral line points to the centreline

Centreline is fitted with a polynomial in (s, ϑ)



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Ego vehicle relative position

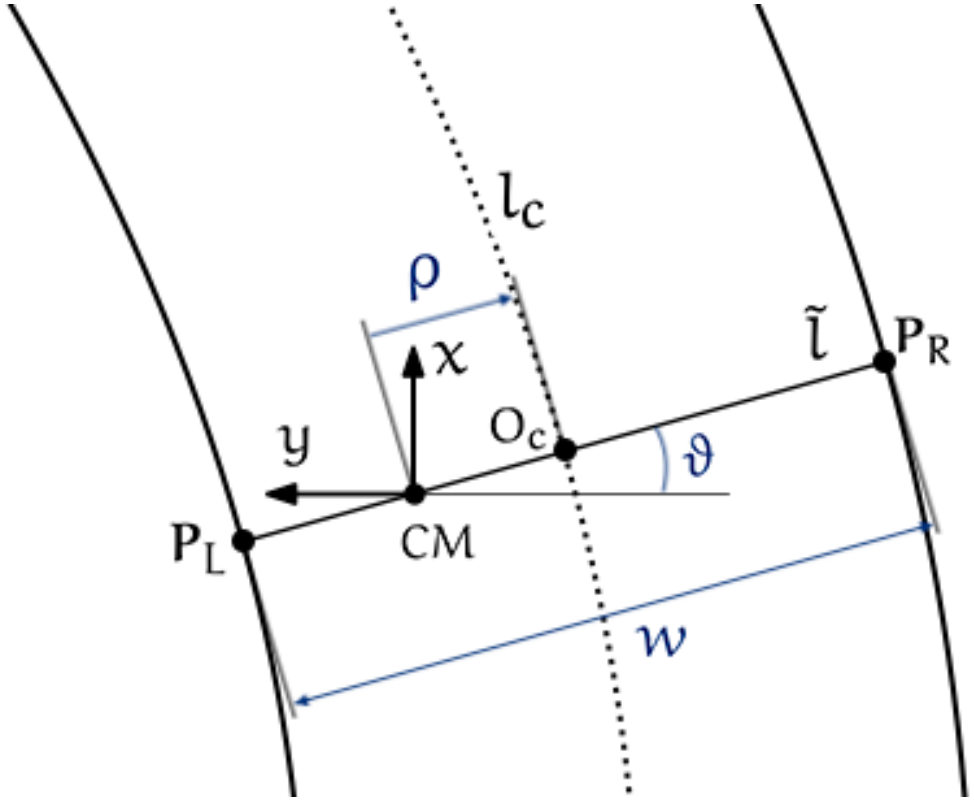
Heading and lateral offset need to be computed exactly at CM

Requires the line $\tilde{l}$ such that:

- $CM \in \tilde{l}$
- $\tilde{l} \perp l_c$

- From $\tilde{l}$ we can retrieve O_c and compute ρ

- Temporal consistency guaranteed using an Extended Kalman Filter which considers (ϑ, ρ, w)



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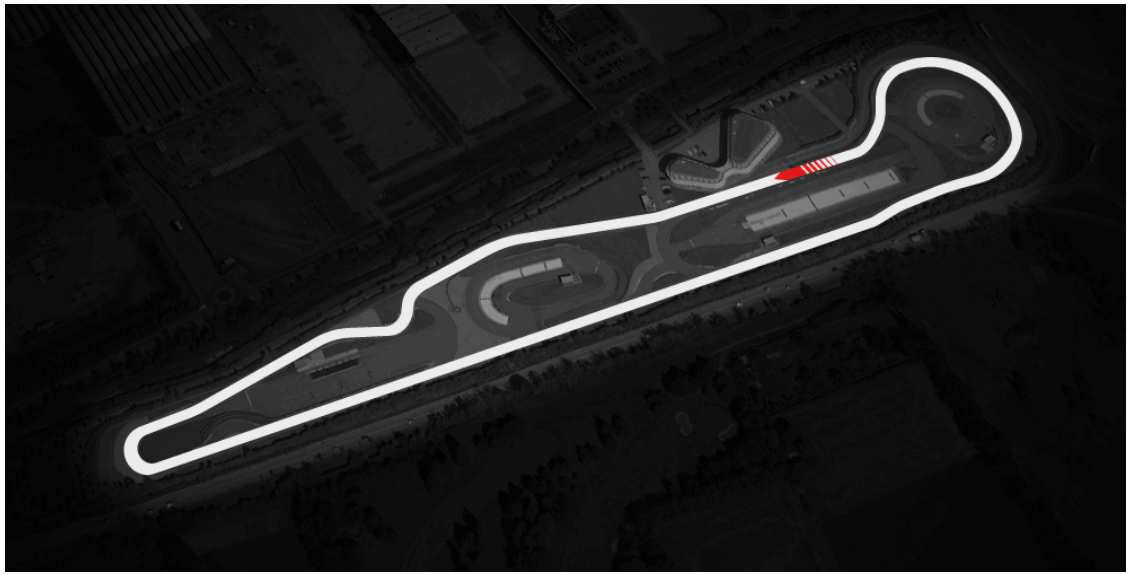
Test areas

Monza ENI Circuit (5.4Km)

Arese test track (1.2Km)



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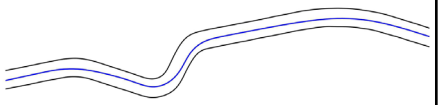
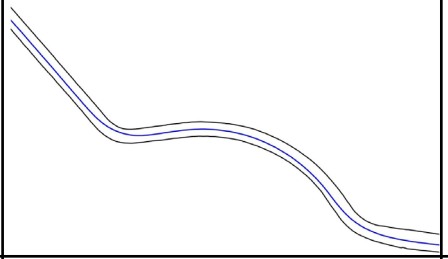
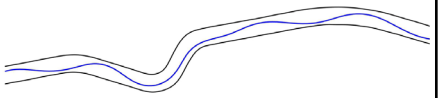
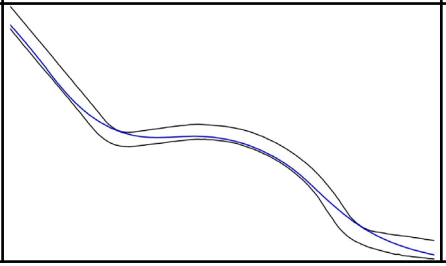
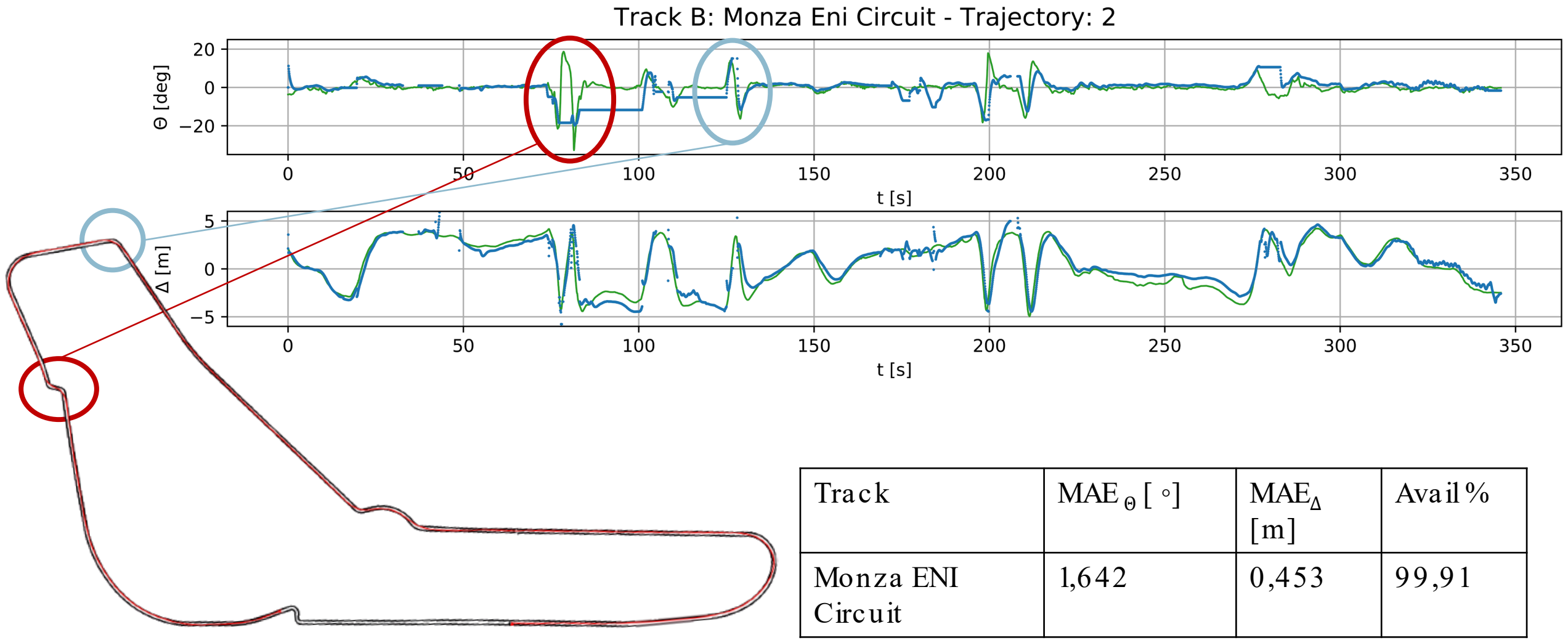
Ego vehicle relative position

	Trajectory sample	MAE_{Θ} [°]	MAE_{Δ} [m]	Avail %
Centered track A (Arese Circuit)		2,892	0,820	99,71
Centered track B (Monza ENI Circuit)		1,642	0,453	99,91
Oscillating track A (Arese Circuit)		3,862	0,946	100
Racing track B (Monza ENI Circuit)		3,12	0,581	95,92

Cudrano, P., Mentasti, S., Matteucci, M., Bersani, M., Arrigoni, S. and Cheli, F., 2020, February. Advances in centerline estimation for autonomous lateral control. In *2020 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1415-1422). IEEE.

Ego vehicle relative position



Track	MAE_{Θ} [°]	MAE_{Δ} [m]	Avail %
Monza ENI Circuit	1,642	0,453	99,91

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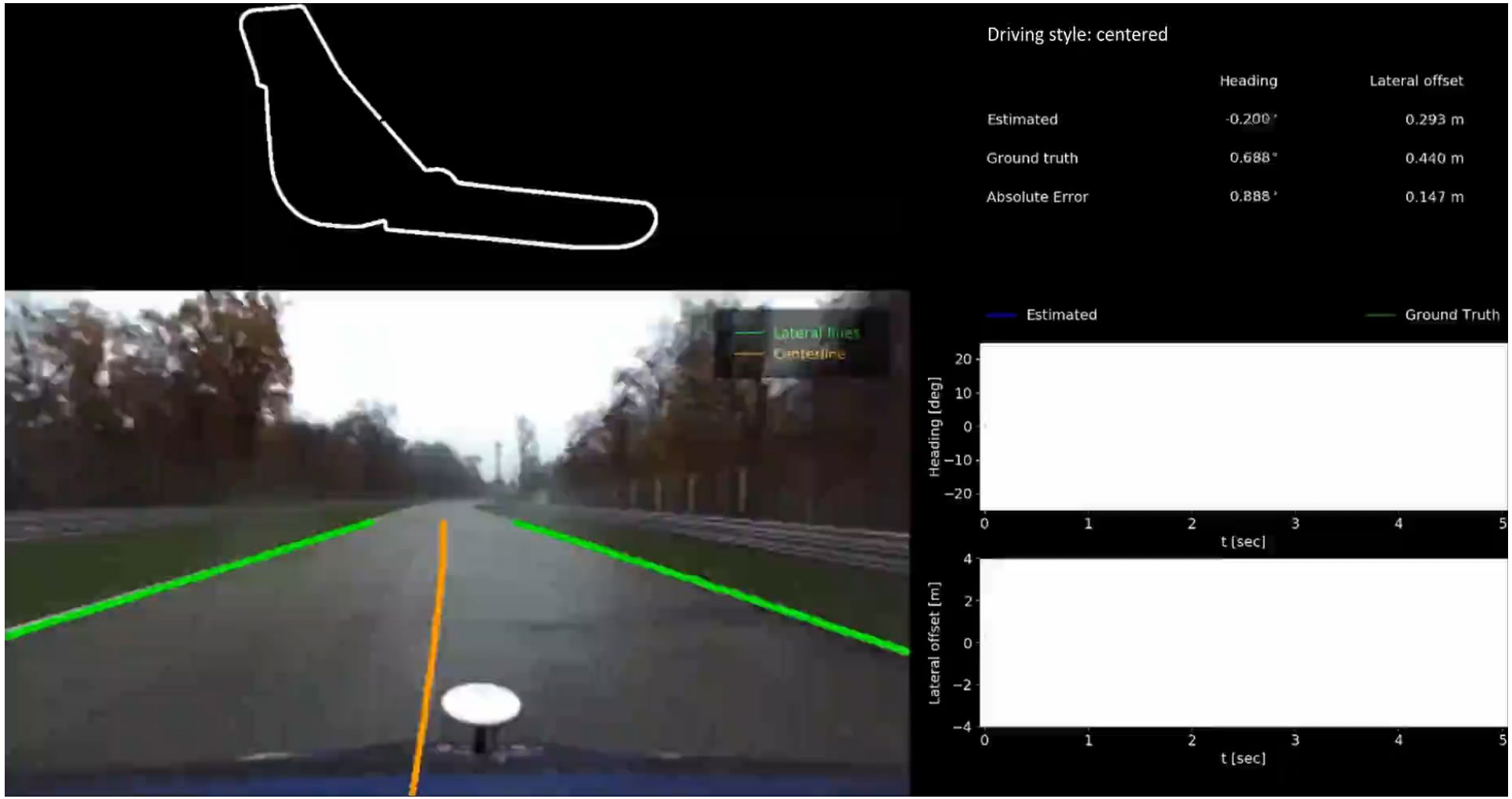
Vision -based ego vehicle state estimation



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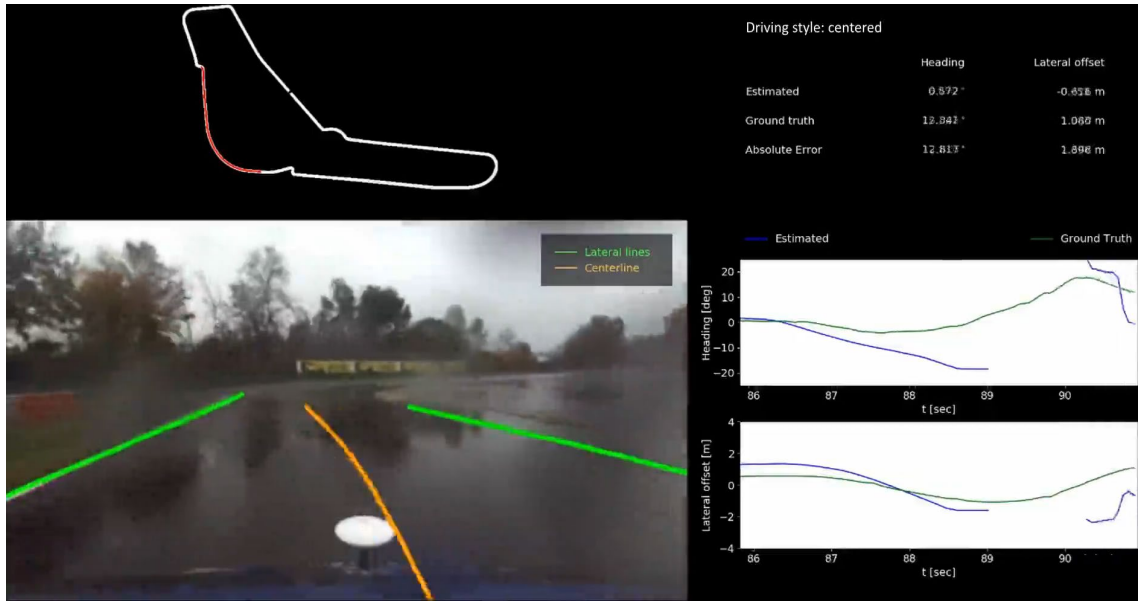
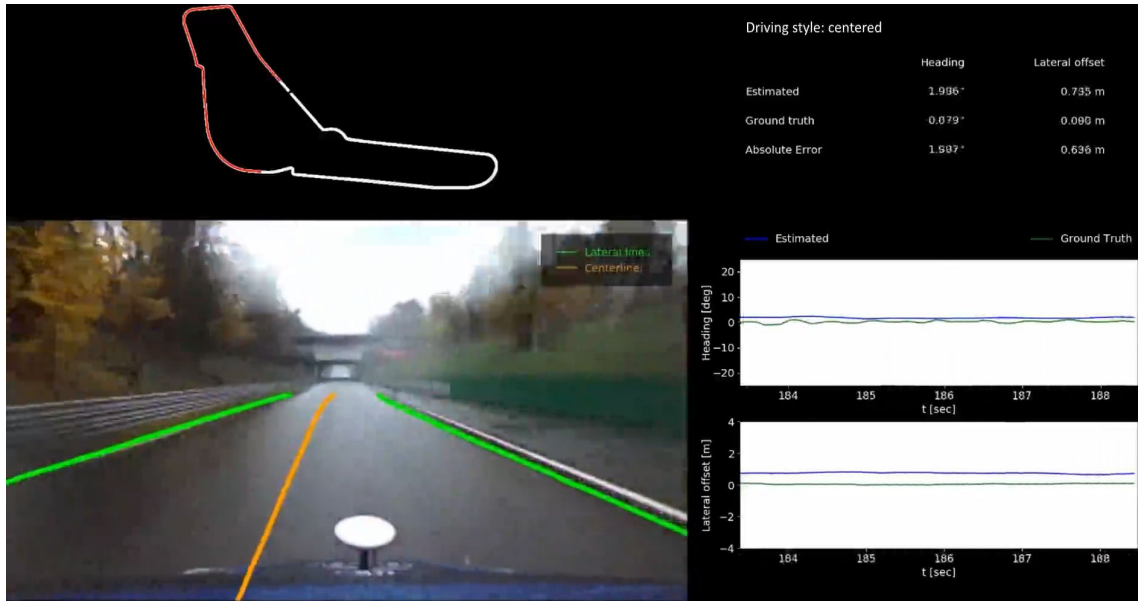
Challenging scenarios

High curvature radius

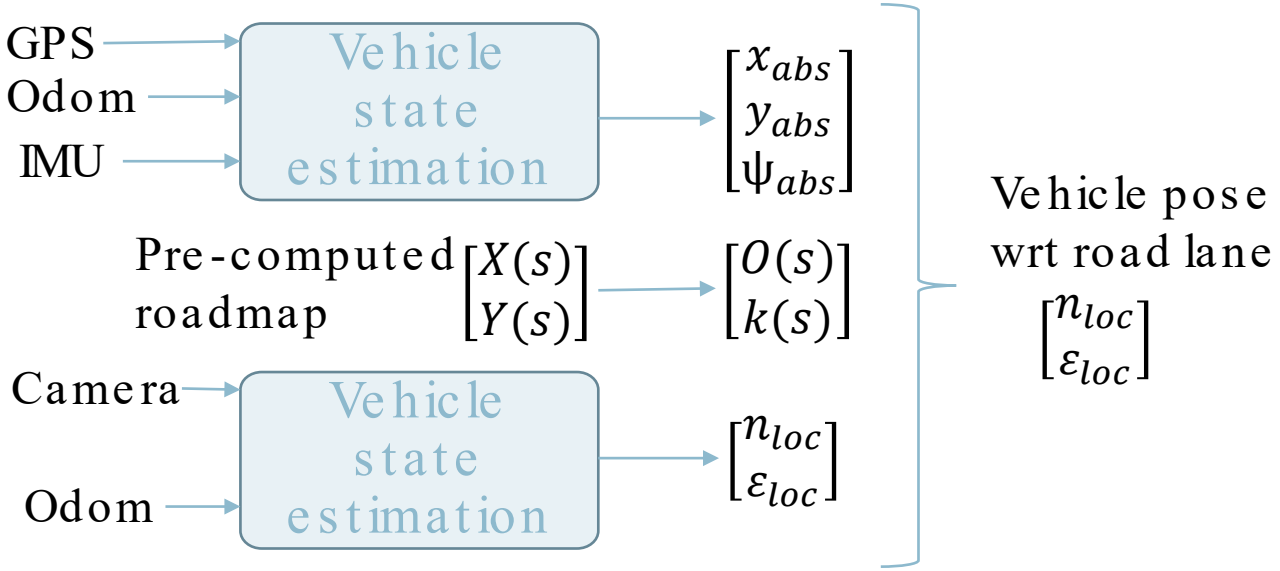


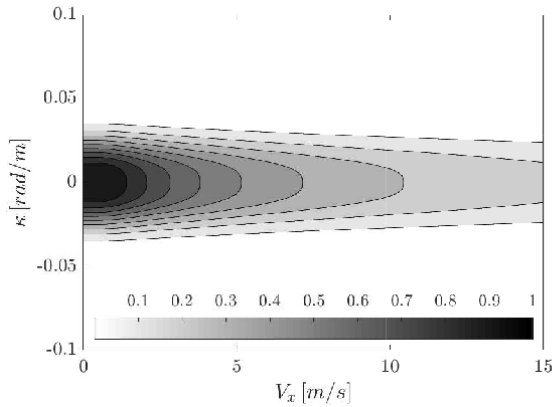
GNSS denied

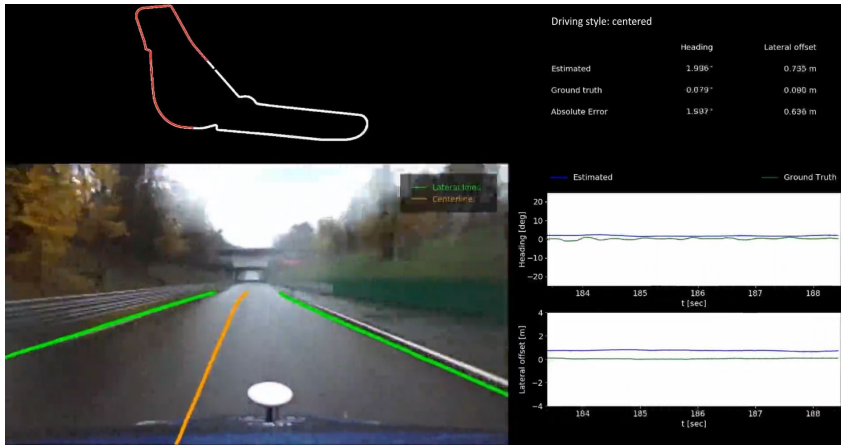


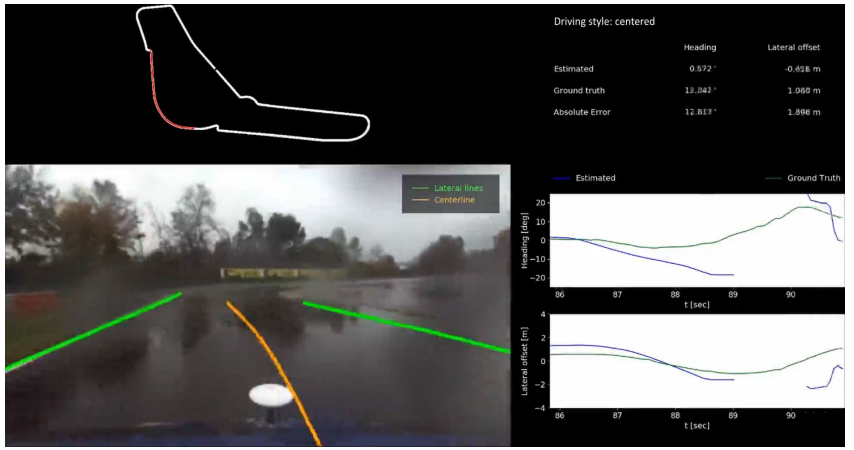
Bersani, M., Mentasti, S., Cudrano, P., Vignati, M., Matteucci, M. and Cheli, F., 2020, September. Robust vehicle pose estimation from vision and INS fusion. In *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)* (pp. 1-6). IEEE.

Challenging scenarios









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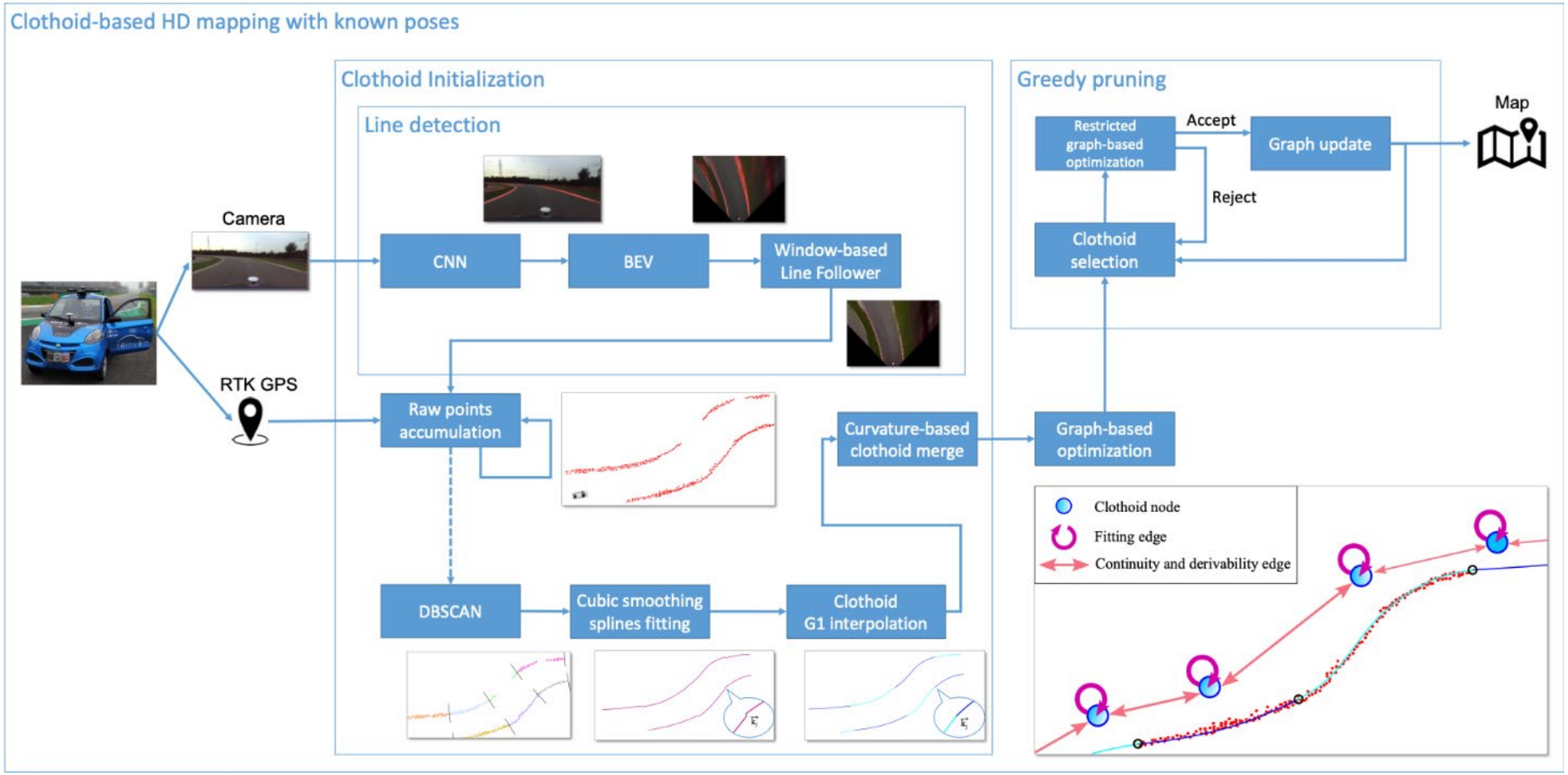
Offline road line detection - Mapping

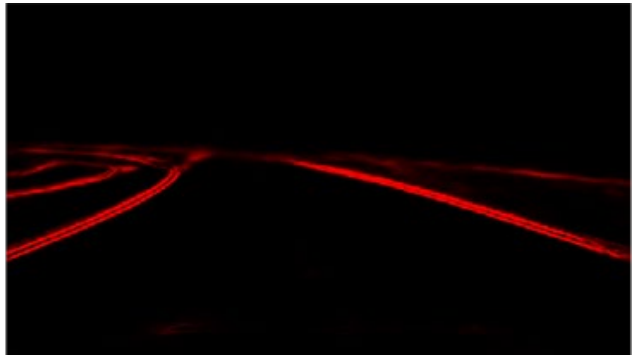


Gallazzi, Barbara, Paolo Cudrano, Matteo Frosi, Simone Mentasti, and Matteo Matteucci. " Clothoidal mapping of road line markings for autonomous driving high -definition maps." In *2022 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1631-1638. IEEE, 2022.
Cudrano, Paolo, Barbara Gallazzi, Matteo Frosi, Simone Mentasti, and Matteo Matteucci. "Clothoid-based lane-level high-definition maps: Unifying sensing and control models." *IEEE Vehicular Technology Magazine* 17, no. 4 (2022): 47-56.

