Road Boundary Estimation in Construction Sites

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Lanes in Construction Sites

- Roadway is often bounded by elevated objects (e.g. guidance walls)
- Lane is often defined by elevated objects and special lane markings (e.g. beacons, yellow lines)

- Questions
  - How can static objects in the environment be detected and modeled efficiently?
  - How can the road boundary be found having available information about static objects?
  - How can information about the road boundaries be used in driver assistance applications?

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Overview

- Location based maps as a way to model the static environment
- Reflectance map generated by an automotive scanning radar
- Occupancy map generated by an automotive mono camera
- Fusion of maps
- Estimating the road boundaries out of a location based map
- Using road boundary information in situation assessment algorithms

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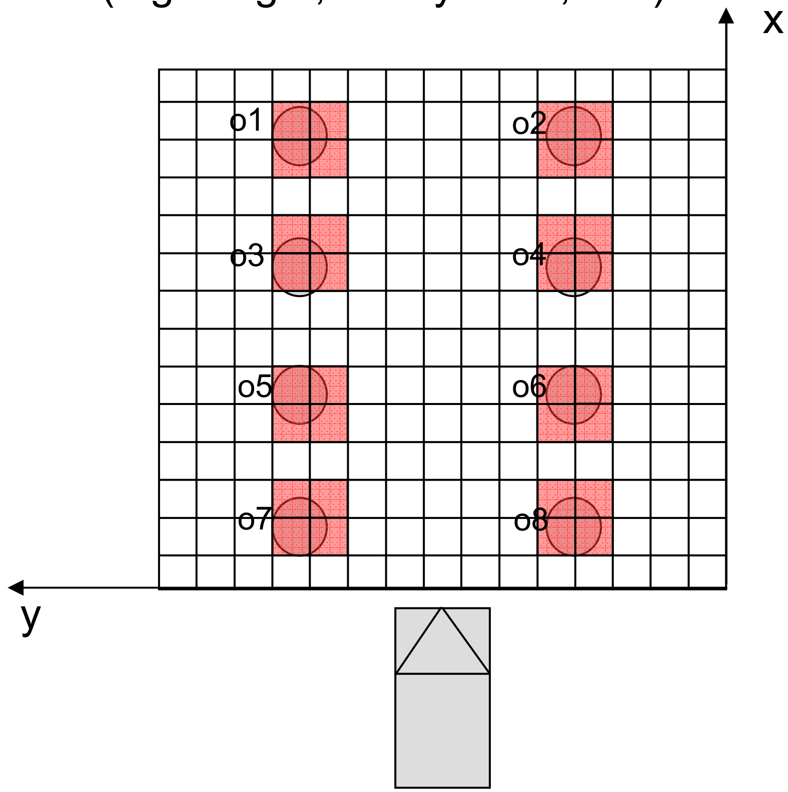
Modelling Static Objects: Loction Based Maps

- Objects (cells) are indexed by location (x,y)
- Each object (cell) has attributes (e.g. height, binary state, etc.)



$$m_{x,y} = \begin{cases} height \\ binary\ state \end{cases}$$

$$m = \{m_{x,y}\}$$

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Location Based Maps

- Binary states can be used to describe arbitrary attributes of cells, e.g.
  - Occupancy (occupied/ not occupied)
  - Reflectance (reflects energy/ does not reflect energy)

- Advantages
  - Simple object definition (cells) as an approximation of real world objects
  - Binary attributes can be estimated efficiently using e.g. a Bayes filter
- Draw backs
  - Discretization of the environment
  - High amount of data needs to be handled

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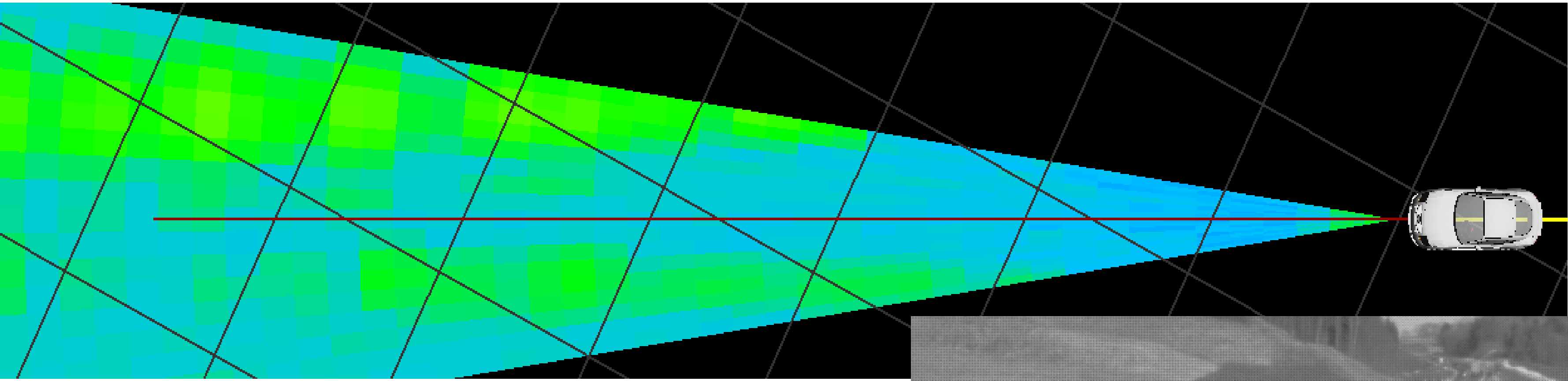
Scanning Radar – Raw Data

- Single plane scanning radar
  - Single scan does not hold direct information about height/traversability of static objects
  - Note: same holds true for other technologies (e.g. scanning laser)

ARS300



➔ Reflectance map

$m_{x,y} = 1$ Cell reflects energy

$m_{x,y} = 0$ Cell does not reflect energy

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