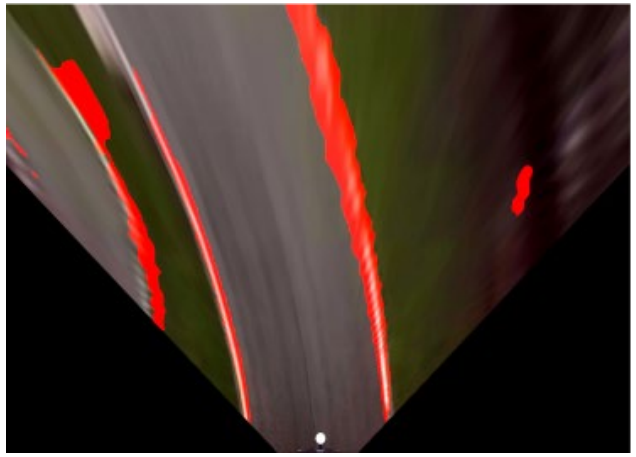
Mapping
Line Detection

RGB

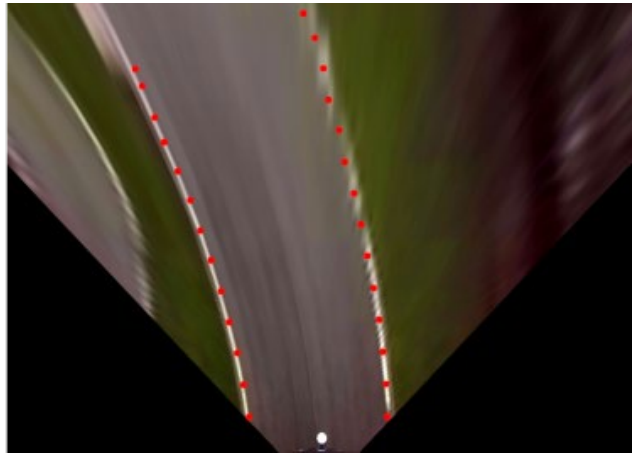
Segmentation



BEV



Points



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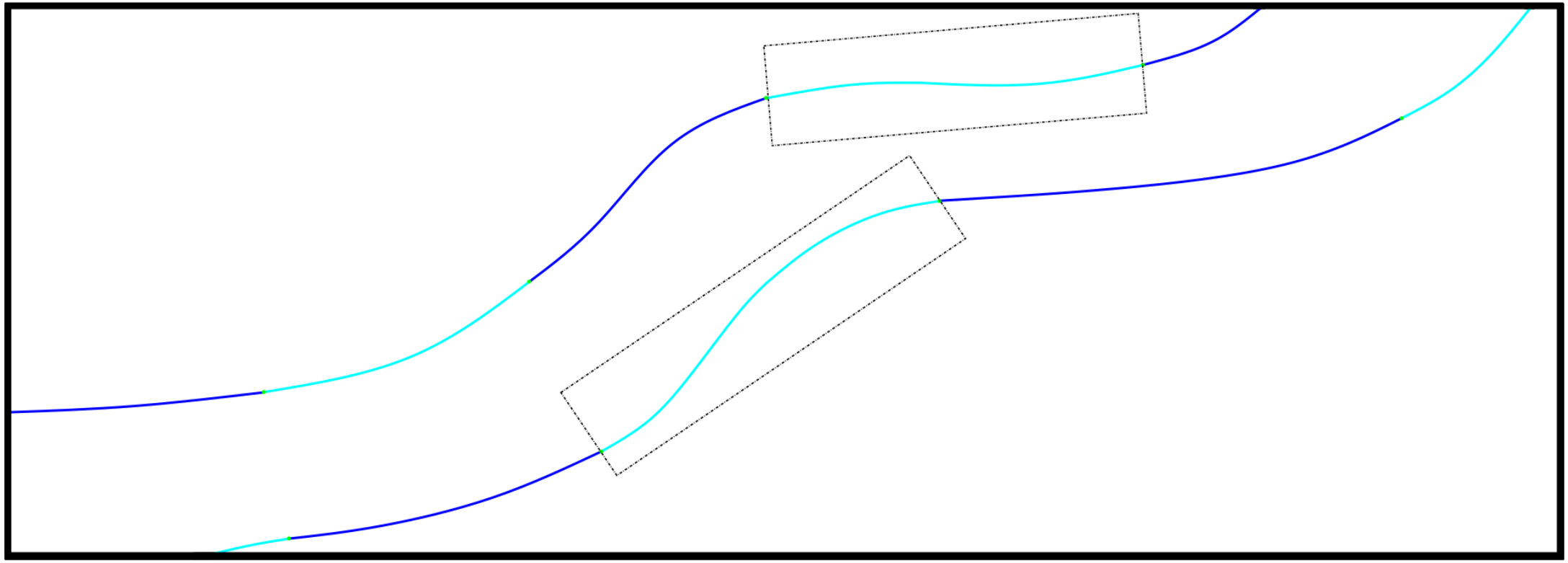
Mapping
Line Detection

Block division → DBSCAN → cubic smoothing splines → knots → clothoids → merging



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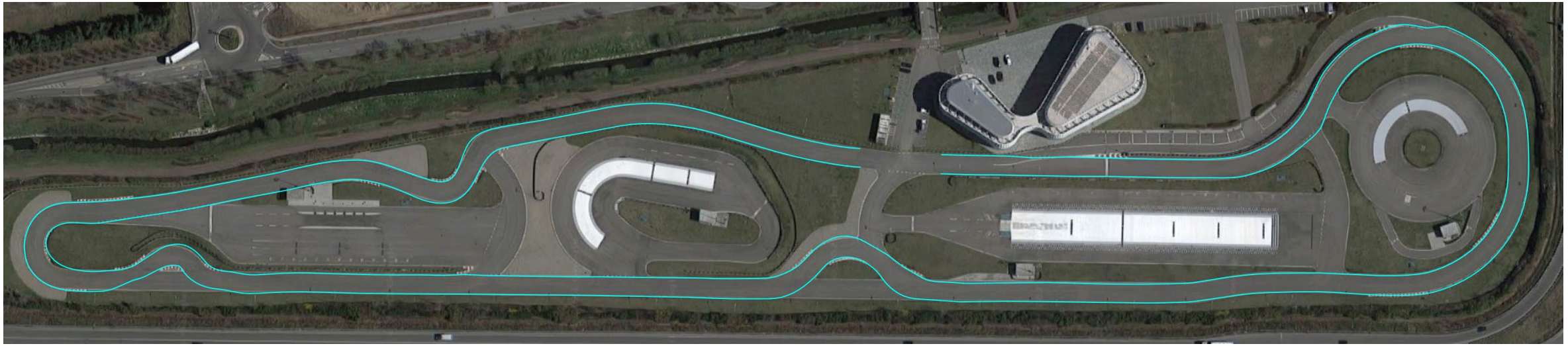
Mapping – Arese



Clothoids quantity	MAE (m)	Continuity (m)		Derivability (°)	
		mean	max	mean	max
~~283~~ 283	0.4103	0.0098	0.0113	0.1139	1.1931

Gallazzi, Barbara, Paolo Cudrano, Matteo Frosi, Simone Mentasti, and Matteo Matteucci. "Clothoidal mapping of road line markings for autonomous driving high-definition maps." In *2022 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1631-1638. IEEE, 2022.
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Mapping – Monza

Clothoids quantity	MAE (m)	Continuity (m)		Derivability (°)	
		mean	max	mean	max
~~924~~	0.2772	0.0088	0.0103	0.0139	0.1064

Mapping – Monza

Gallazzi, Barbara, Paolo Cudrano, Matteo Frosi, Simone Mentasti, and Matteo Matteucci. " Clothoidal mapping of road line markings for autonomous driving high -definition maps." In *2022 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1631-1638. IEEE, 2022.
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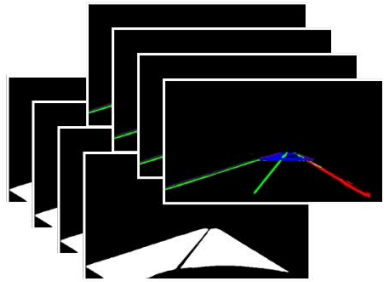
Semantic Mapping

On the road

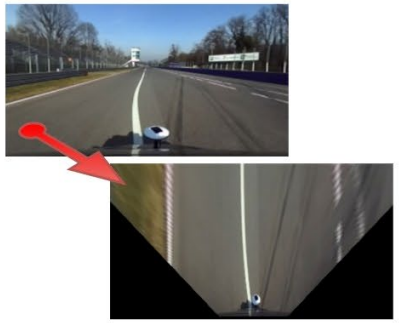
1 Input collection

RTK-GNSS data
x, y, z ...

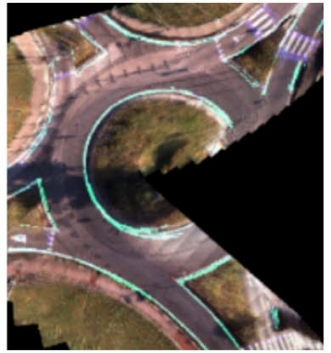
2 Segmentation



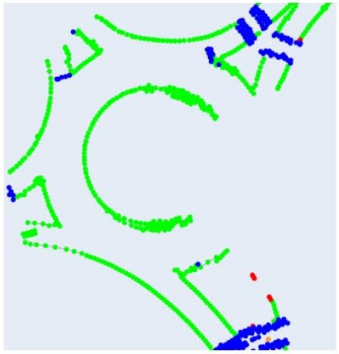
3 BEV projection



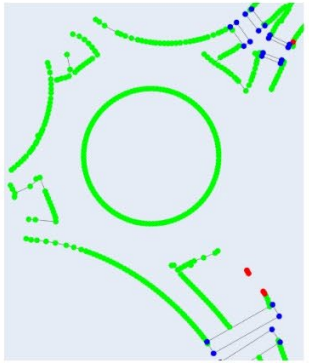
4 Pixel-level map



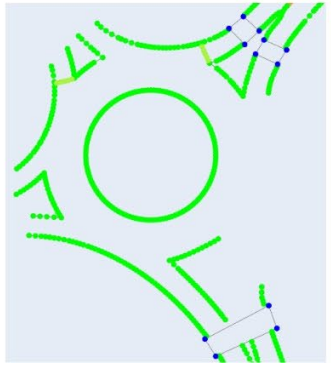
5 Graph-level map



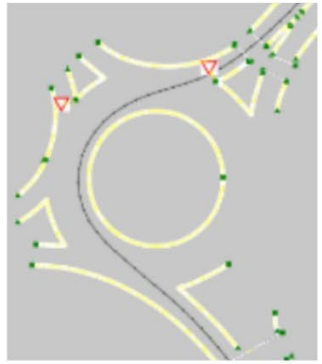
6 Post-processing



7 Editing



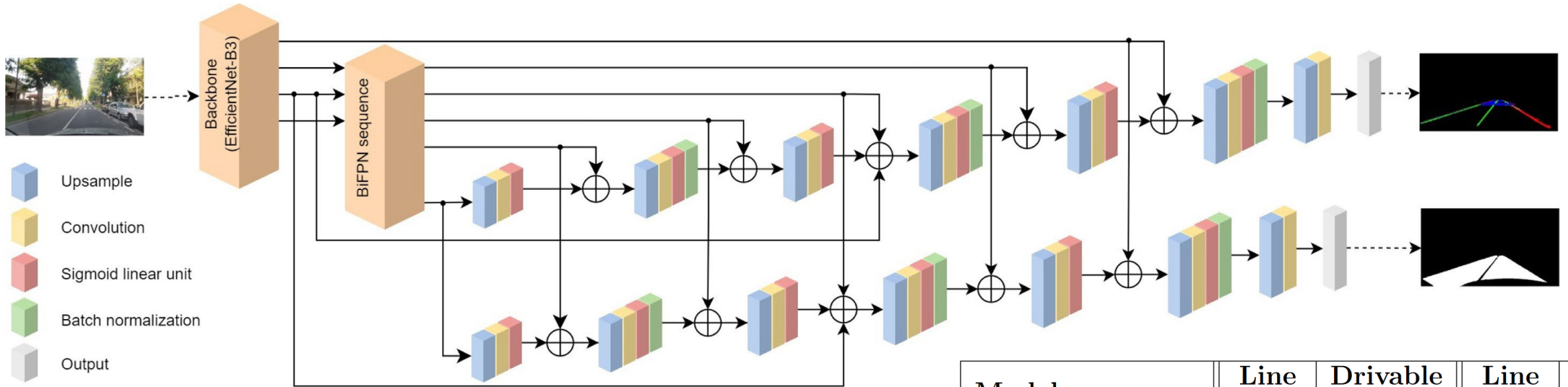
8 Lanelet2 HD map



Bellusci, Matteo, Paolo Cudrano, Simone Mentasti, Riccardo Erminio Filippo Cortelazzo, and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane-level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

Semantic Mapping

On the road



Model	Line IoU	Drivable IoU	Line Acc	Drivable Acc
HybridNets	**53.82**	86.59	59.81	86.87
Yolop	49.70	86.00	65.40	**97.40**
YolopV2	53.24	**88.41**	80.11	91.31
RoadStarNet-FT	53.45	87.66	66.50	87.89
RoadStarNet-F*	44.41	88.34	**82.44**	89.09

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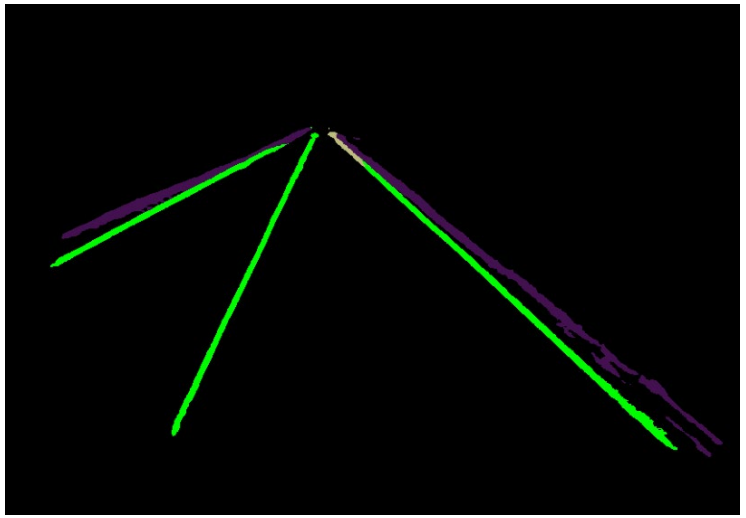
Semantic Mapping

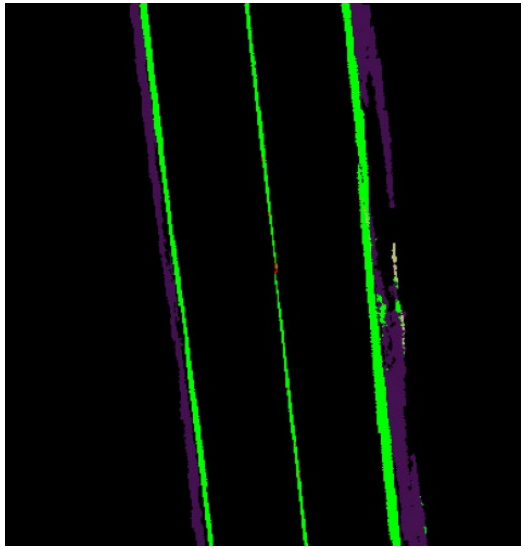
On the road

RGB image

Multiclass segmentation



BEV



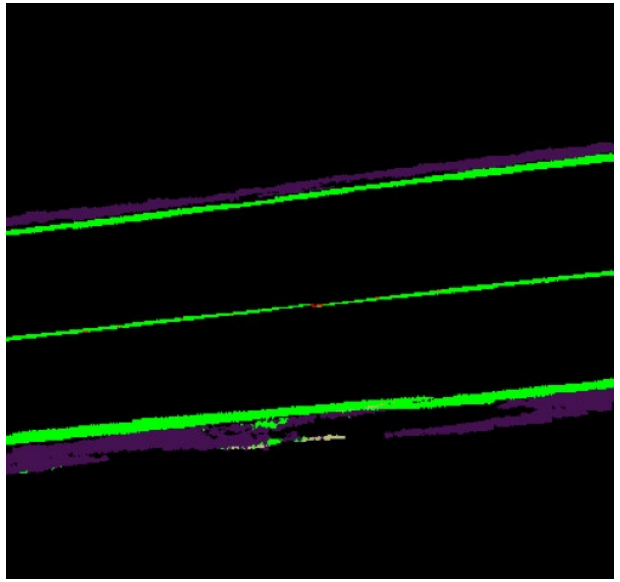
x: 362847.110, y: 5107972.381 z: 186.048
roll: 95.9881351, pitch: 89.7408898, yaw: 24.0095672

Bellusci, Matteo, Paolo Cudrano , Simone Mentasti, Riccardo Erminio Filippo Cortelazzo , and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane -level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

Semantic Mapping

On the road

Aligned BEVusing vehicle state

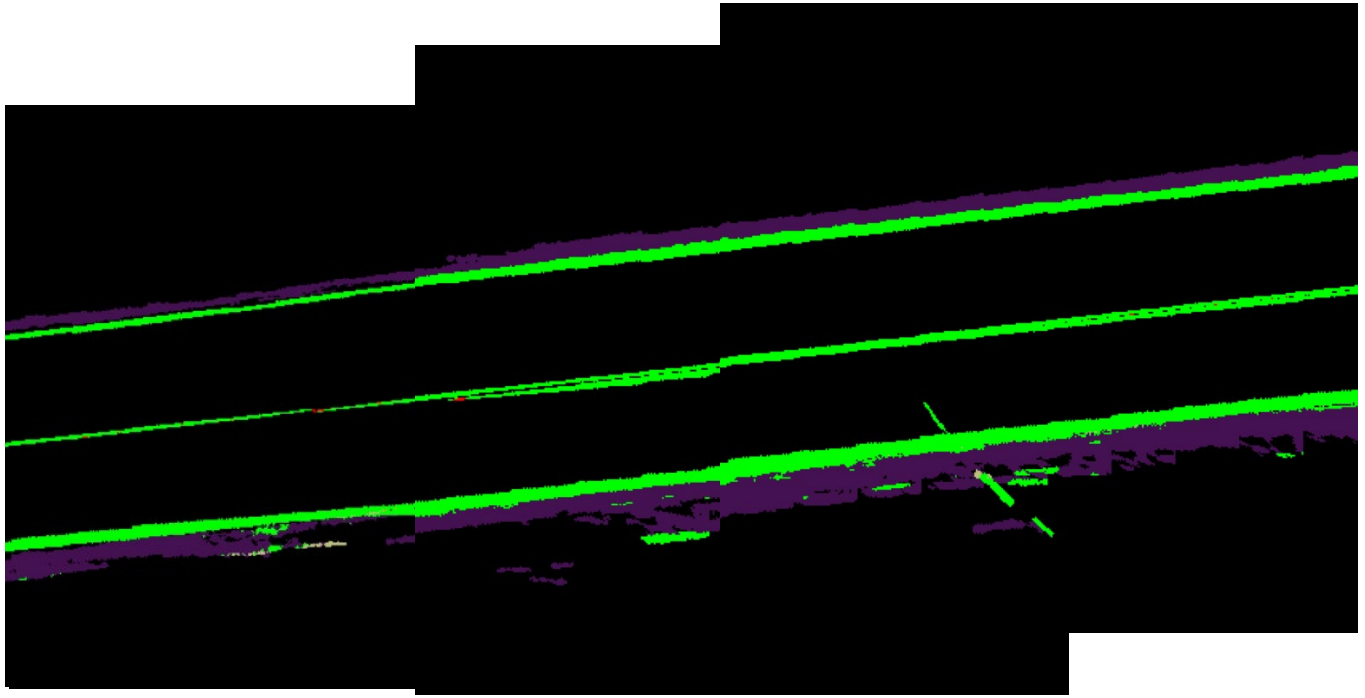


x: 362847.110, y: 5107972.381 z: 186.048

Bellusci, Matteo, Paolo Cudrano , Simone Mentasti, Riccardo Erminio Filippo Cortelazzo , and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane -level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

Semantic Mapping

On the road



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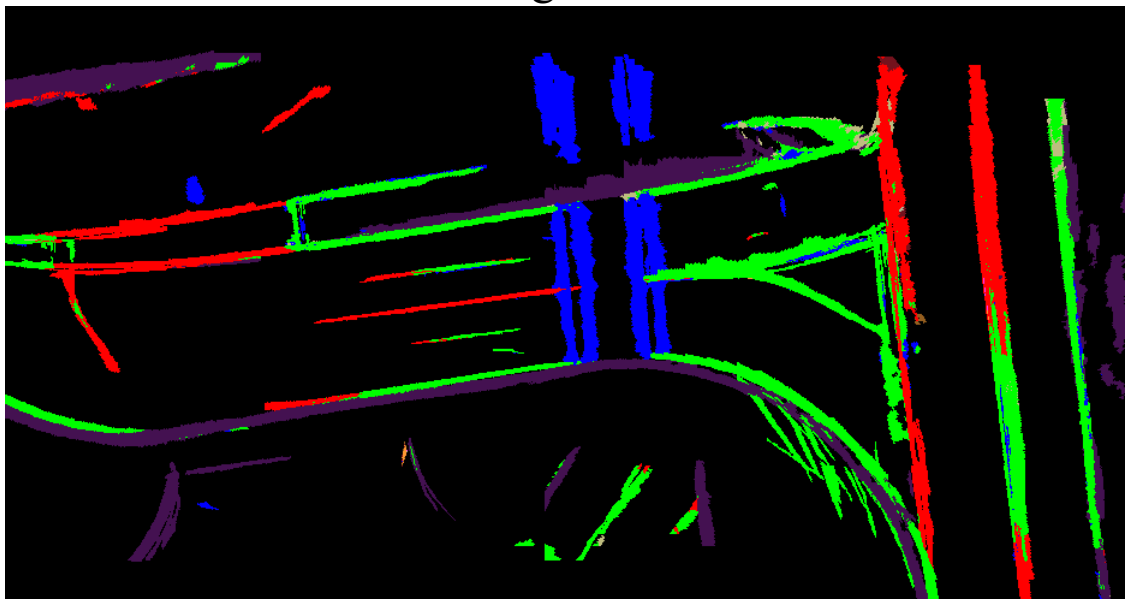
Semantic Mapping

On the road

Combined Segmentation BEV



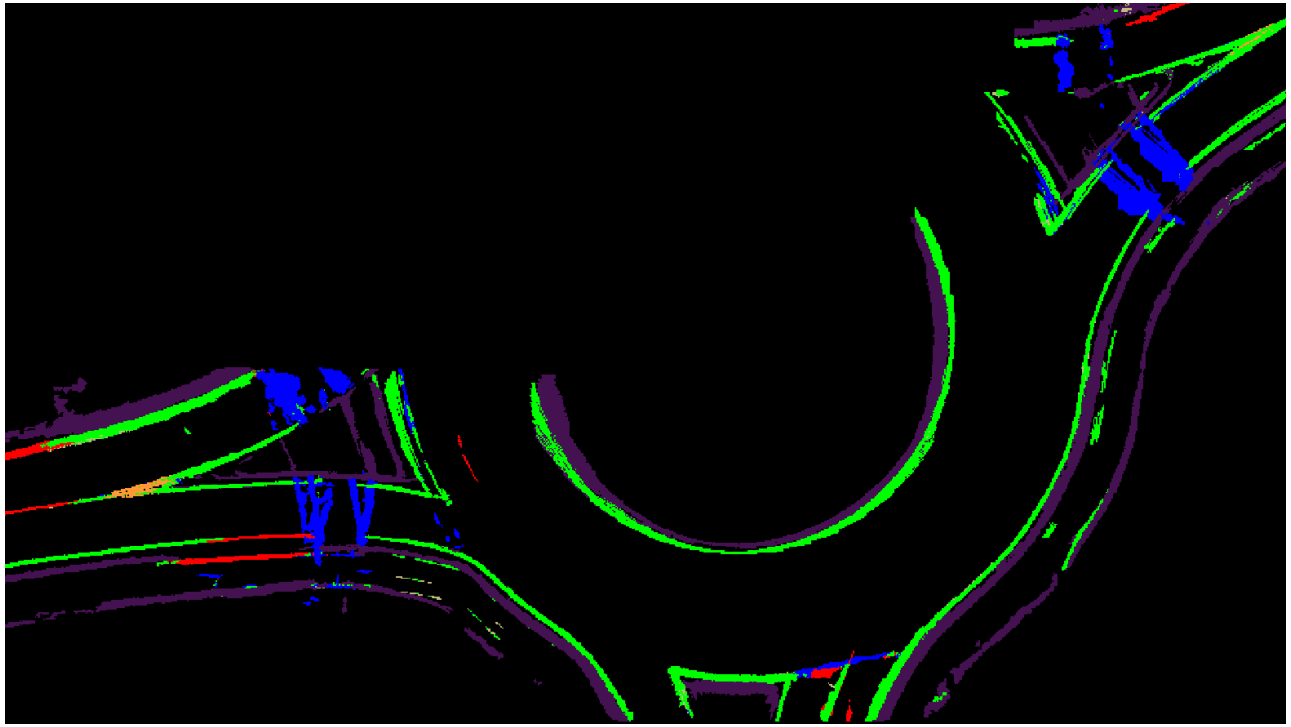
Combined RGB BEV

Bellusci, Matteo, Paolo Cudrano, Simone Mentasti, Riccardo Erminio Filippo Cortelazzo, and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane-level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

Semantic Mapping

On the road

Combined Segmentation BEV



Monza Coverage

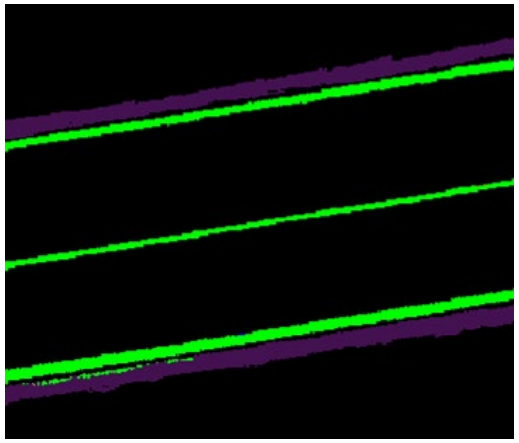
Model	Roggia	Lesmo	Ascari	Parabolica
HybridNets	0,3163m (85,49%)	**0,3236m** (61,69%)	**0,3377m** (64,76%)	**0,3109m** (64,70%)
Yolop	0,2933m (86,73%)	0,4222m (90,03%)	0,4162m (98,07%)	0,4074m (78,00%)
YolopV2	0,3723m (94,56%)	0,7340m (98,77%)	0,5955m (98,07%)	0,4545m (97,58%)
RoadStarNet-FT	**0,2872m** (83,64%)	0,4222m (83,69%)	0,3752m (90,20%)	0,3842m (80,30%)
RoadStarNet-F*	0,4047m **(98,73%)**	0,6277m **(99,96%)**	0,5457m **(99,82%)**	0,4750m **(98,90%)**

Bellusci, Matteo, Paolo Cudrano , Simone Mentasti, Riccardo Erminio Filippo Cortelazzo , and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane -level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

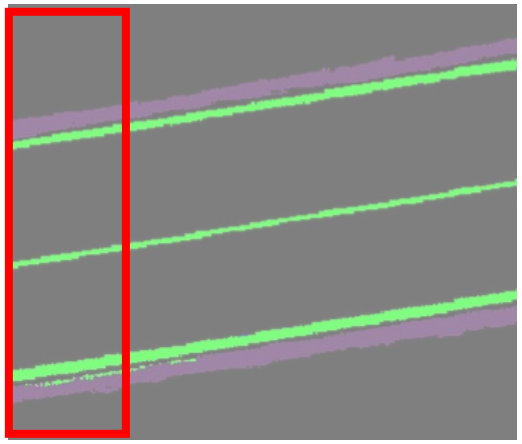
Semantic Mapping

Graph generation

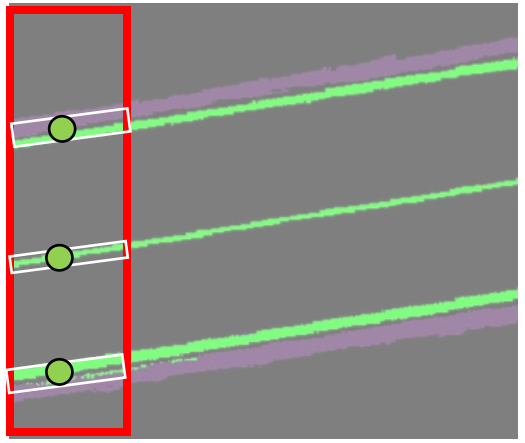
BEV



Fixed-size road area



Line points



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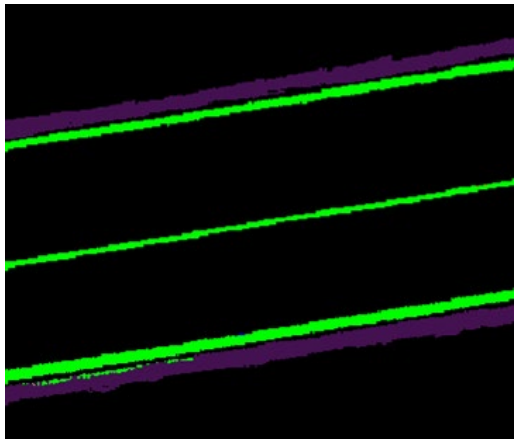
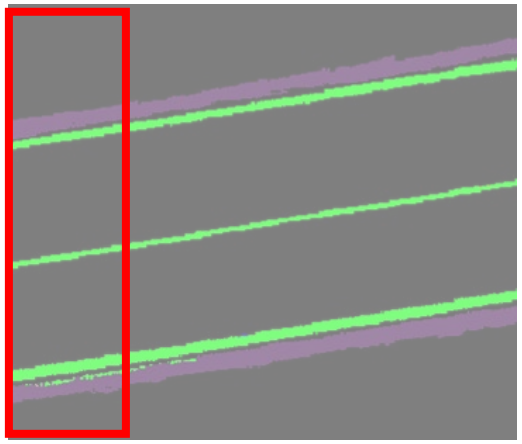
Semantic Mapping

Graph generation

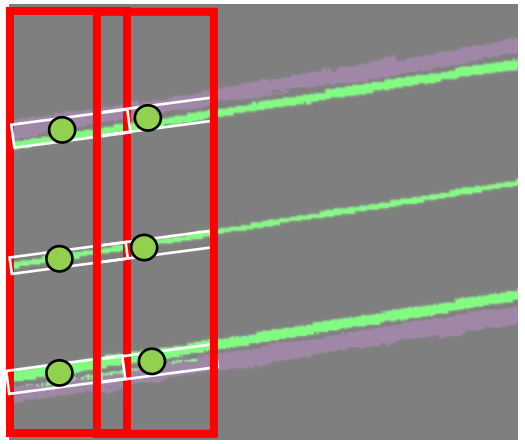
BEV



Fixed-size road area



Sliding window



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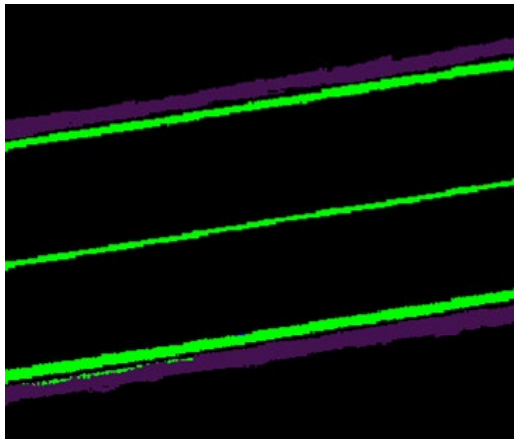
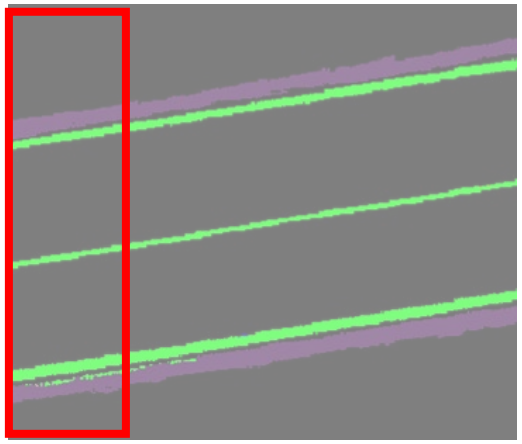
Semantic Mapping

Graph generation

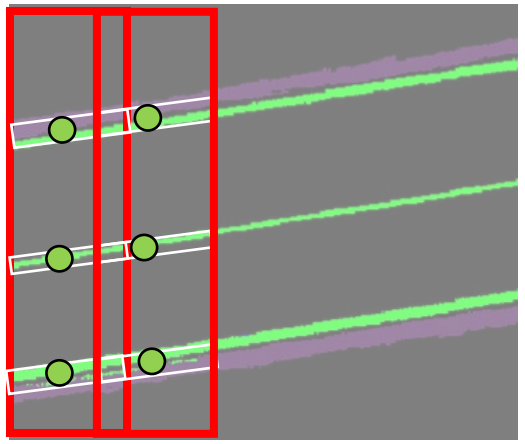
BEV



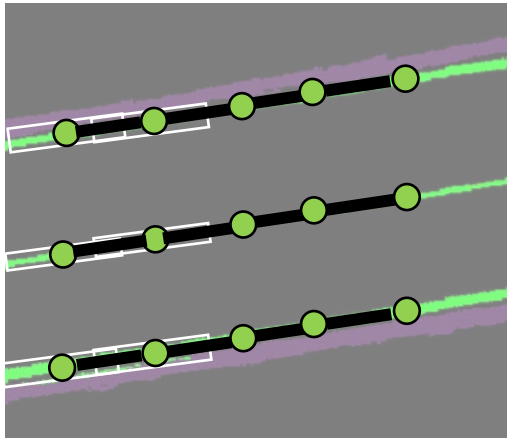
Fixed-size road area



Sliding window



Line points



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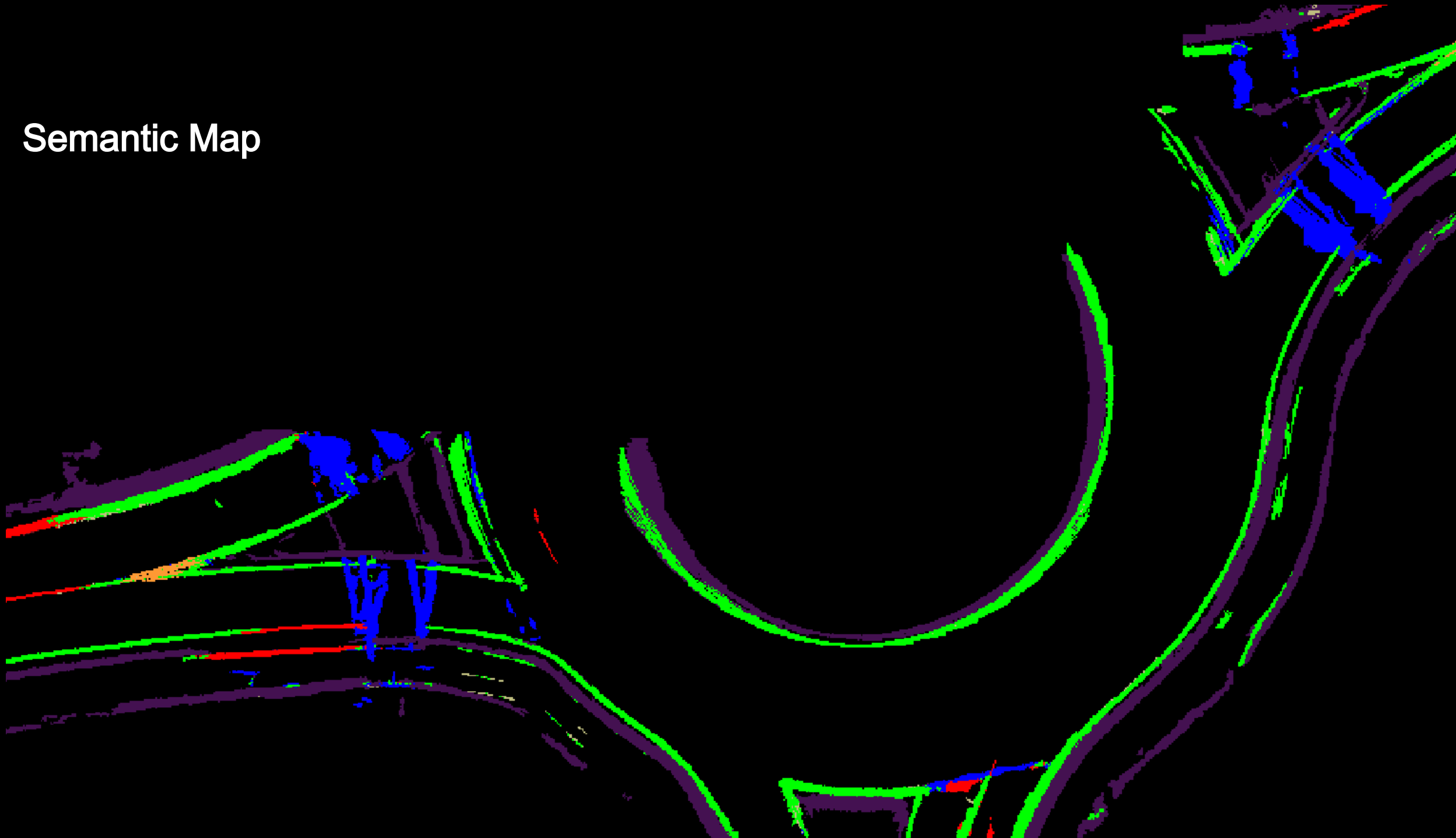
Semantic Map

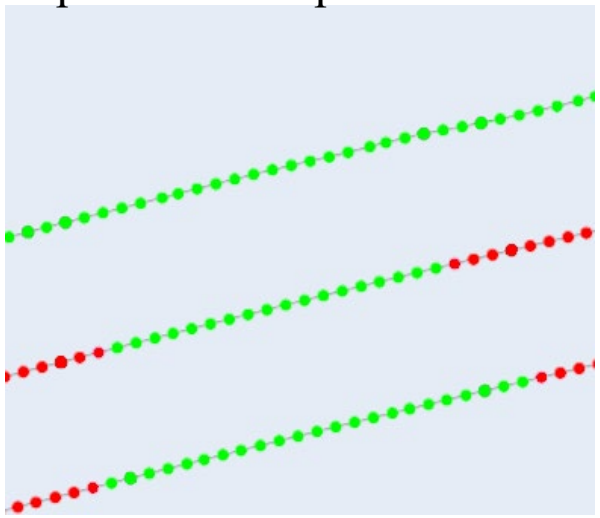


Graph-based map

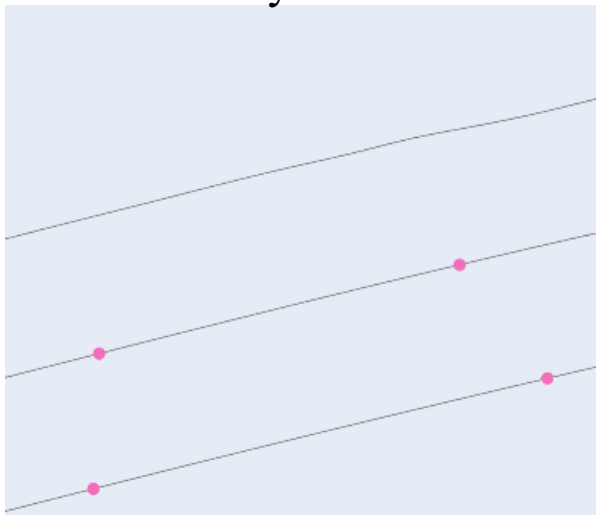
Semantic Mapping

Graph reduction

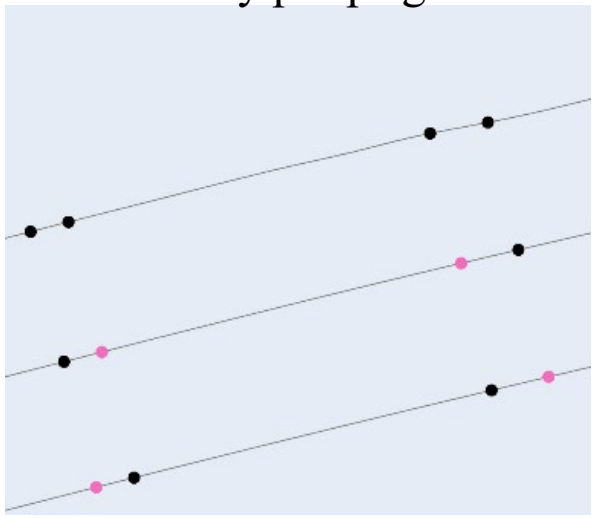
Graph based representation



Boundary detection



Boundary propagation



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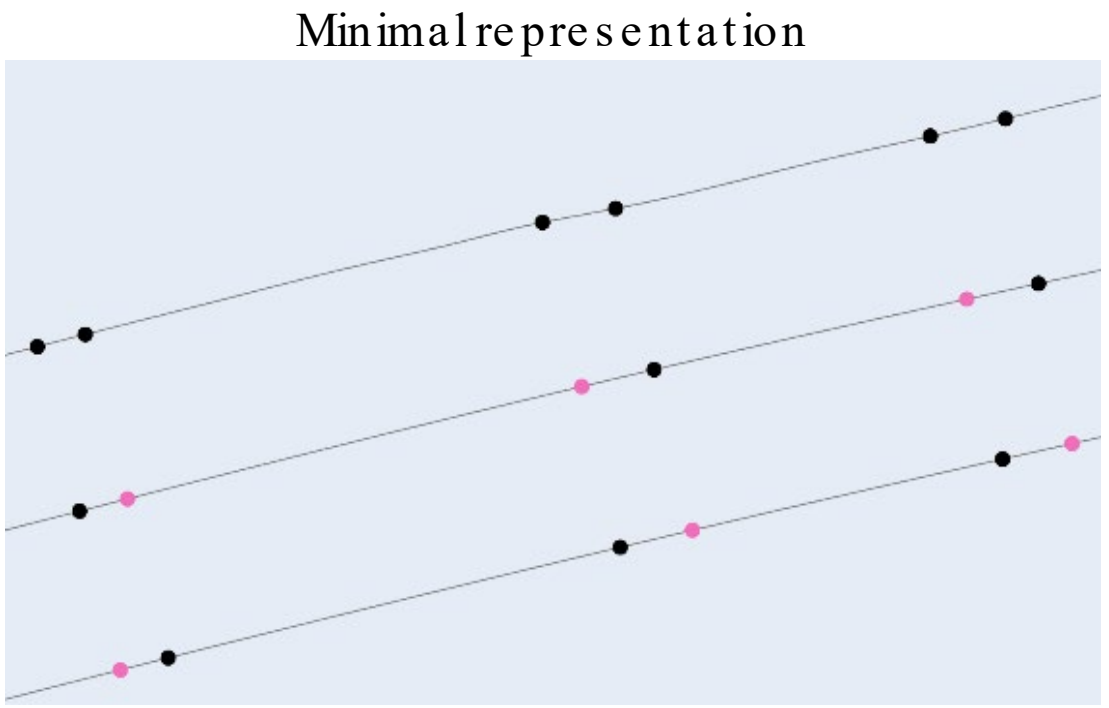
Semantic Mapping

Graph reduction

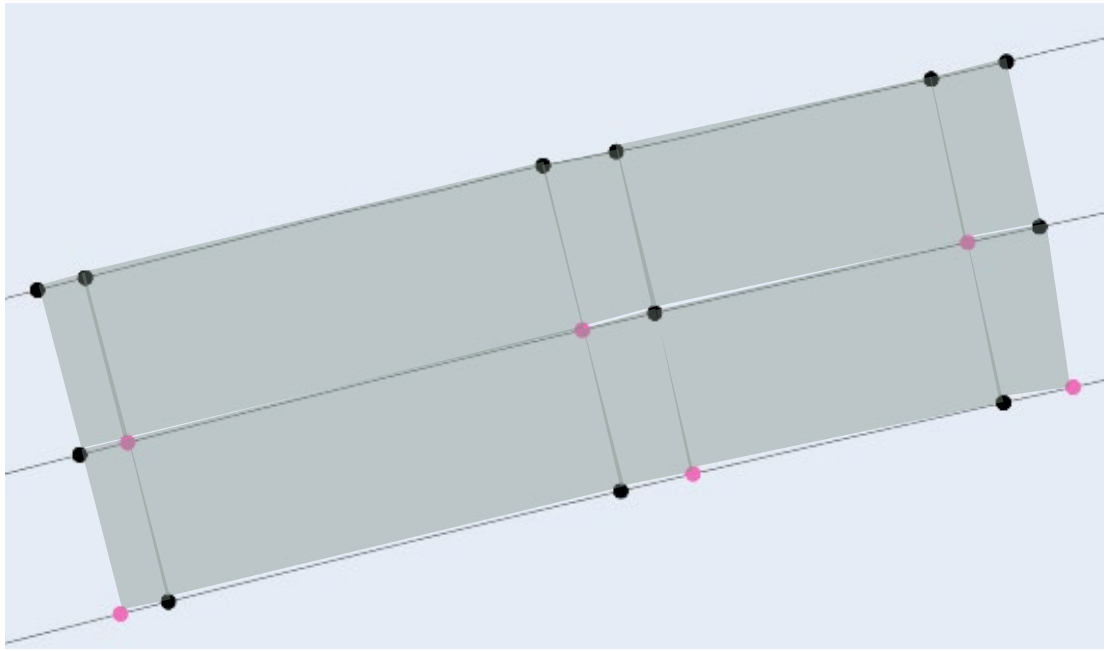


Bellusci, Matteo, Paolo Cudrano, Simone Mentasti, Riccardo Erminio Filippo Cortelazzo, and Matteo Matteucci. "Semantic interpretation of raw survey vehicle sensory data for lane-level HD map generation." *Robotics and Autonomous Systems* 172 (2024): 104513.

Semantic Mapping

Lane Classification

Lane boundaries definition



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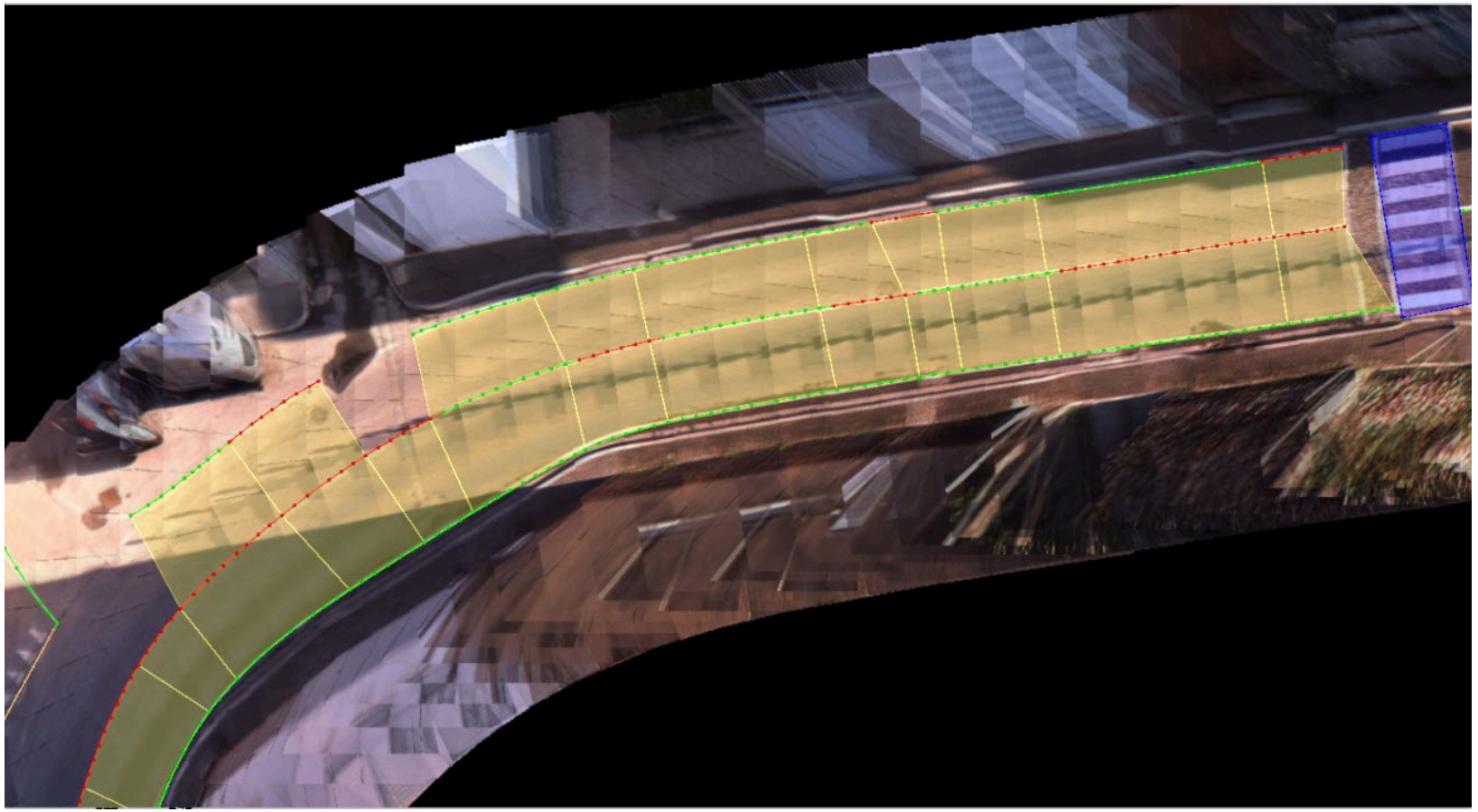
Semantic Mapping

Lane Classification



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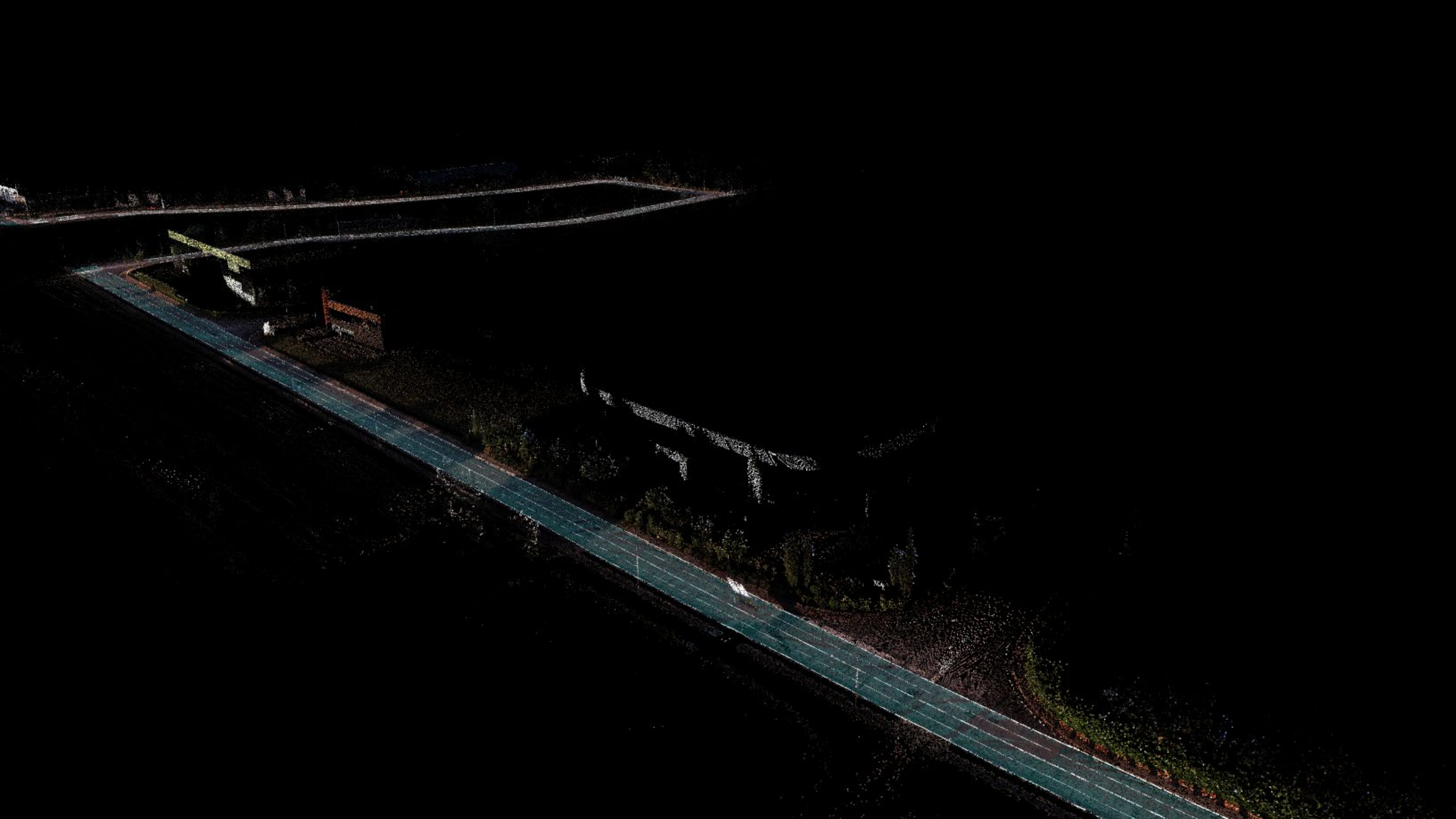
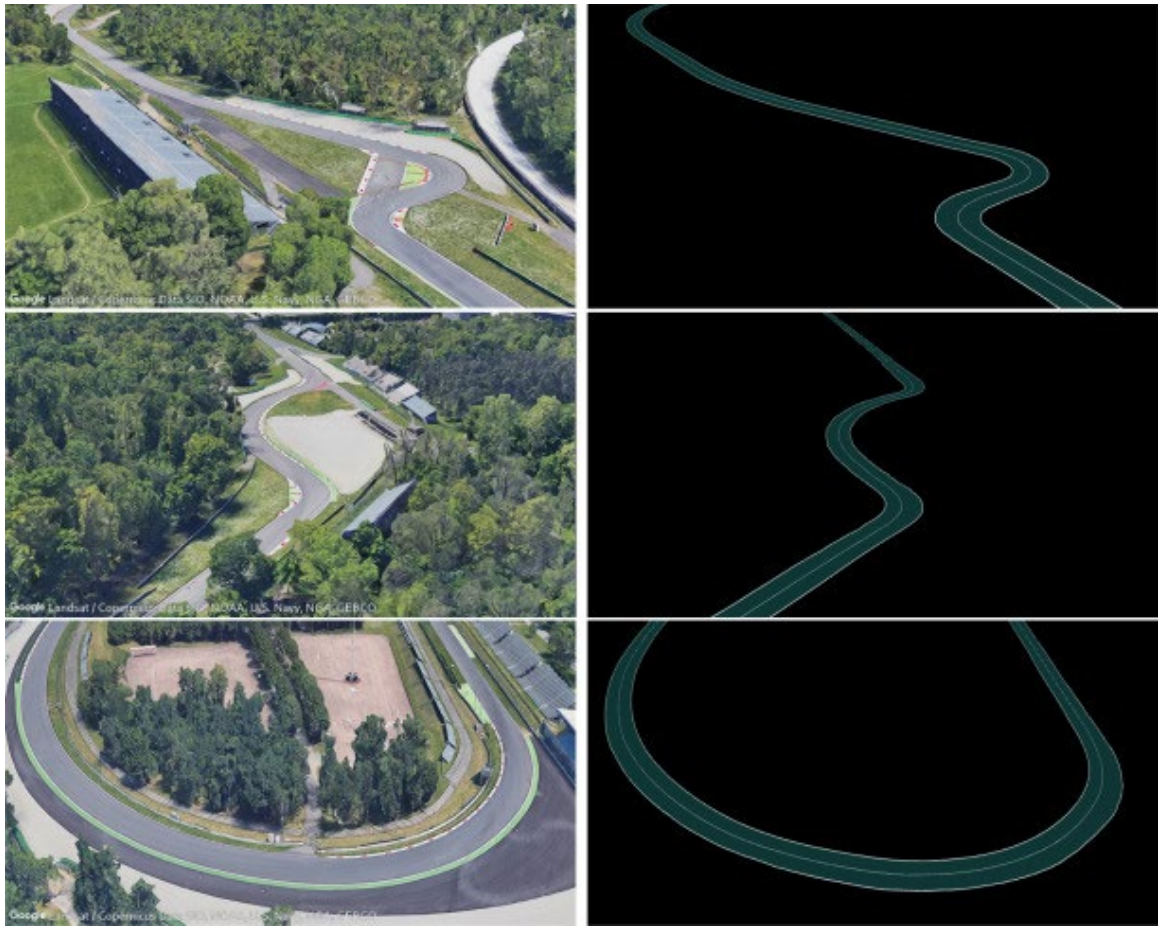
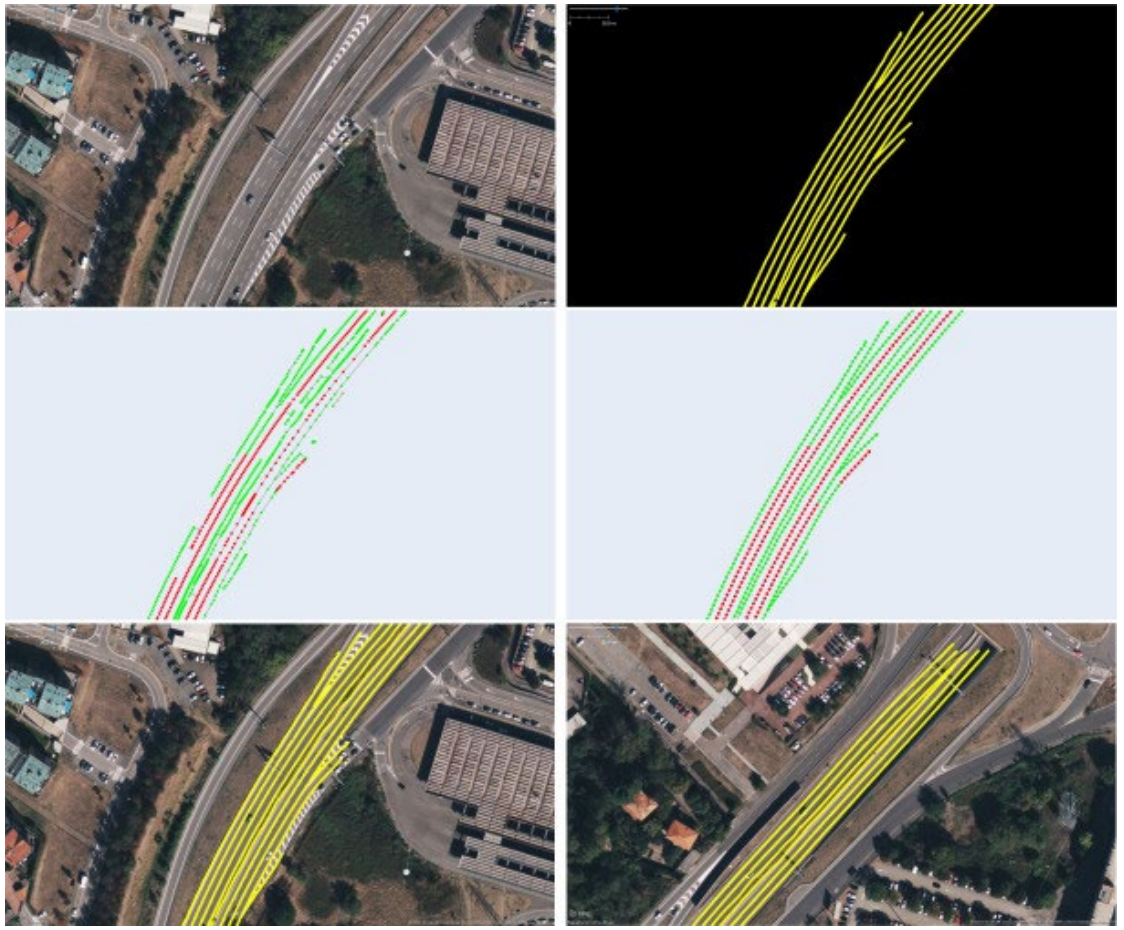


Semantic Mapping

Results





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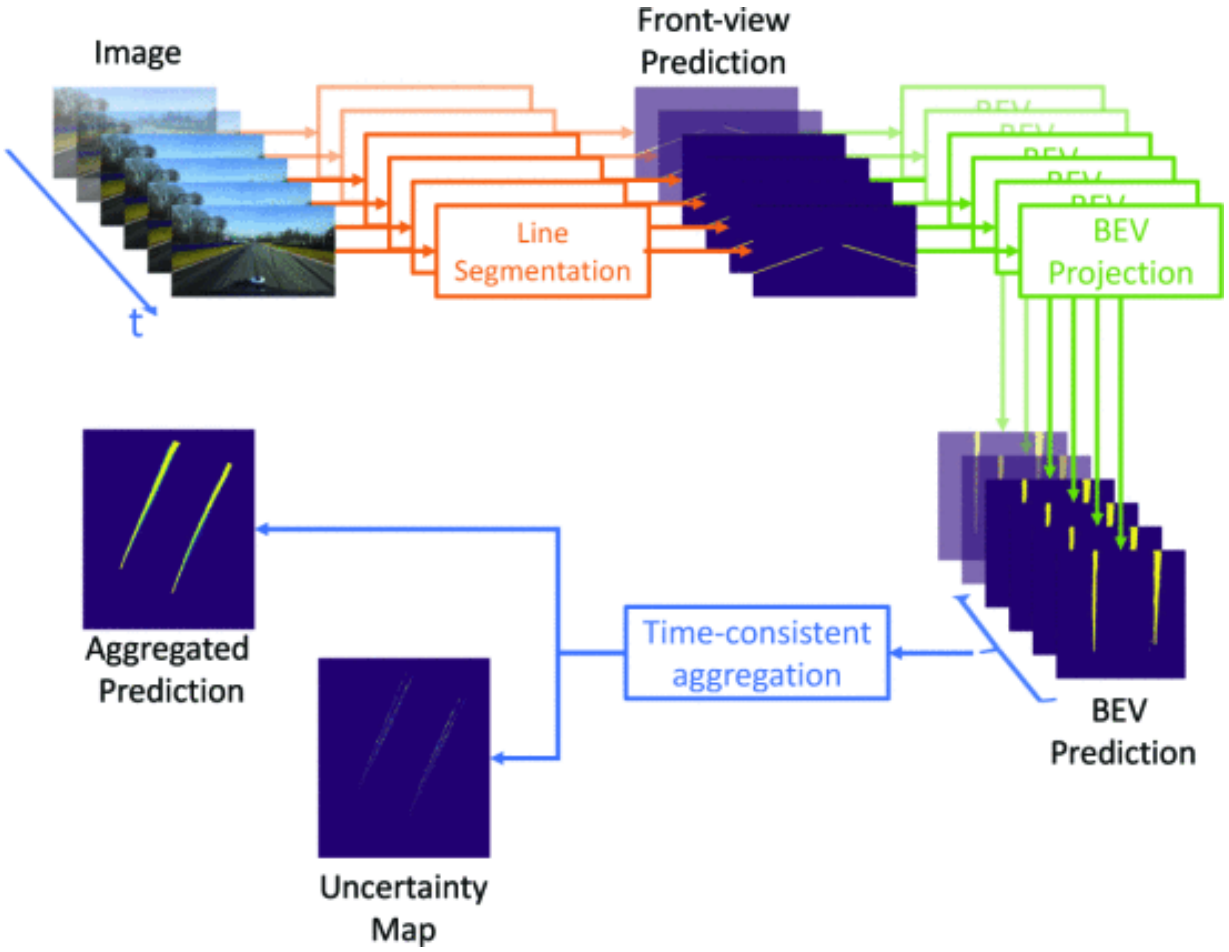
Temporal Consistency

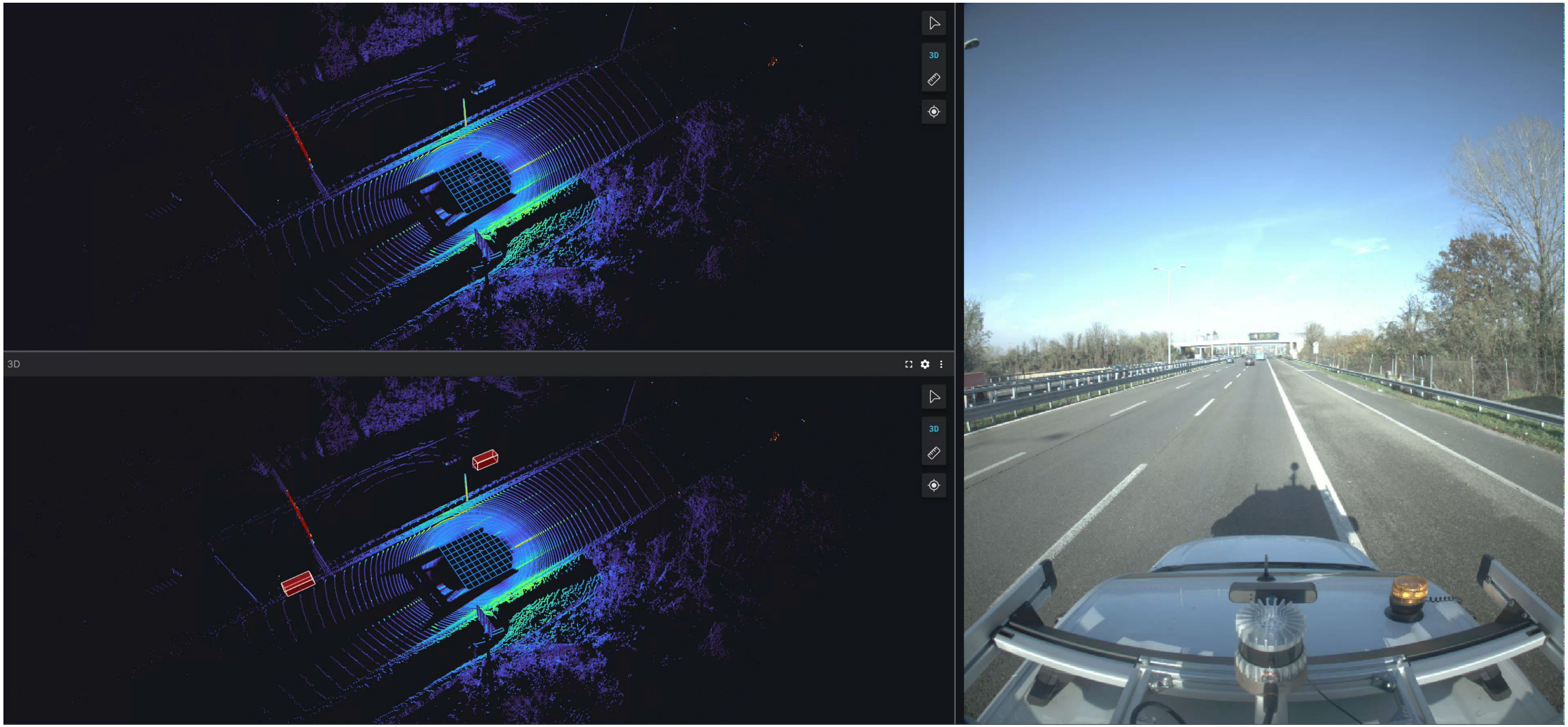
And The Rise Of Transformers



Cudrano , Paolo, Simone Mentasti, Riccardo Erminio Filippo Cortelazzo , and Matteo Matteucci. "OptimusLine: Consistent Road Line Detection Through Time." In *2024 IEEE Intelligent Vehicles Symposium (IV)*, pp. 2198-2205. IEEE, 2024.

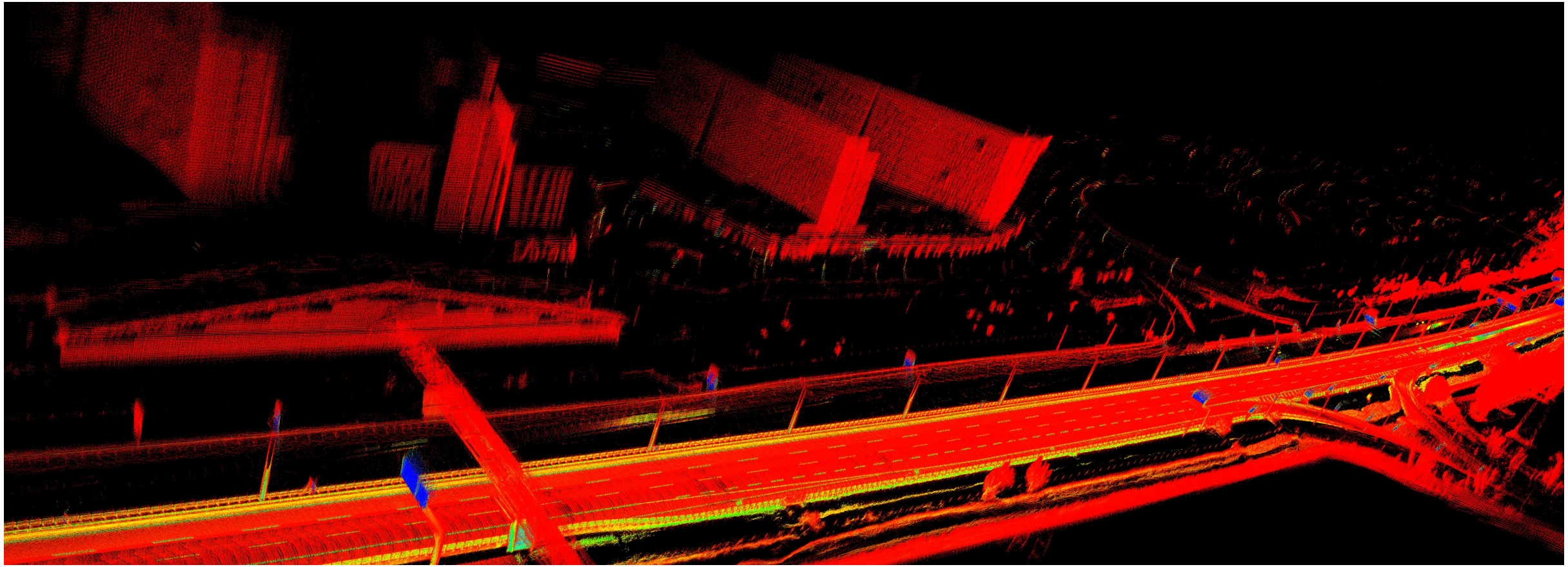
Why use cameras?

The power of high resolution LiDARDs



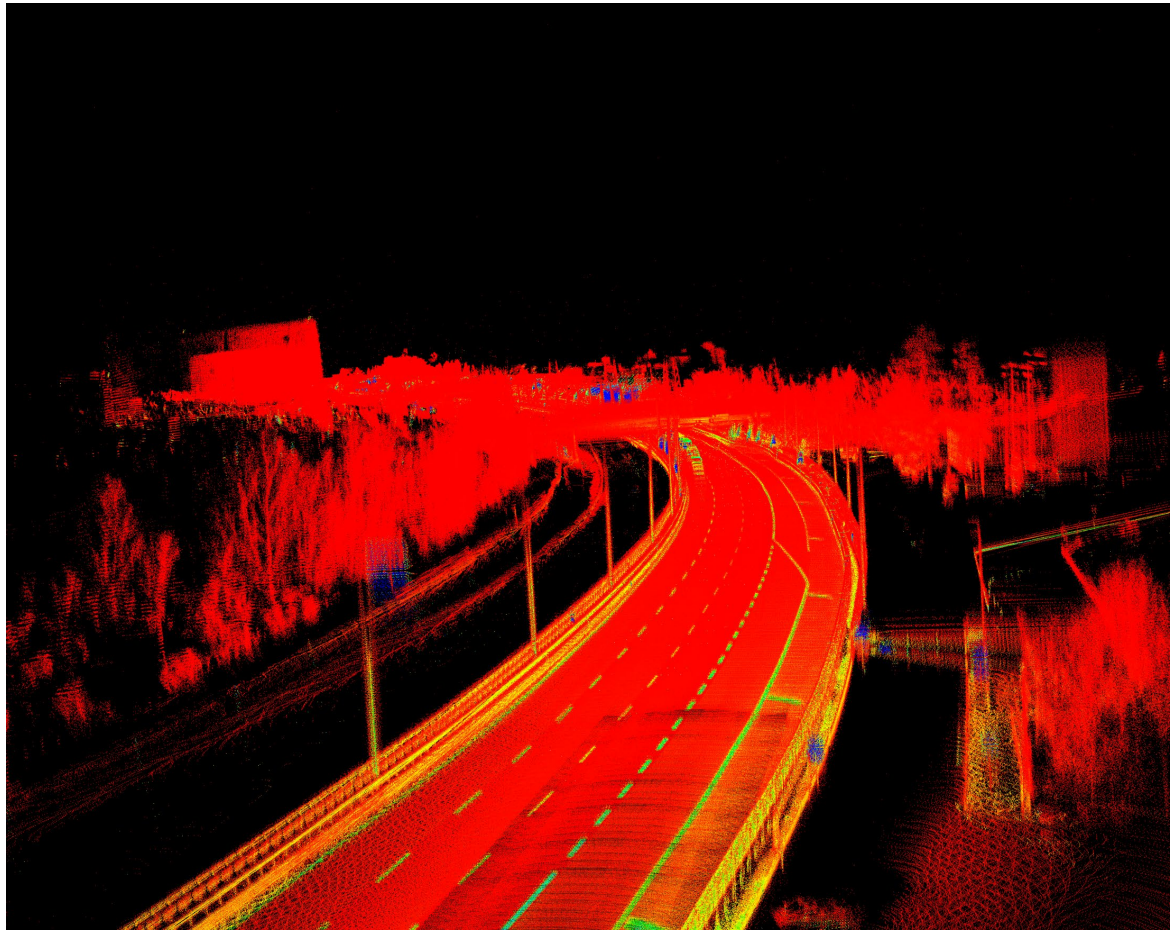
Why use cameras?

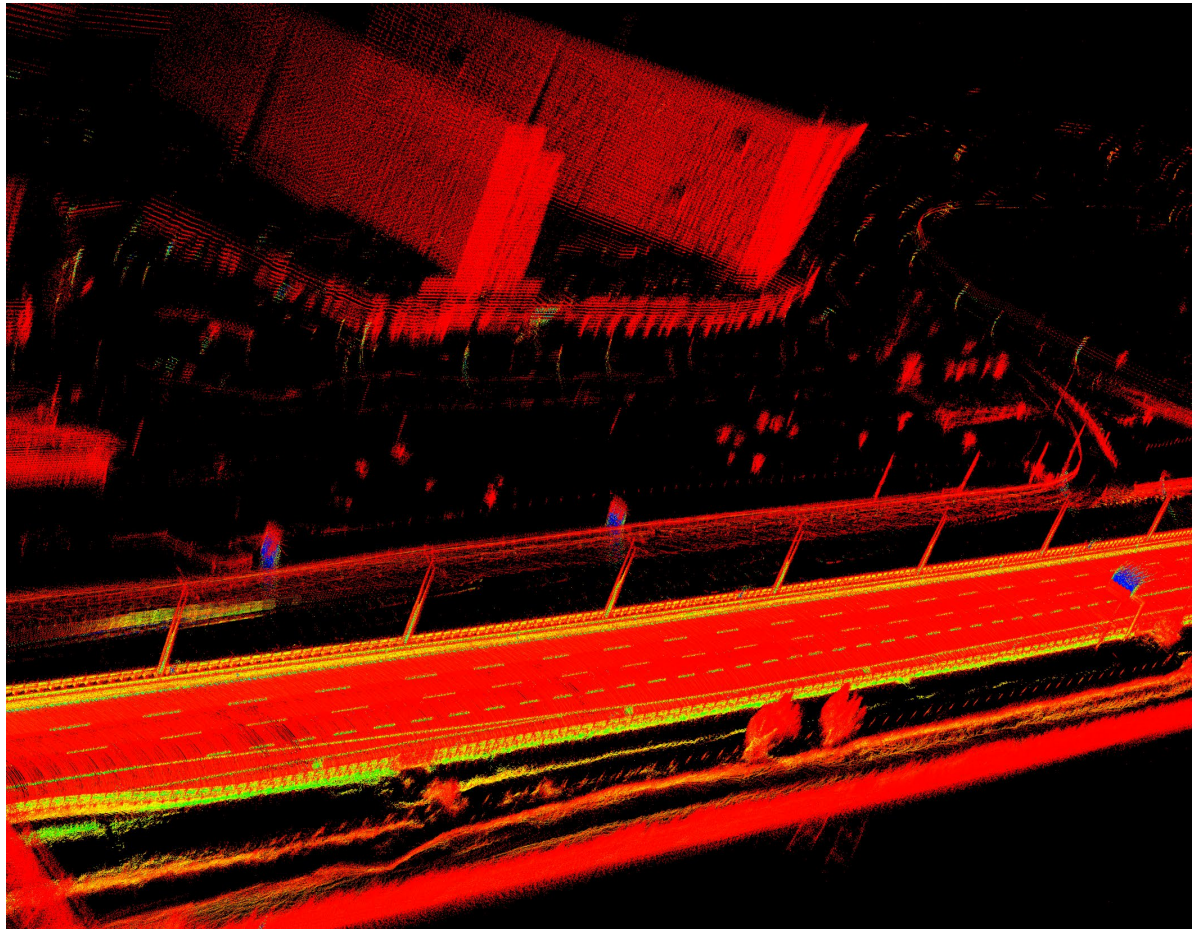
The power of high resolution LiDARDs



Why use cameras?

The power of high resolution LiDARDs



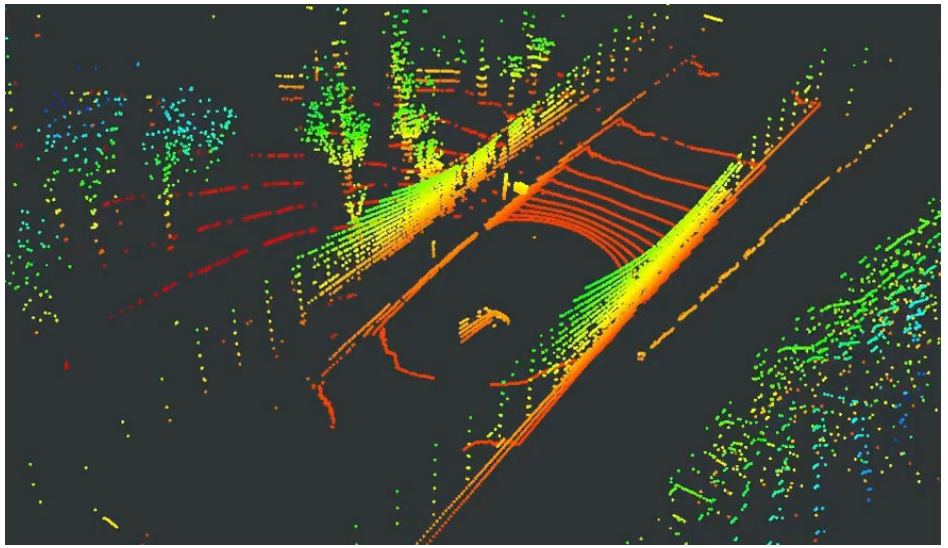


Seeing the others

Sensors with semantic

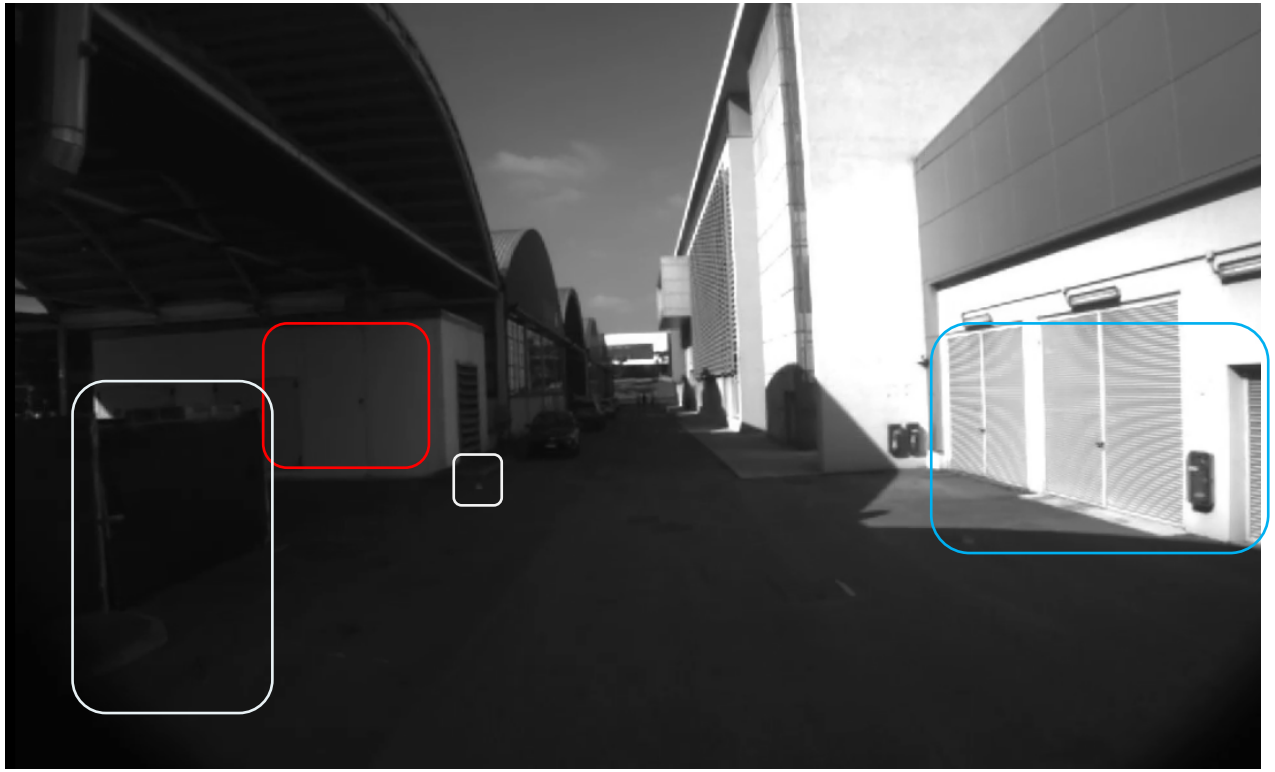
Cameras

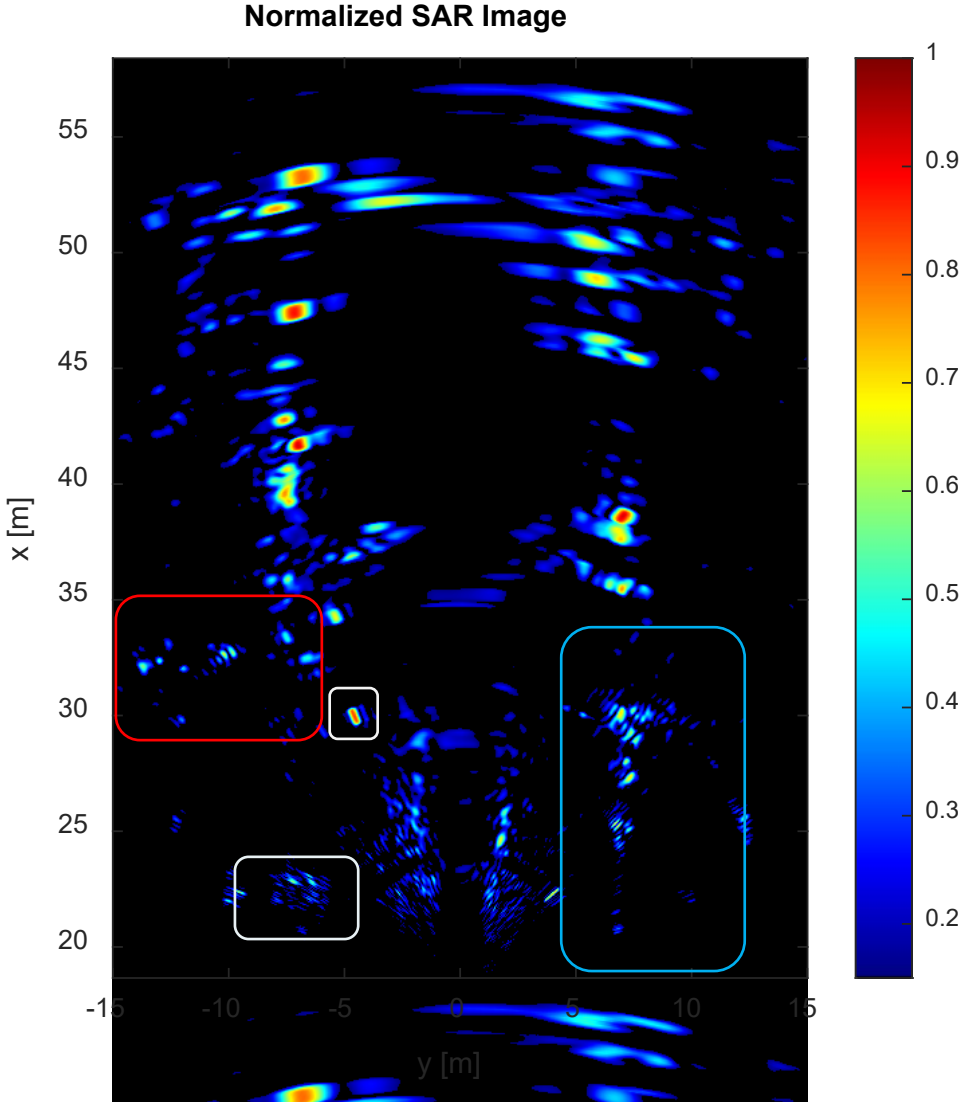
LiDARs



Seeing the others

Radars



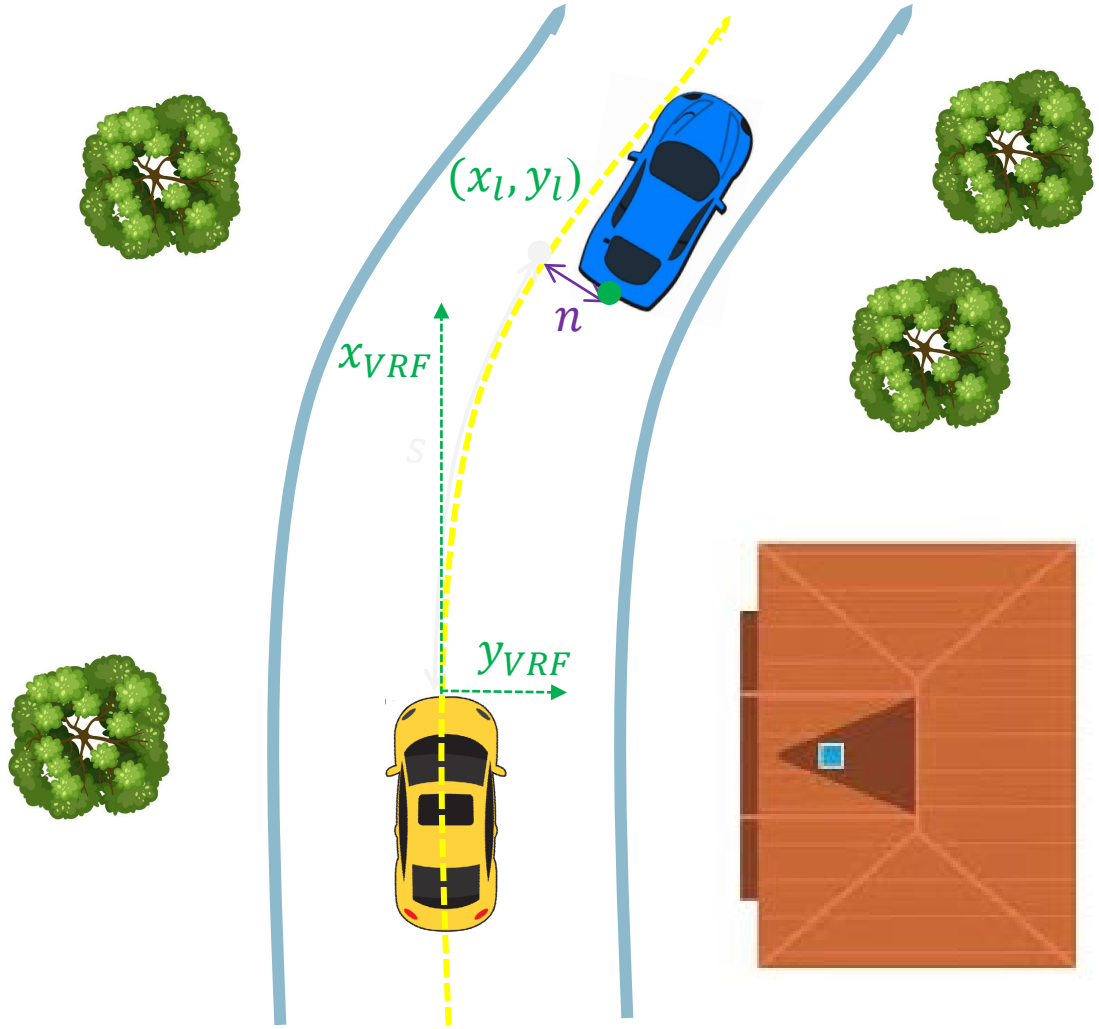


Seeing the others

Only the relevant ones

The object you are really interested in are the one you are going to crash with

Represent object in trajectory space



Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

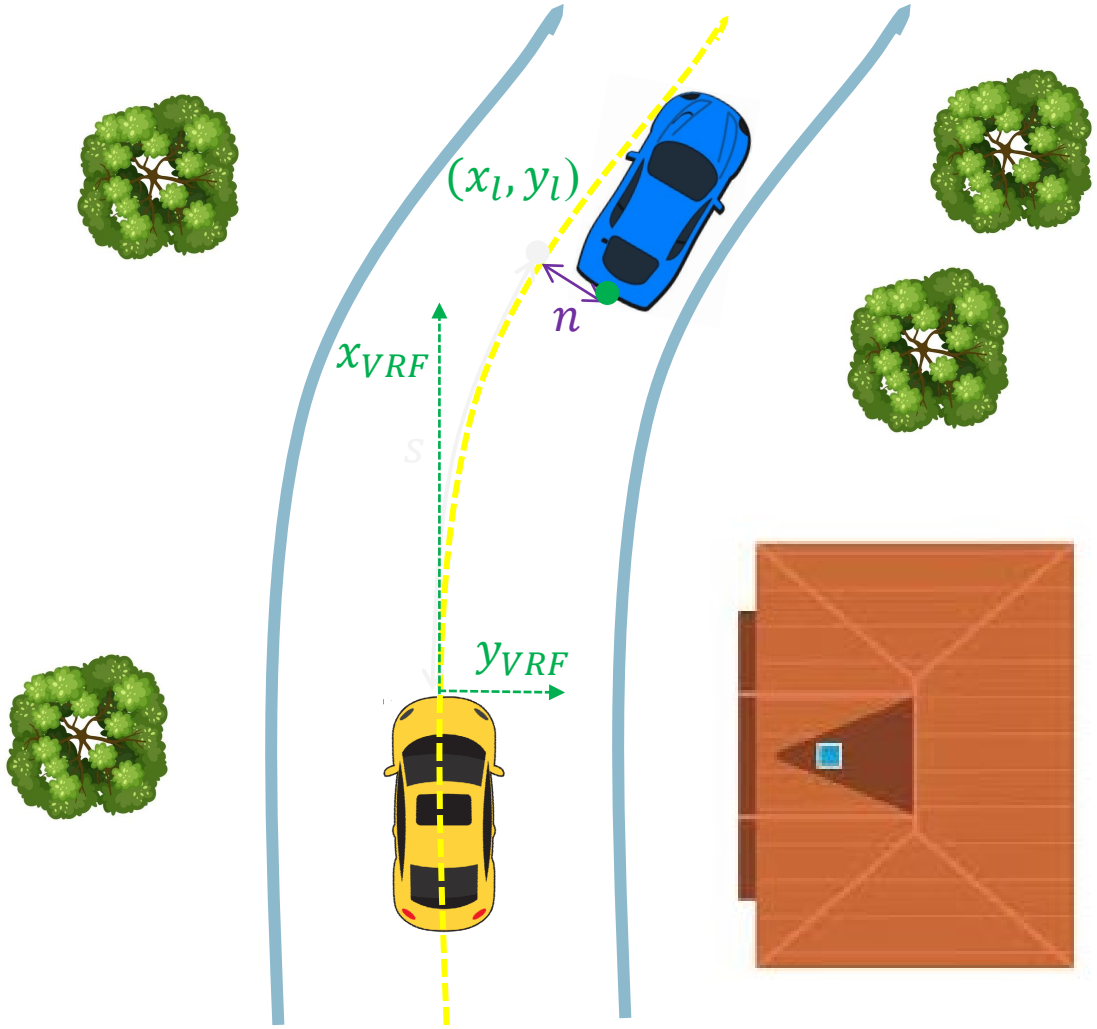
Seeing the others

In the correct reference frame

The object you are really interested in are the one you are going to crash with

Represent object in trajectory space

Sensors work in ego vehicle reference frame



Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others

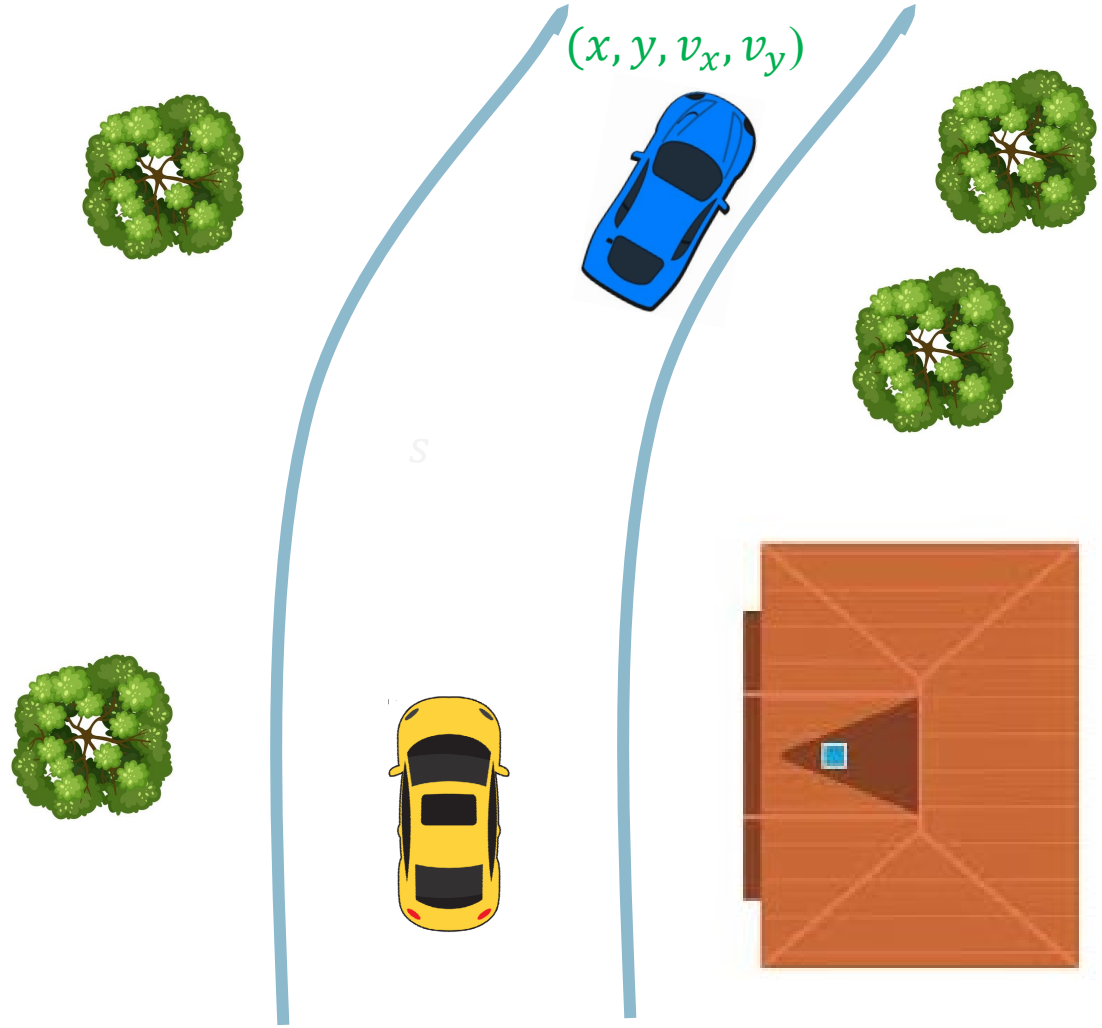
Radar

The object you are really interested in are the one you are going to crash with

Represent object in trajectory space

Sensors work in ego vehicle reference frame

RADAR (x,y,v_x,v_y)



Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others

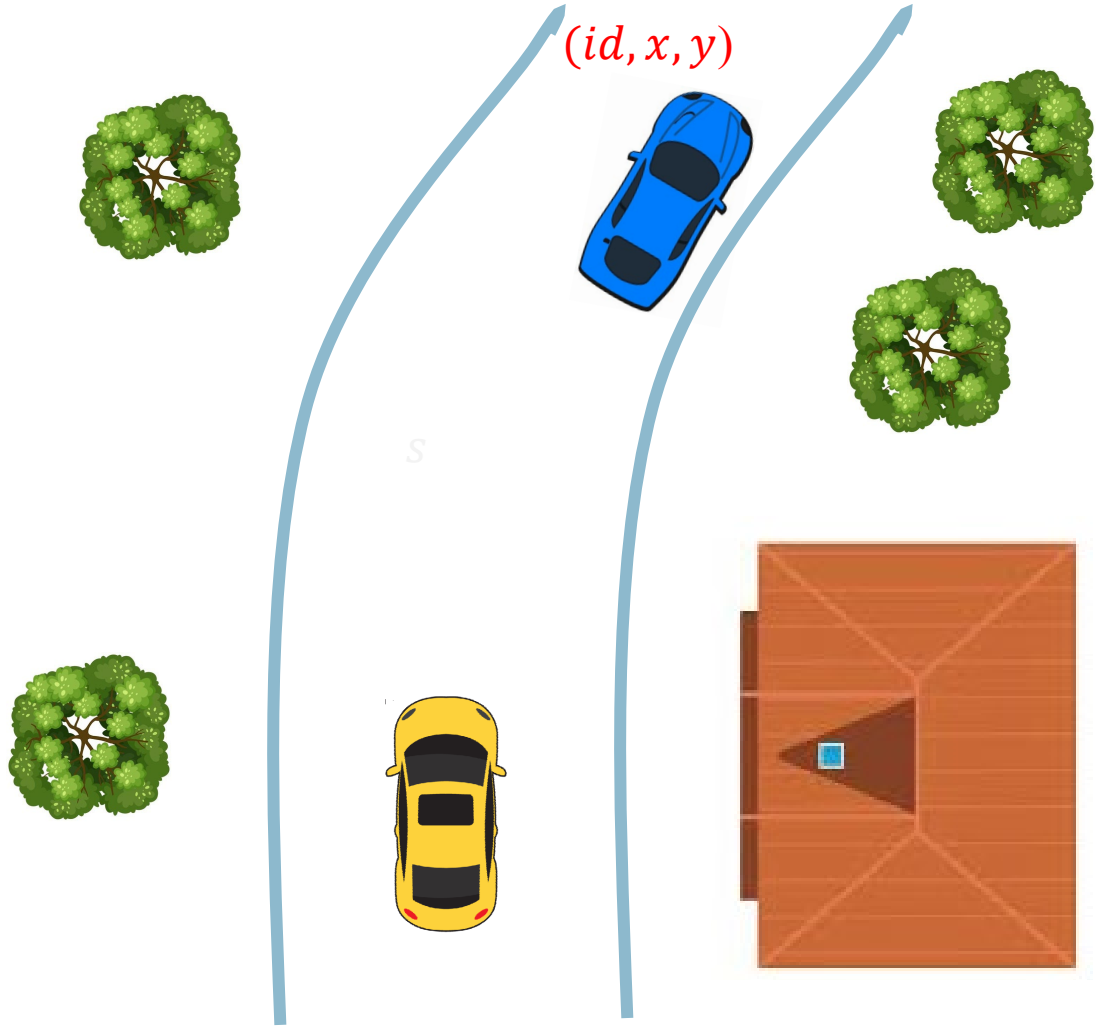
LiDAR

The object you are really interested in are the one you are going to crash with

Represent object in trajectory space

Sensors work in ego vehicle reference frame

RADAR (x,y,v_x,v_y)
LiDAR/Camera (id,x,y)



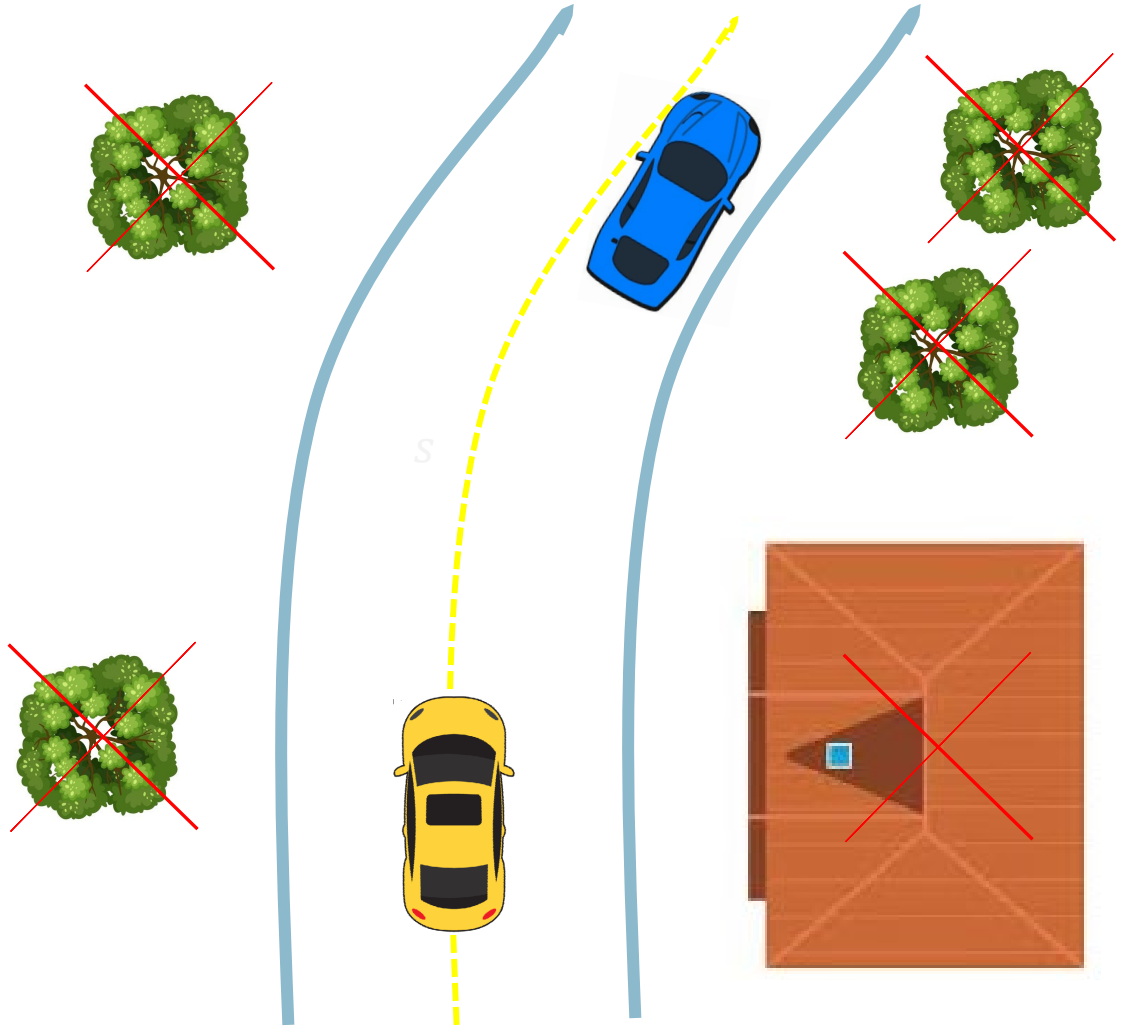
Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others

On the road

Vision provide us the road shape

Everything outside of the boundaries is discarded



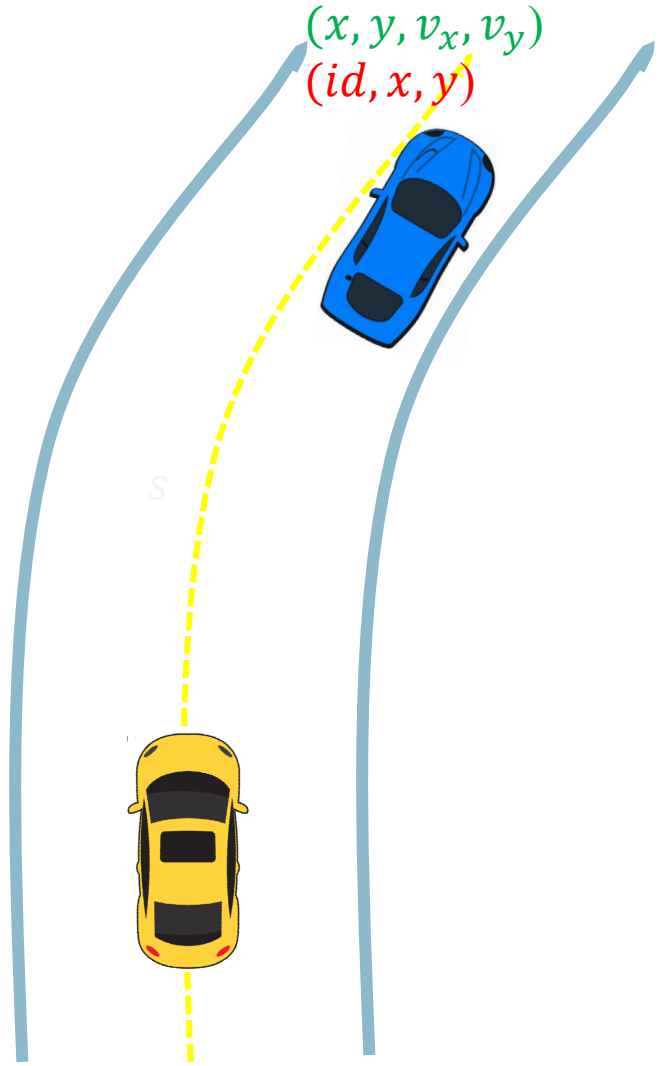
Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others

Fusion

First we linearly combine the two sensors

$$\begin{cases} x_{F_j}^{VRF} = 0.8\, x_{l,o_i}^{VRF} + 0.2\, x_{r,o_j}^{VRF} \\ y_{F_j}^{VRF} = 0.8\, y_{l,o_i}^{VRF} + 0.2\, y_{r,o_j}^{VRF} \\ V_{x,F_j}^{VRF} = V_{x,r_j}^{VRF} \\ V_{y,F_j}^{VRF} = V_{y,r_j}^{VRF} \end{cases}$$

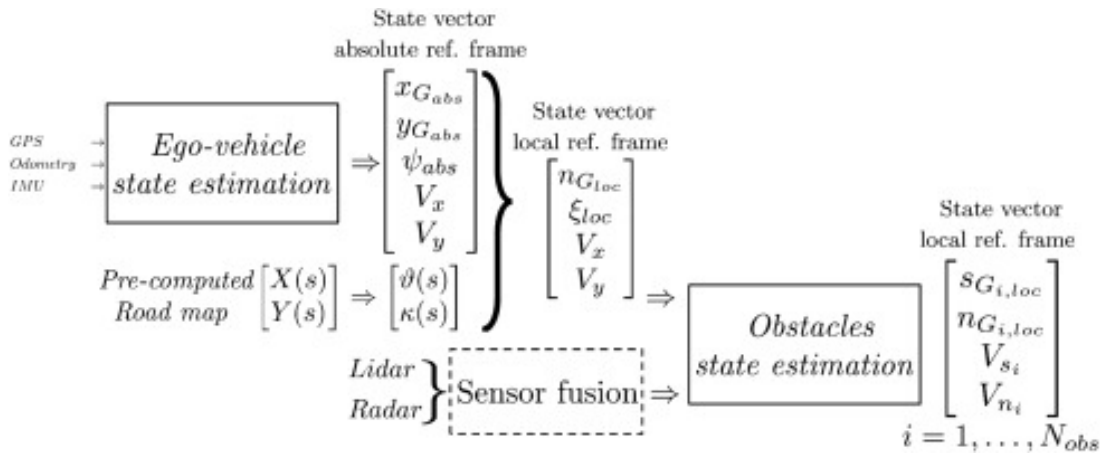


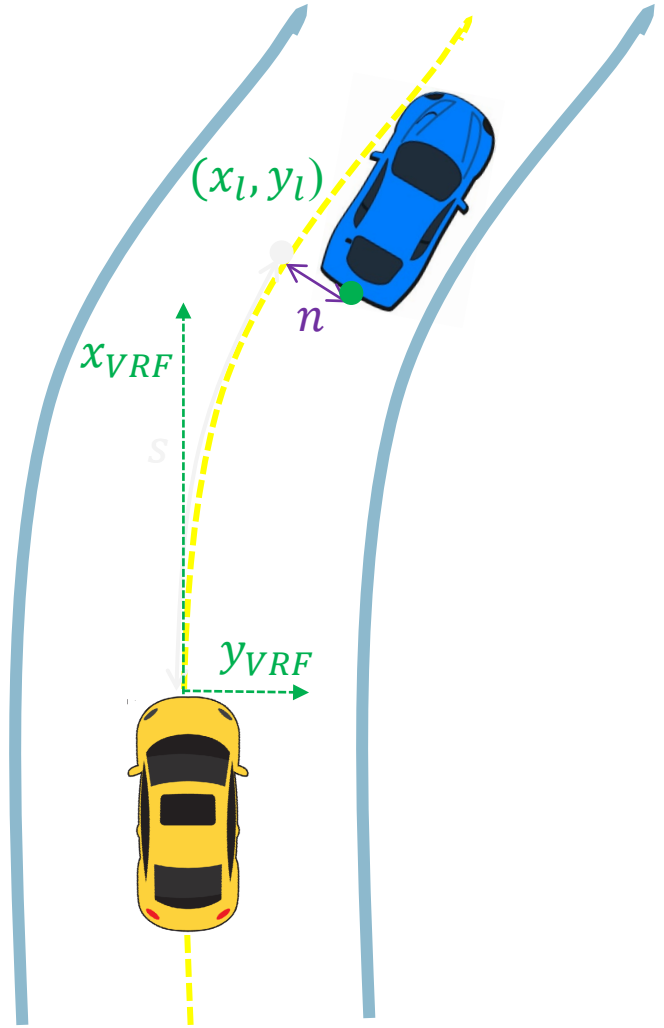
Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others

Joint state

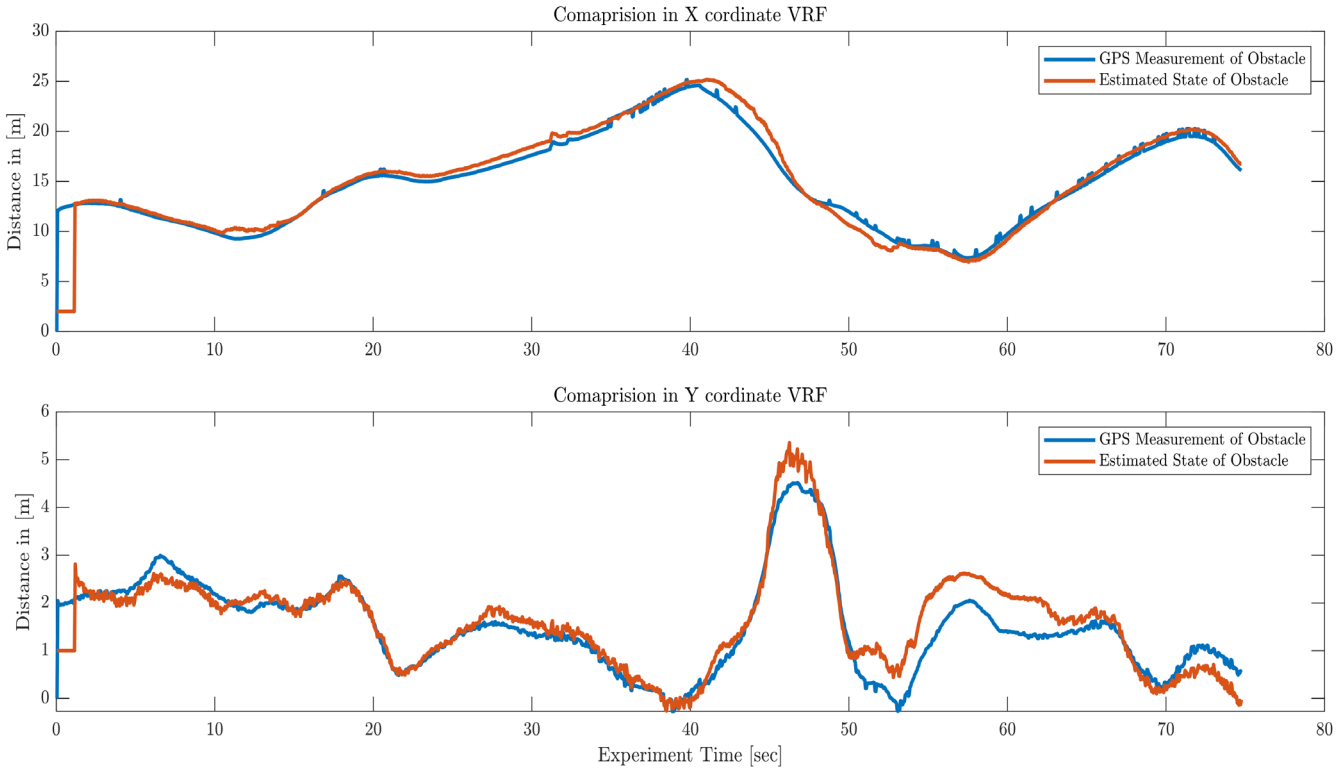
Then we represent the obstacle referenced to the ideal ego vehicle trajectory

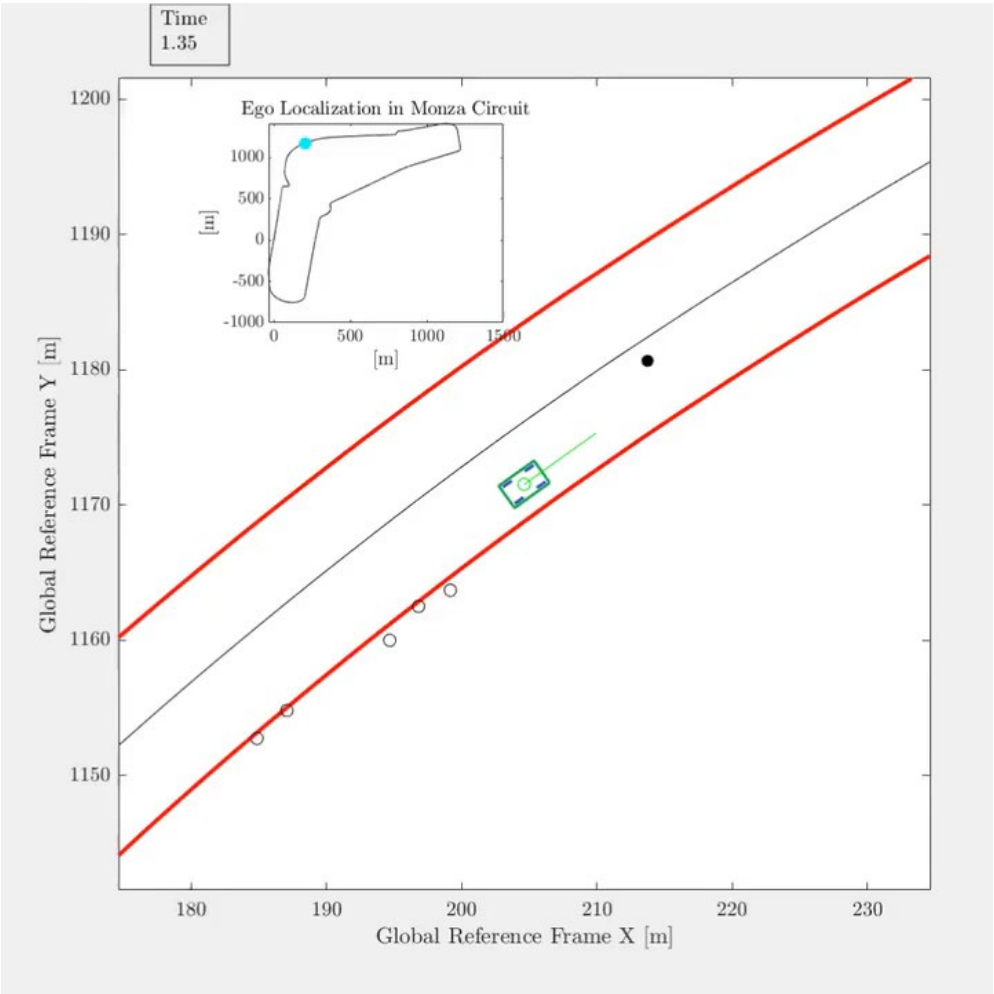




Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

Seeing the others



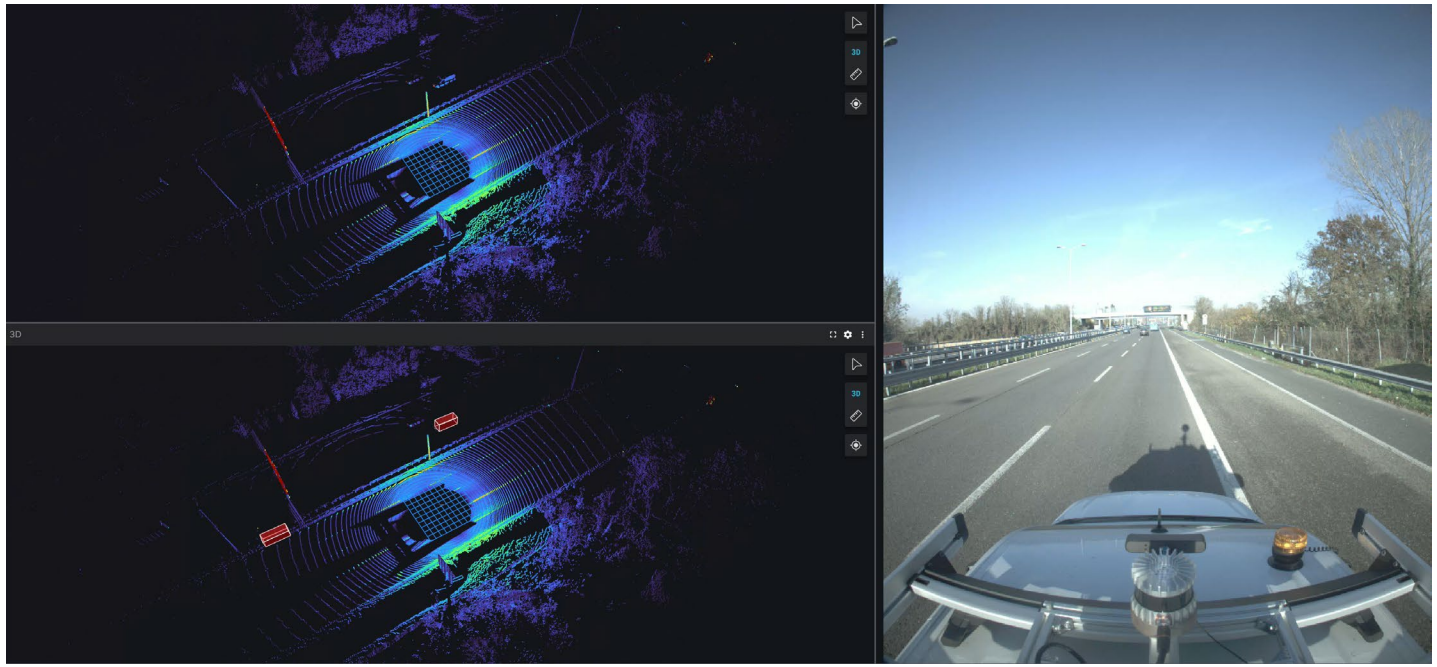


Bersani, M., Mentasti, S., Dahal, P., Arrigoni, S., Vignati, M., Cheli, F. and Matteucci, M., 2021. An integrated algorithm for ego-vehicle and obstacles state estimation for autonomous driving. *Robotics and Autonomous Systems*, *139*, p.103662.

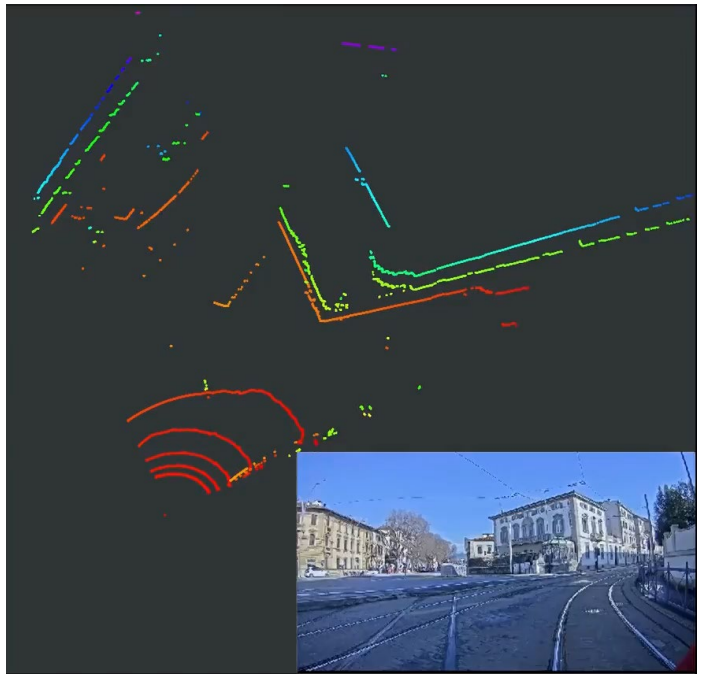
Seeing the others

LiDAR data

High-resolution LiDAR (128 planes)

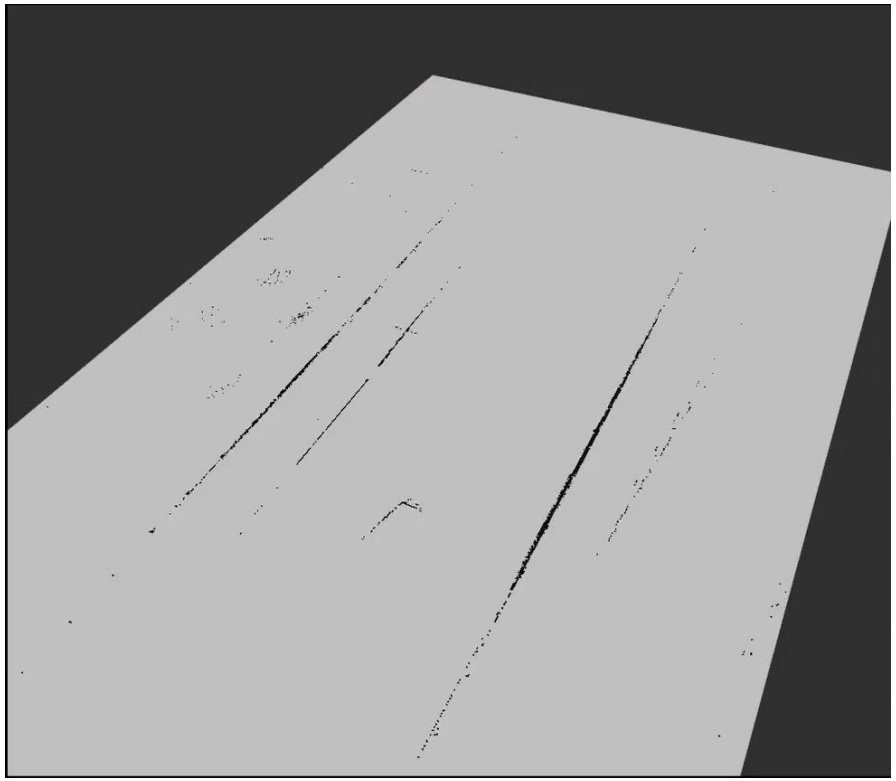


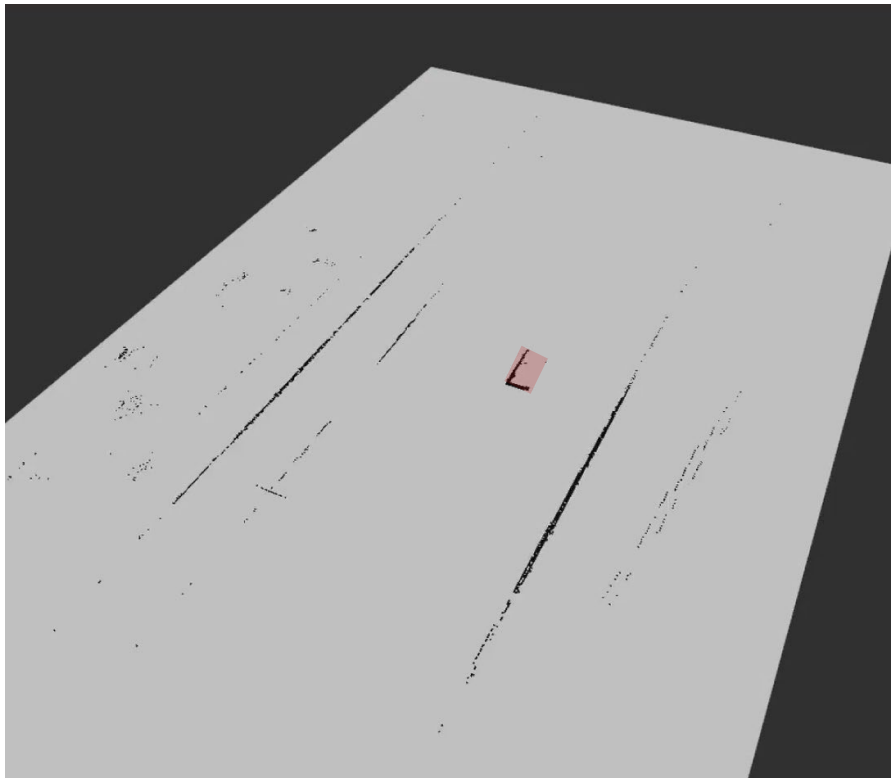
Low resolution LiDAR (8 planes)



Seeing the others

Occupancy Grid



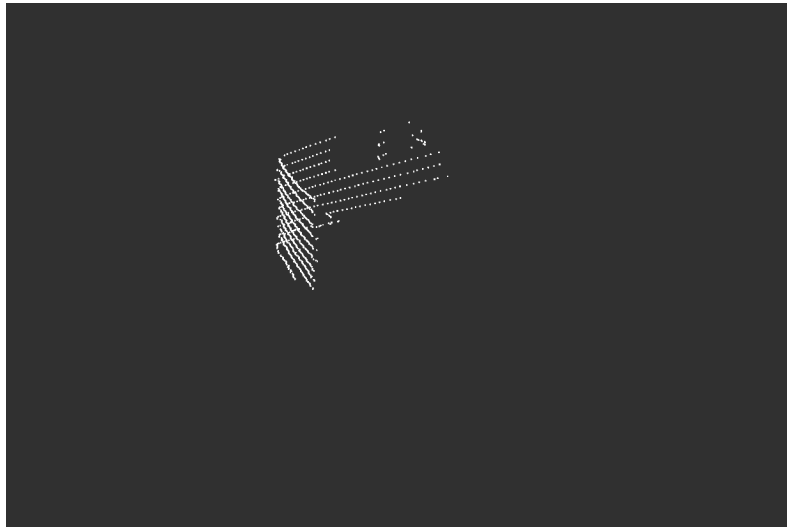


Mentasti, S., Matteucci, M., Arrigoni, S. and Cheli, F., 2021, November. Two algorithms for vehicular obstacle detection in s parse pointcloud . In *2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)* (pp. 1-6). IEEE.

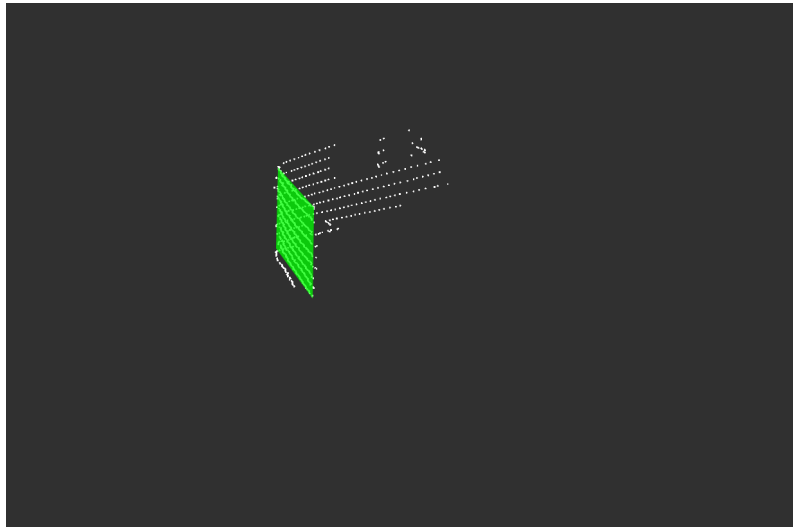
Seeing the others

3D Bounding Boxes

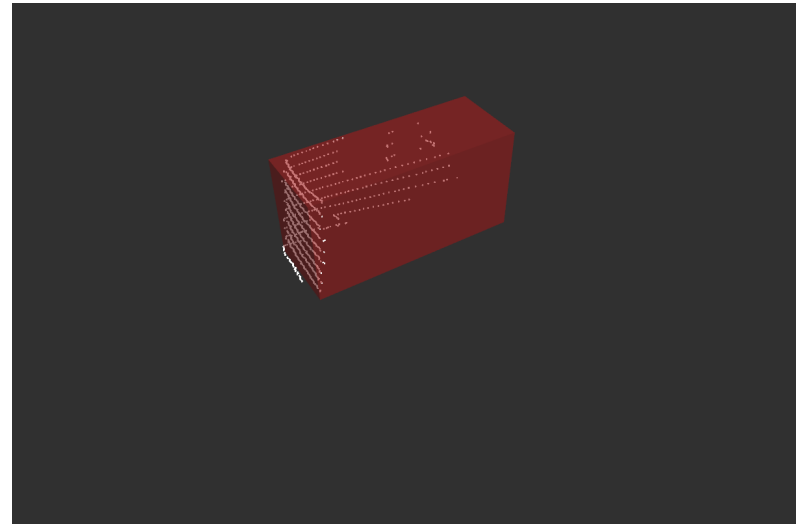
Cropped PointCloud



Plane Fitting

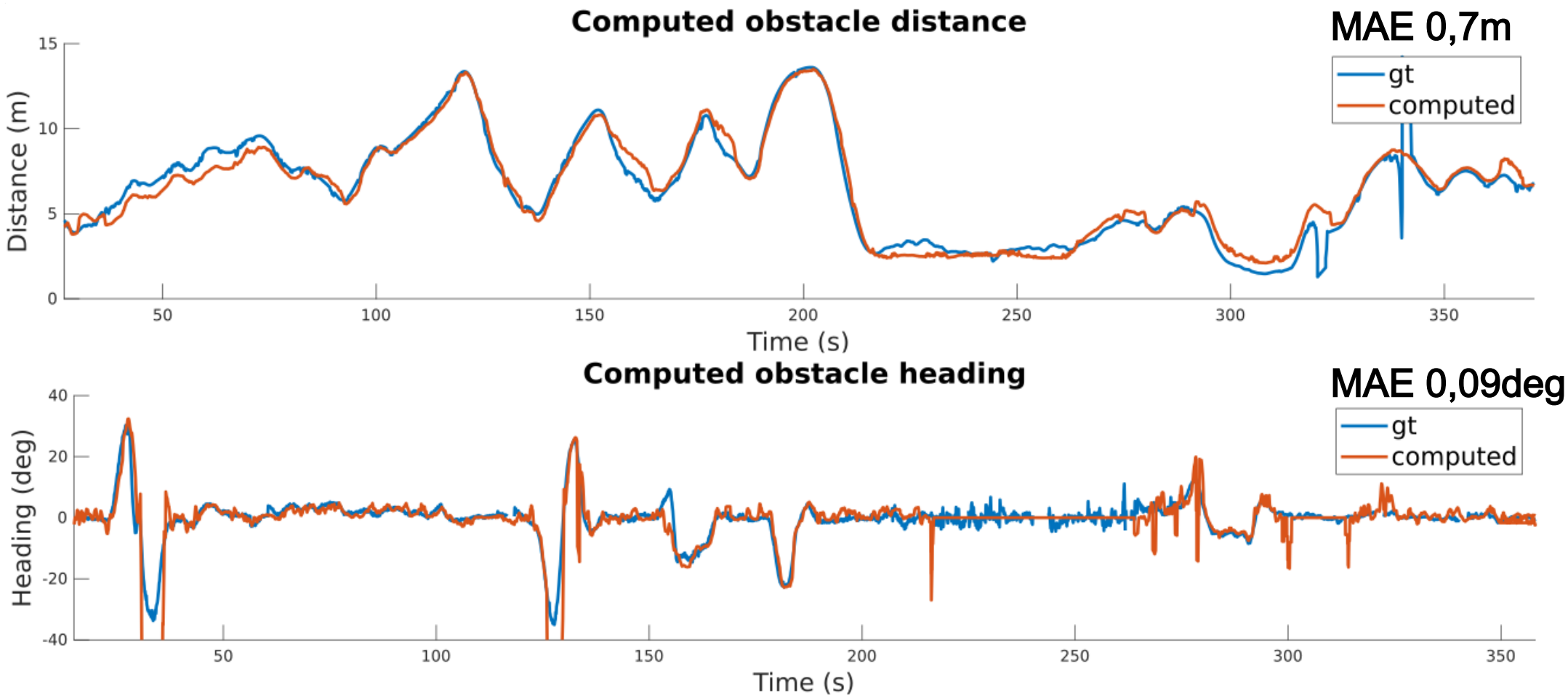


Bounding Box Fitting



Mentasti, S., Matteucci, M., Arrigoni, S. and Cheli, F., 2021, November. Two algorithms for vehicular obstacle detection in s parse pointcloud . In *2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)* (pp. 1-6). IEEE.

Seeing the others



Mentasti, S., Matteucci, M., Arrigoni, S. and Cheli, F., 2021, November. Two algorithms for vehicular obstacle detection in s parse pointcloud . In *2021 AEIT International Conference on Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE)* (pp. 1-6). IEEE.

Cooperative Connected Vehicles Perception

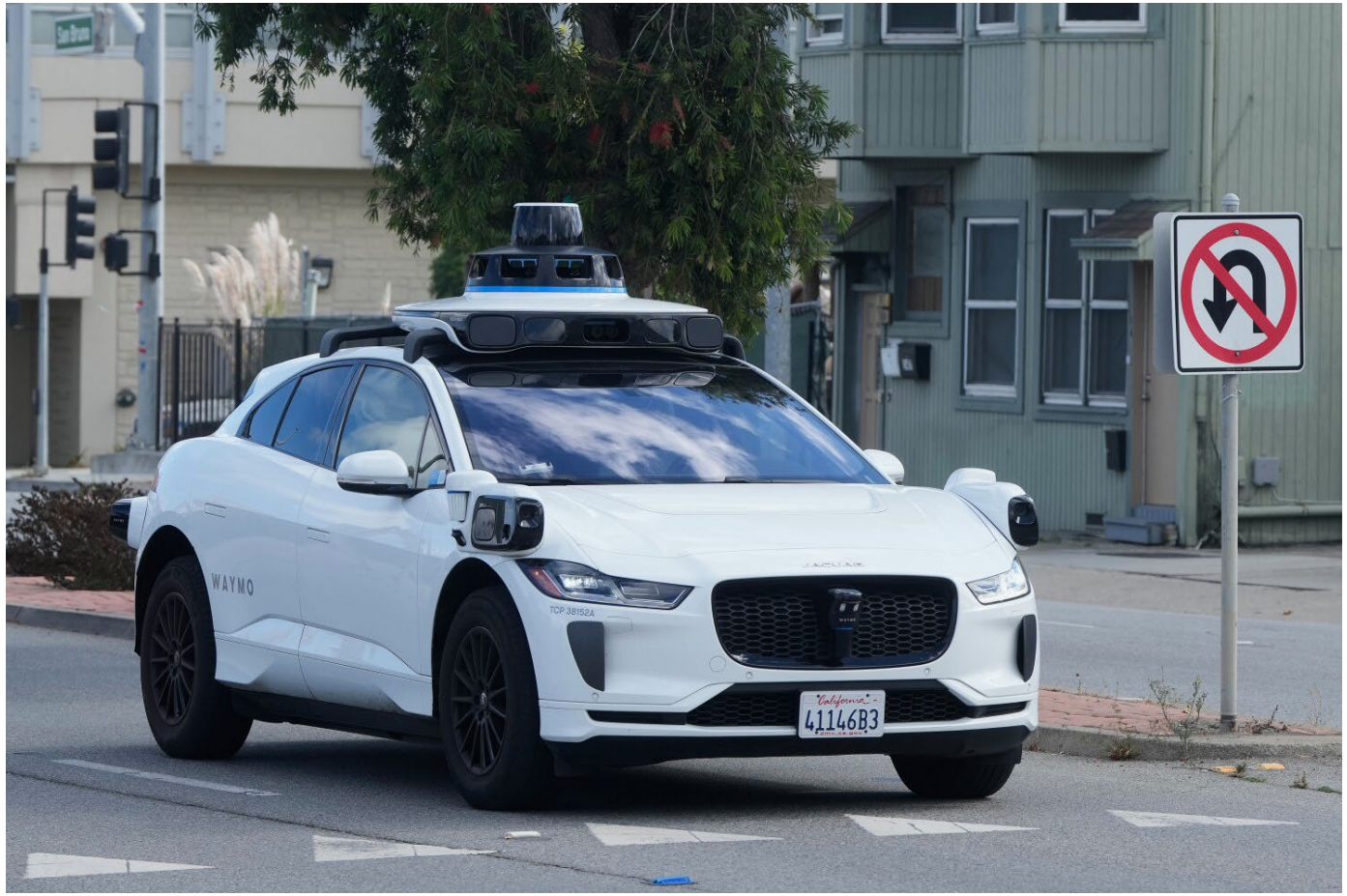
02

Autonomous Vehicles limits

Expensive

Subject to malfunctions

Fragile



Acceptability

Regulations

Explainability

Accountability

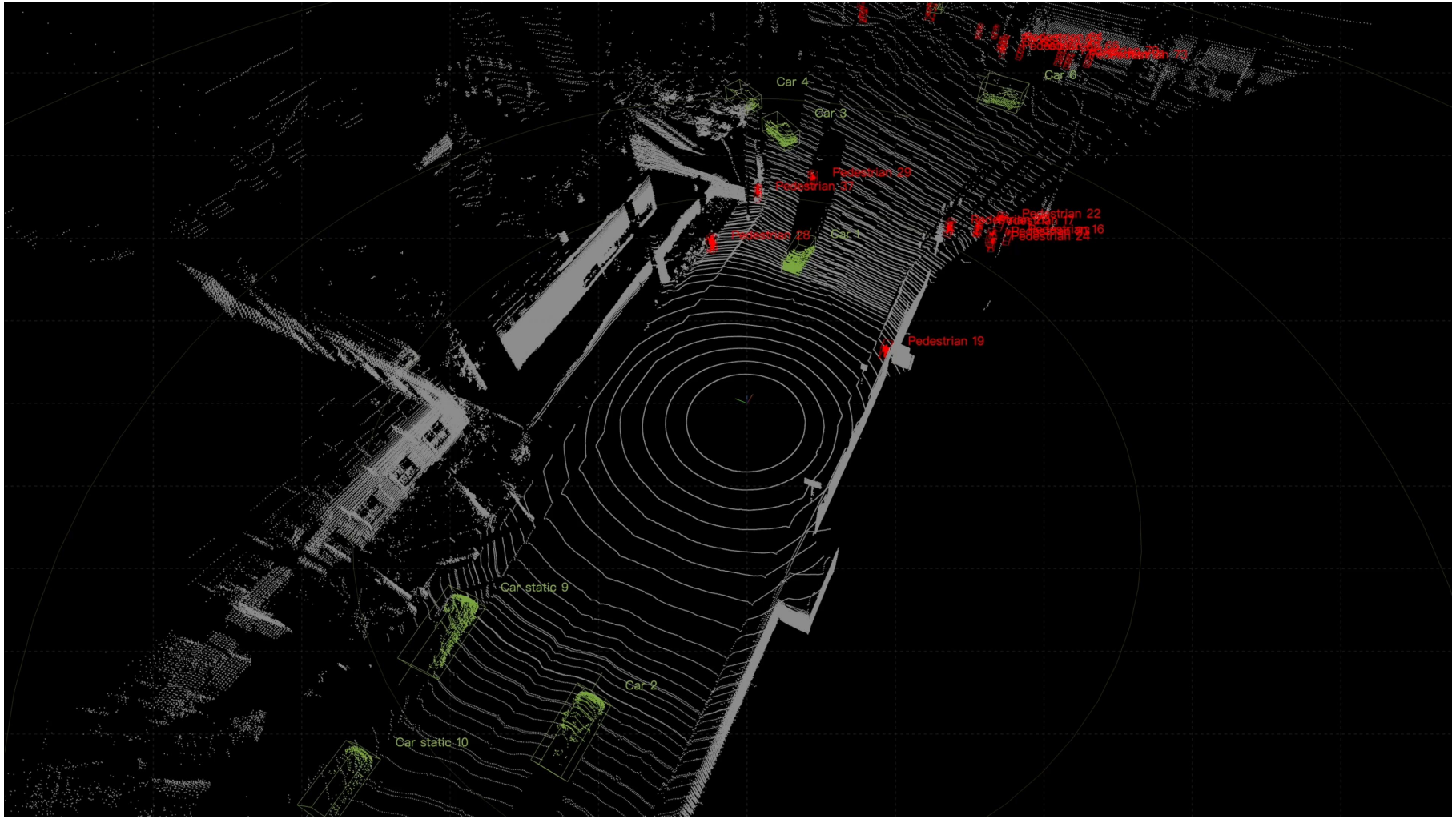
Matteucci, M., Mentasti, S., Schiaffonati , V. and Fossa, F., 2023. Contextual Challenges to Explainable Driving Automation: The Case of Machine Perception. In *Connected and Automated Vehicles: Integrating Engineering and Ethics* (pp. 37-61). Cham: Springer Nature Switzerland.

Instrumented Public Transportation

90/91 Milan

Florence Tram Line

From a higher point of view

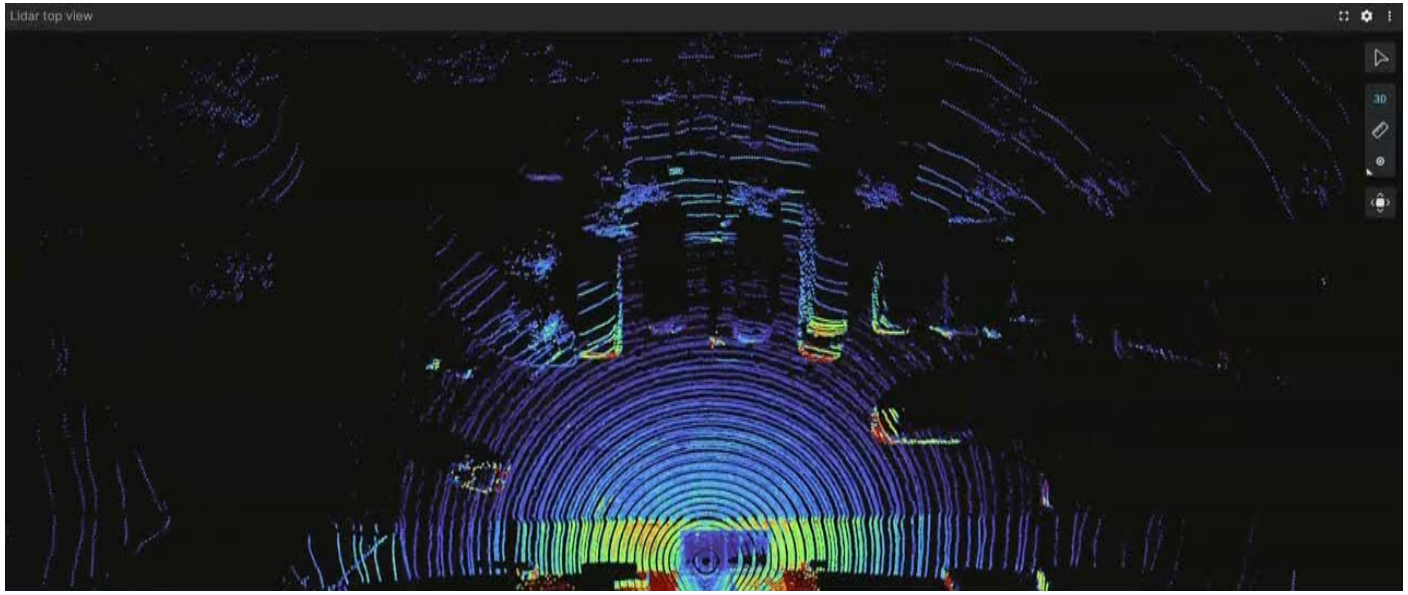


Xiang, H., Zheng, Z., Xia, X., Xu, R., Gao, L., Zhou, Z., Han, X., Ji, X., Li, M., Meng, Z. and Jin, L., 2024, September. V2x-real: a largs-scale dataset for vehicle-to-everything cooperative perception. In *European Conference on Computer Vision* (pp. 455-470). Cham: Springer Nature Switzerland.

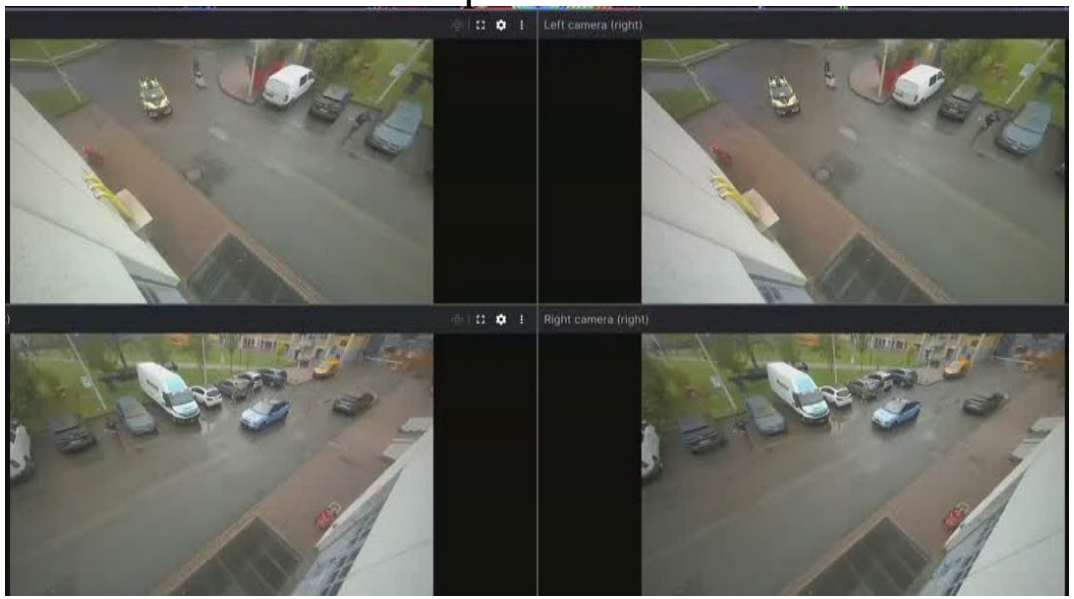
From a higher point of view

PoliMi Test Area

Dome LiDAR



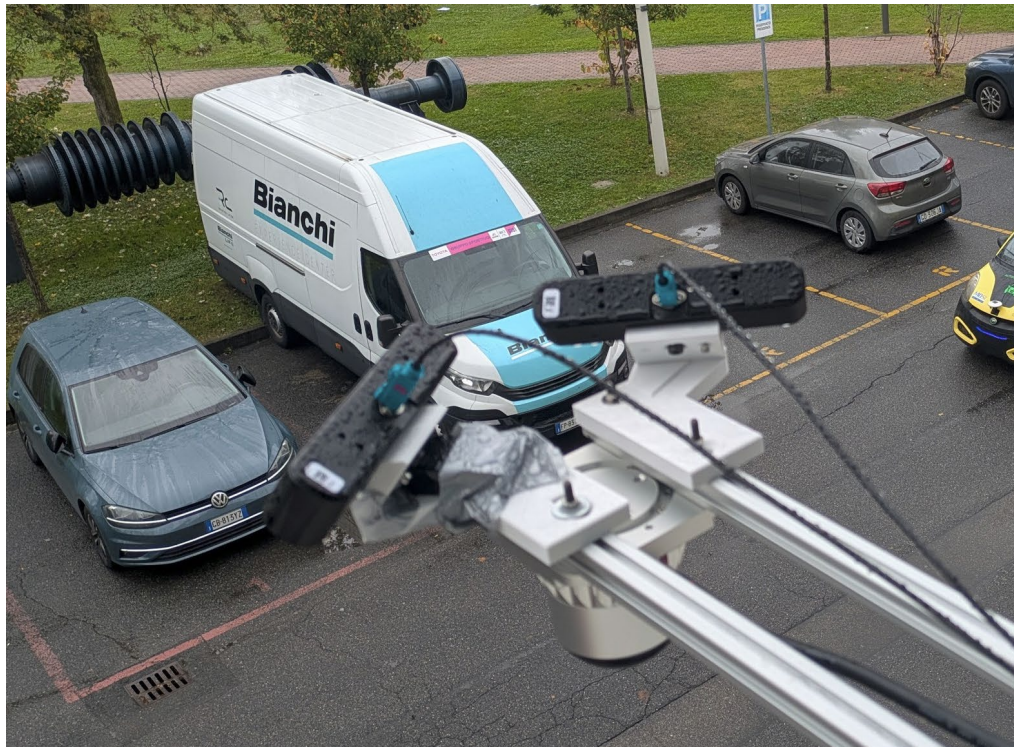
Multiple Cameras

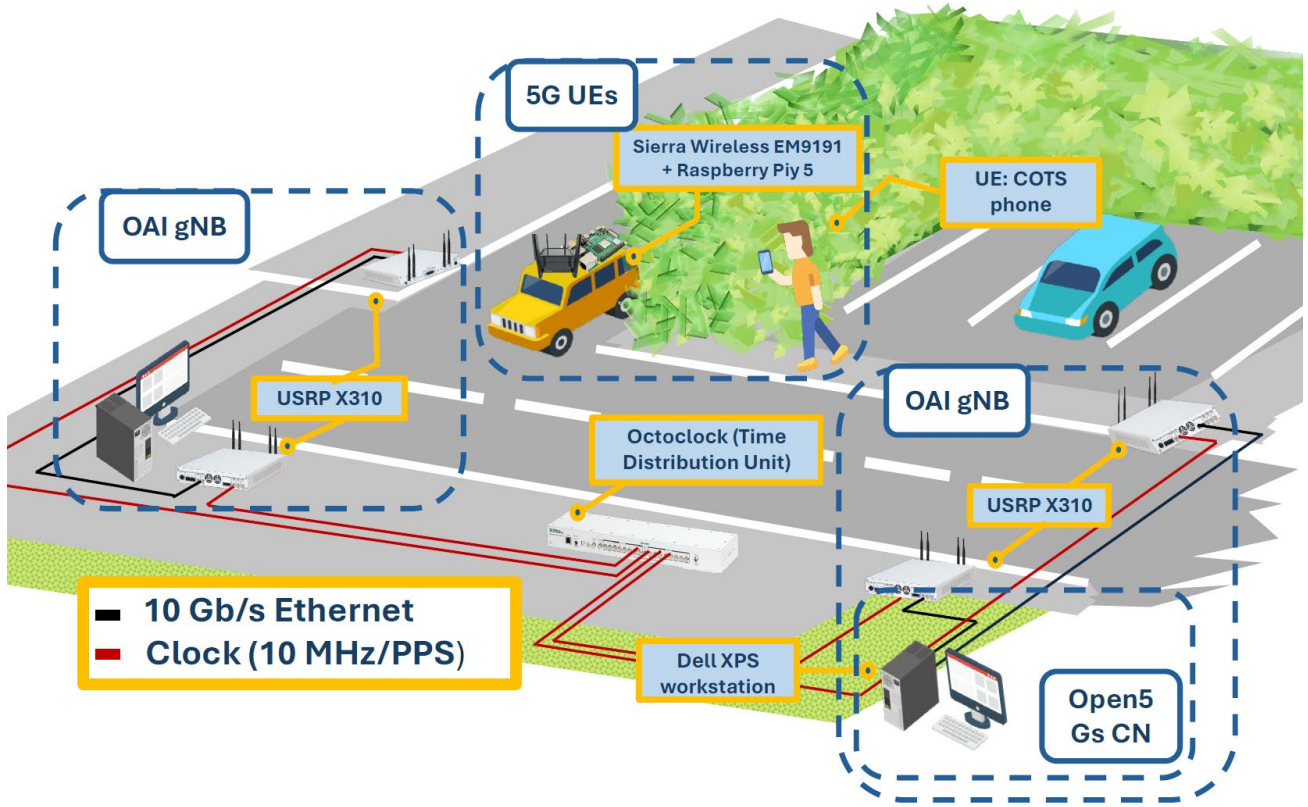


Mentasti, S., Barbiero, A. and Matteucci, M., 2024, June. Heterogeneous Data Fusion for Accurate Road User Tracking: A Distri but ed Multi-Sensor Collaborative Approach. In *2024 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1658-1665). IEEE.

From a higher point of view

PoliMi Test Area





Mentasti, S., Barbiero, A. and Matteucci, M., 2024, June. Heterogeneous Data Fusion for Accurate Road User Tracking: A Distri but ed Multi-Sensor Collaborative Approach. In *2024 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1658-1665). IEEE.

Testing Scenarios

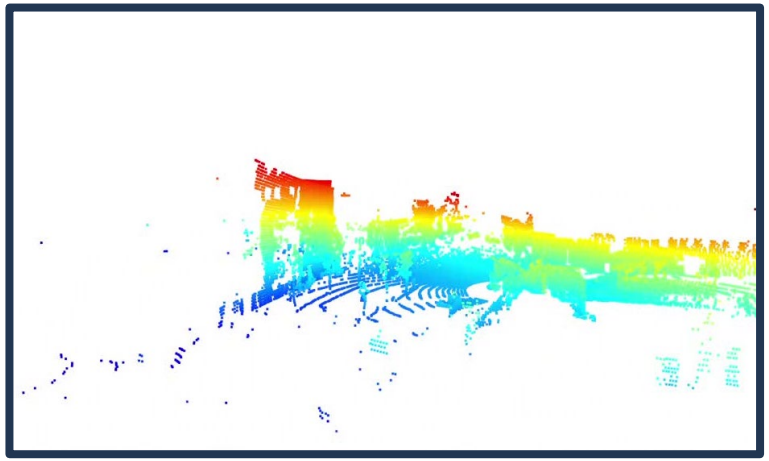
Vulnerable Road Users Protection

Autonomous parking

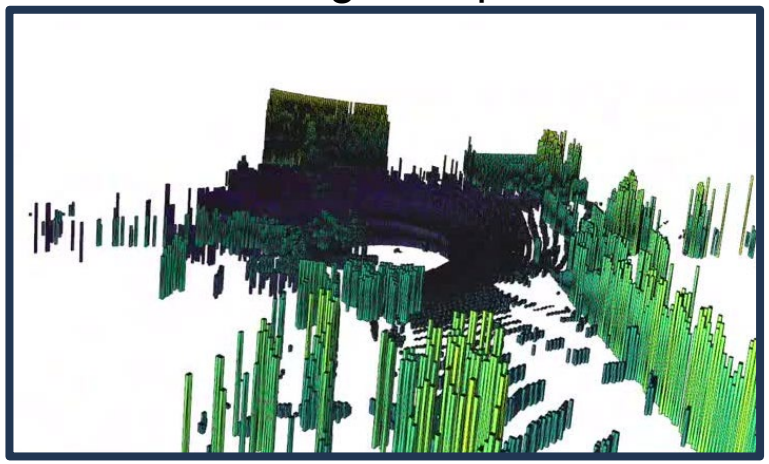
Limiting the power

2.5D grid -maps

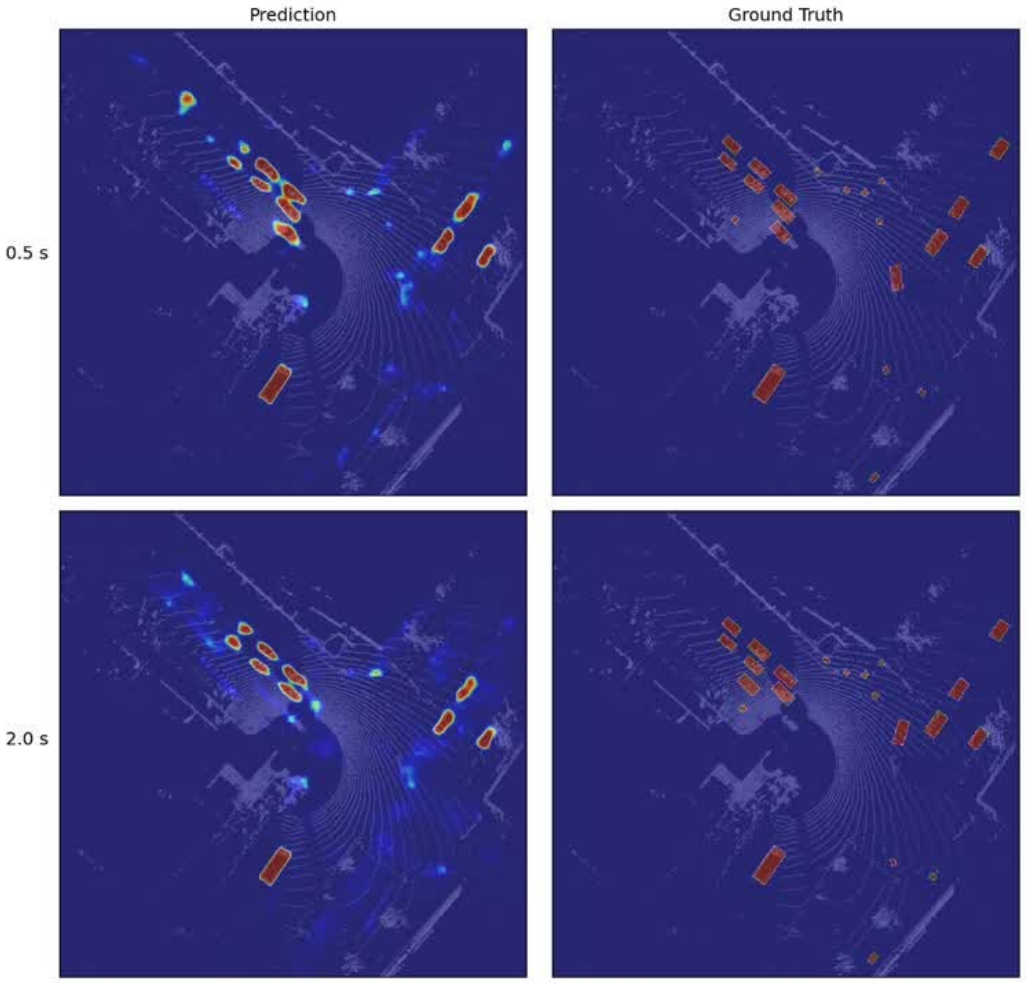
PointCloud



Height Map

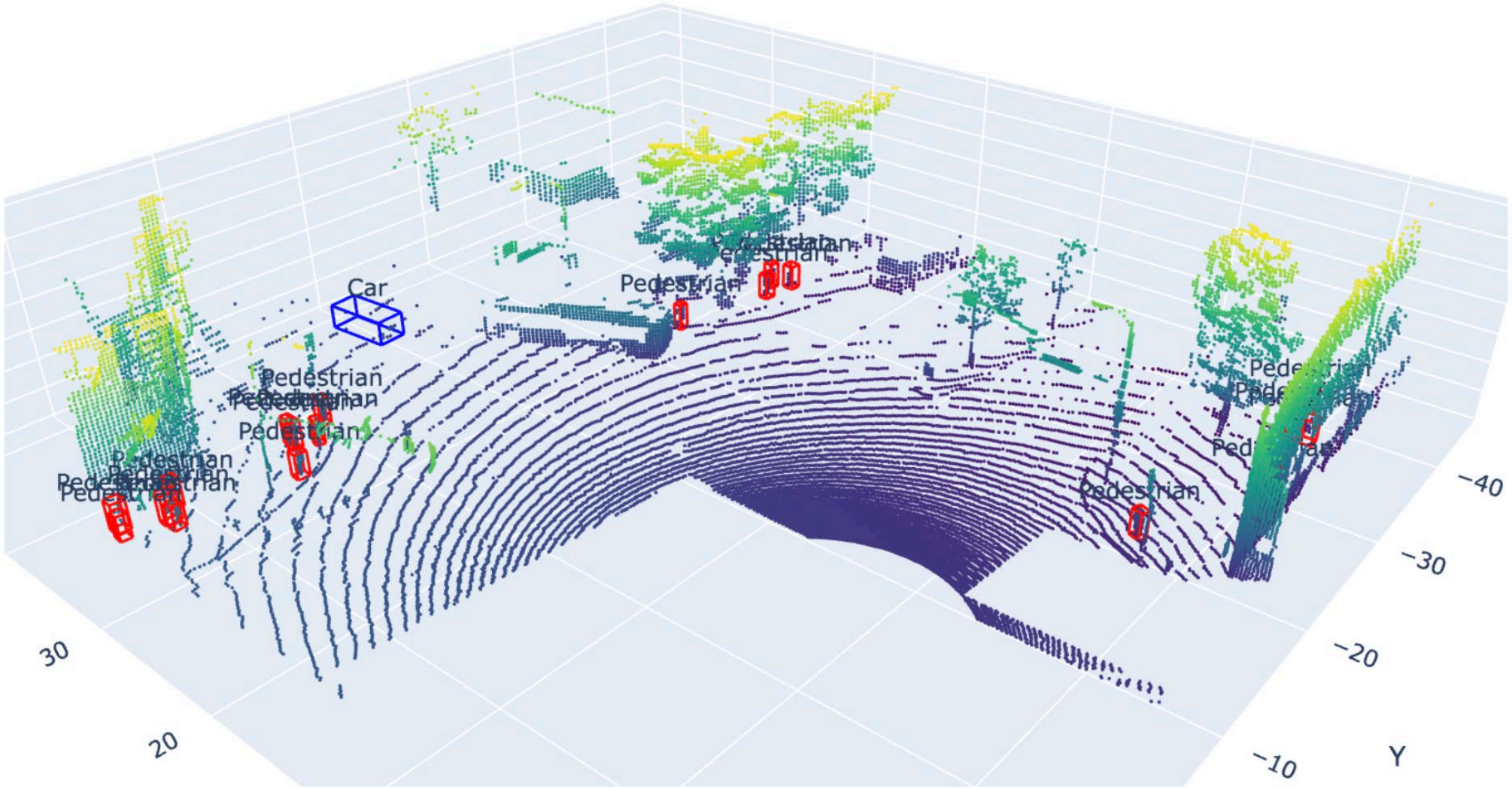


Detection and Prediction



Limiting the power

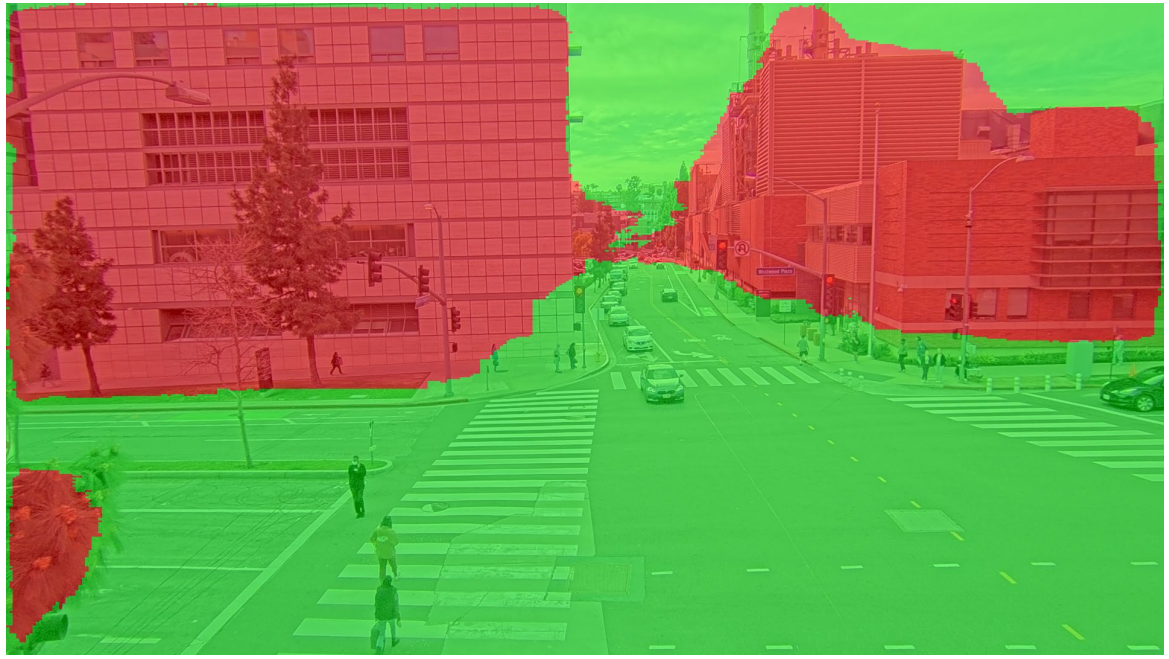
Context -aware filtering



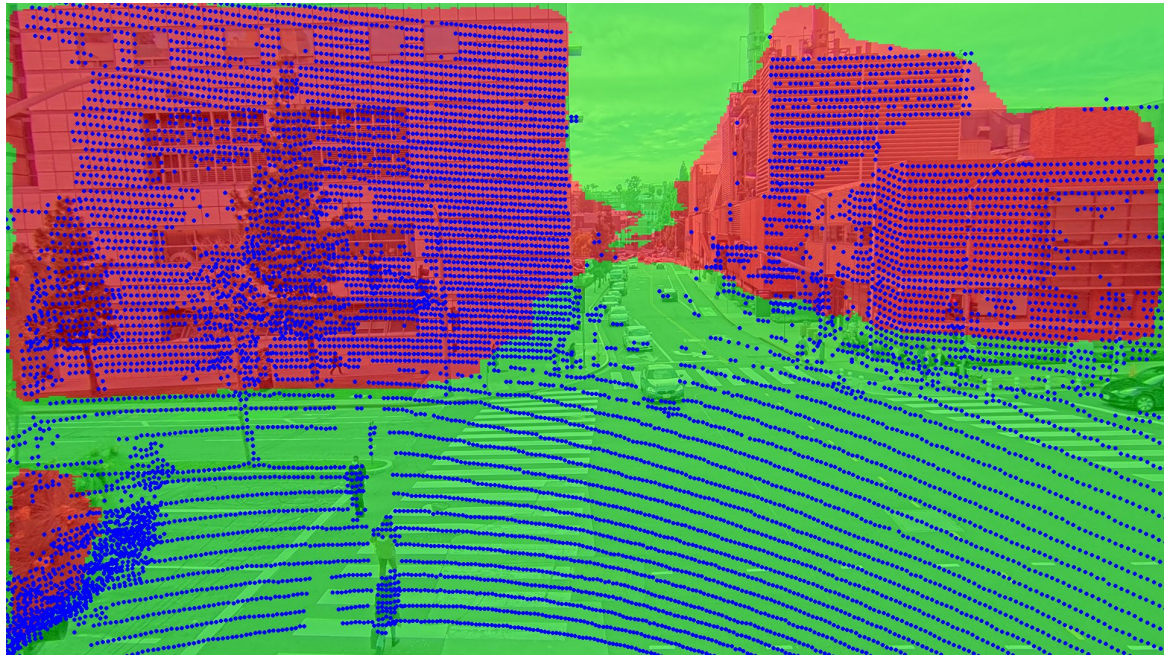
Limiting the power

Context -aware filtering

Static object not of interest



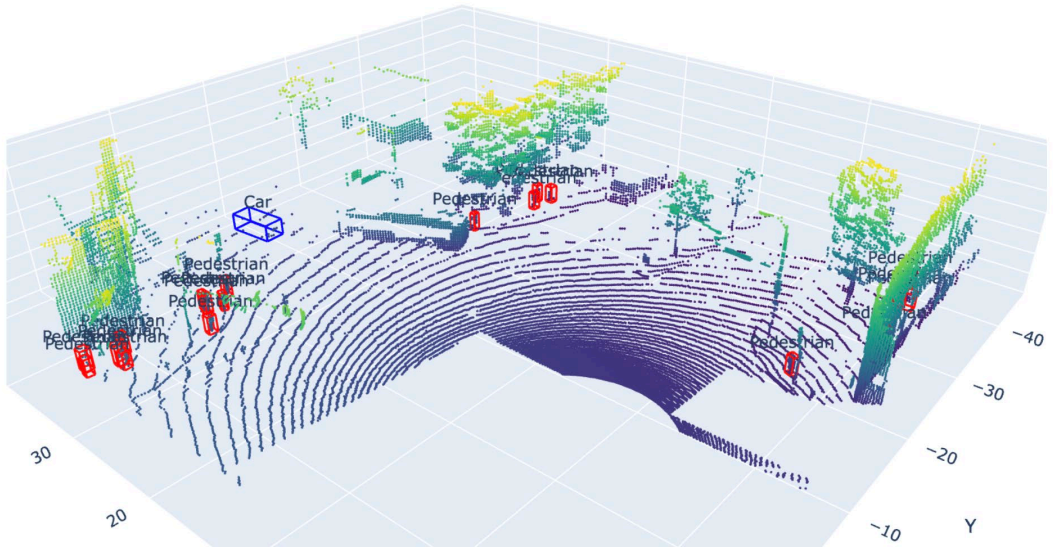
Filtered PointCloud



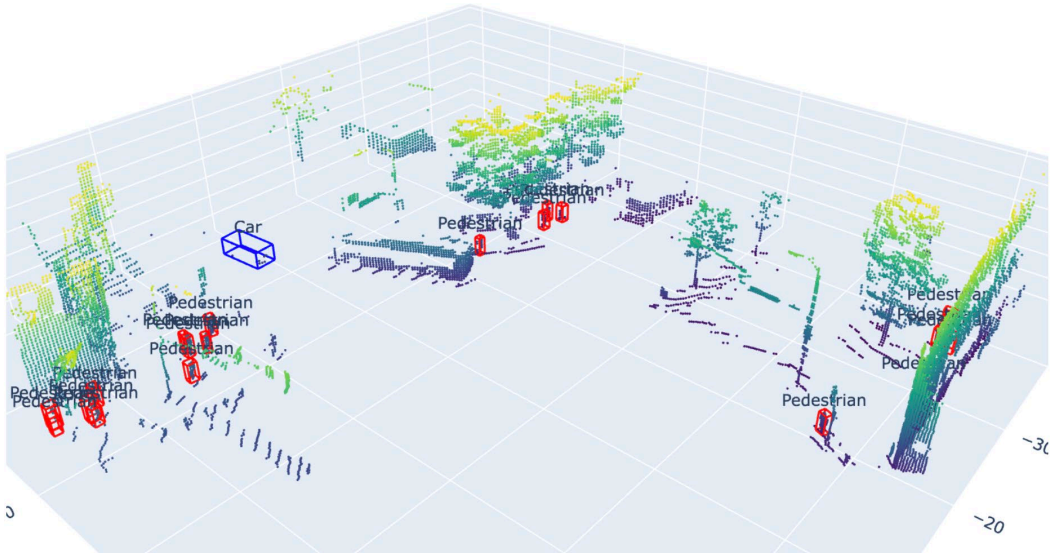
Limiting the power

Context -aware filtering

Original PointCloud



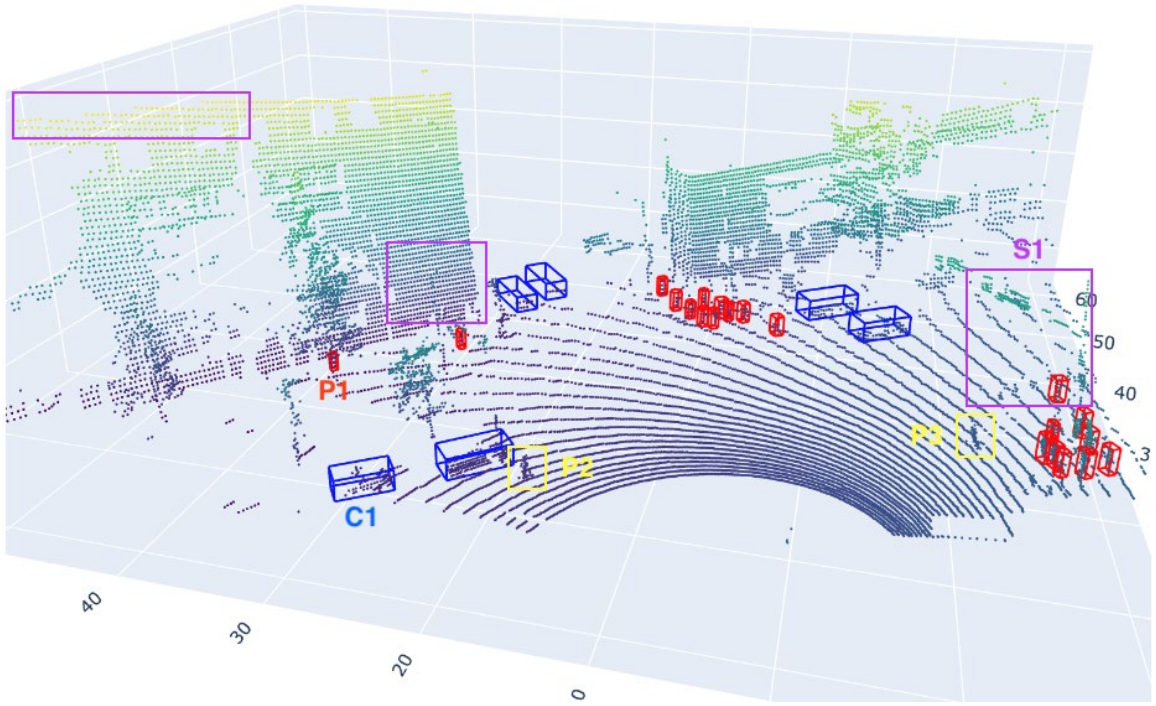
Ground removed



Limiting the power

Context -aware filtering

Original PointCloud



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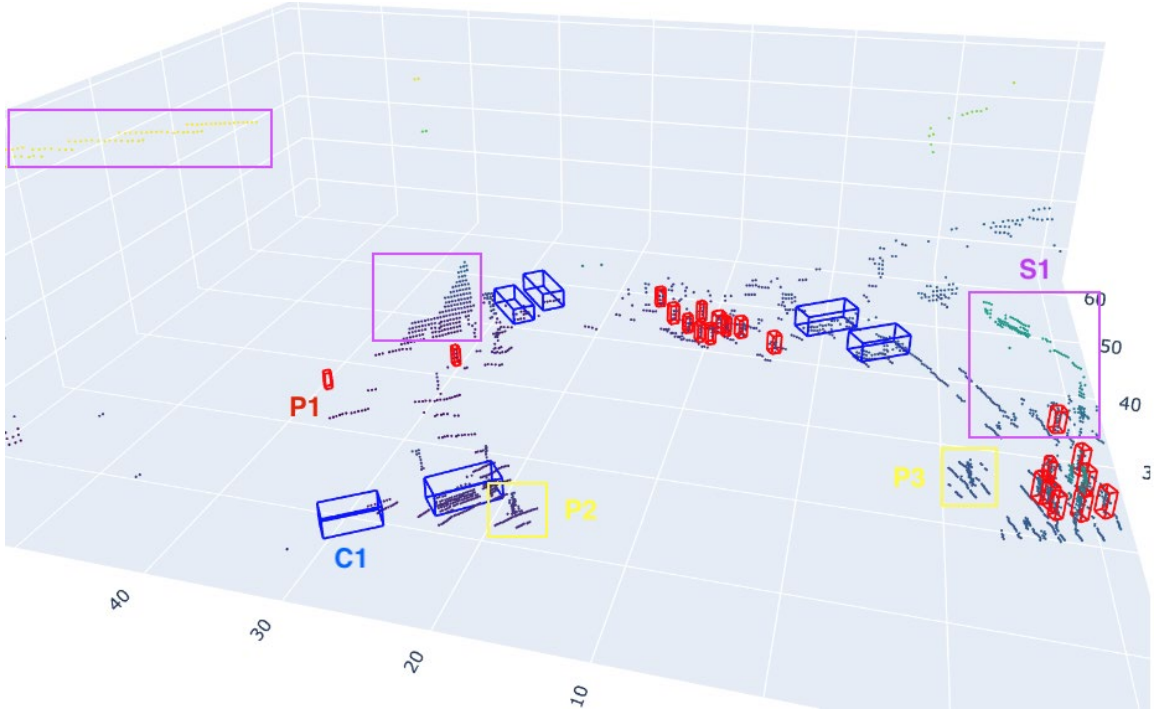
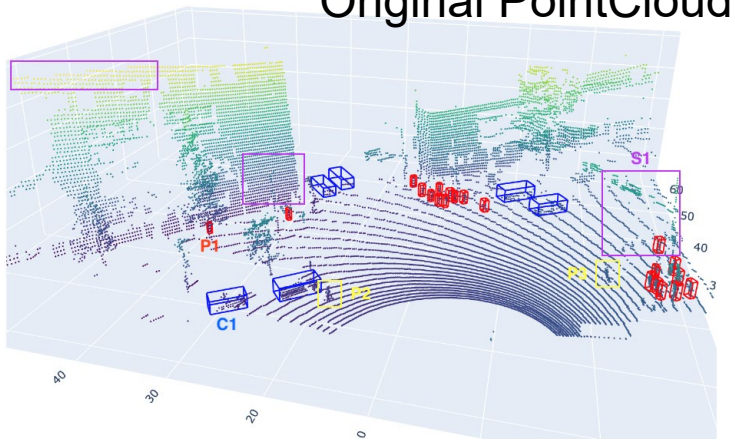


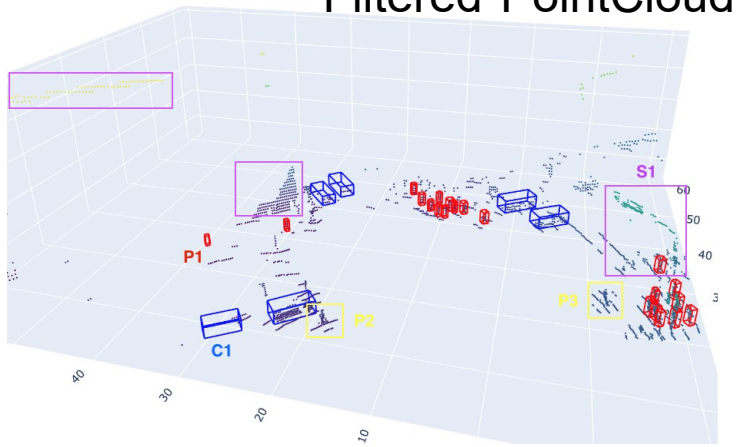
Limiting the power

Context -aware filtering

Original PointCloud



Filtered PointCloud



Inference Type	PC Size	Model	Car@0.50	Ped@0.35	mAP
No Filtered Inference	19294	MVXNet1	79.66	**52.32**	**65.99**
		MVXNet2	**80.63**	48.25	64.44
		SECOND	78.78	40.83	59.81
Static Object Removal Filter	13672 (-29.13%)	MVXNet1	75.86 (-3.8%)	**50.03** (-2.3%)	**62.95** (-3%)
		MVXNet2	**76.60** (-4%)	44.77 (-3.5%)	60.69 (-3.7%)
		SECOND	74.83 (-3.9%)	36.72 (-4.1%)	55.77 (-4%)
Object-aware Ground Plane Filter	11011 (-42.93%)	MVXNet1	74.30 (-5.3%)	**52.91** (+0.6%)	**63.61** (-2.4%)
		MVXNet2	**76.94** (-3.7%)	46.93 (-1.3%)	61.93 (-2.5%)
		SECOND	76.02 (-2.8%)	39.64 (-1.2%)	57.83 (-2%)
Combined Filters	**5016** (-74.00%)	MVXNet1	70.69 (-8.9%)	**50.63** (-1.7%)	**60.66** (-5.3%)
		MVXNet2	**72.79** (-7.8%)	43.27 (-5%)	58.03 (-6.4%)
		SECOND	72.48 (-6.3%)	35.56 (-5.3%)	54.02 (-5.8%)

Other research Areas

03

International Competitions

International Field Robot Event

1 3

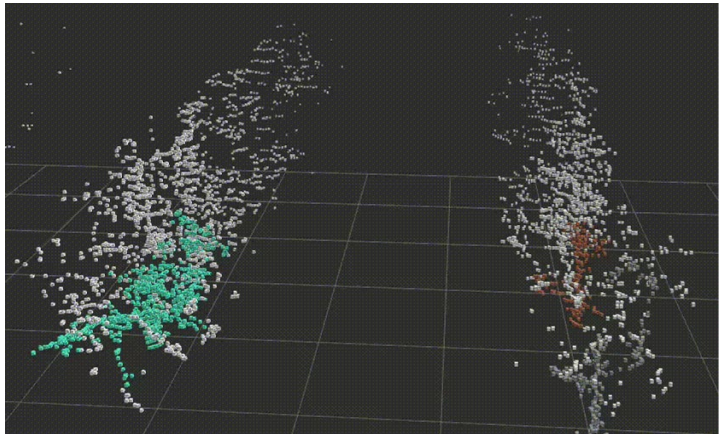
DRONE CONTEST
an open innovation challenge by Leonardo
6th EDITION 2025

1 2 2

Agri - Robotics

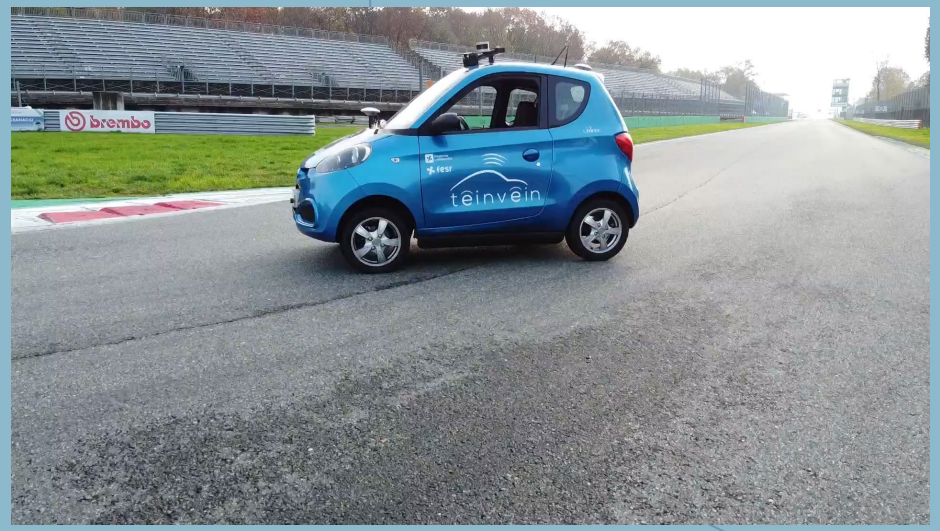
Autonomous Field Coverage

Semantic Vineyards SLAM



Fruit Picking


Rai 1 HD
UNA STORIA DA CANTARE
QUESTA SERA ORE 21:25
linea verde
Life


brembo
teinvein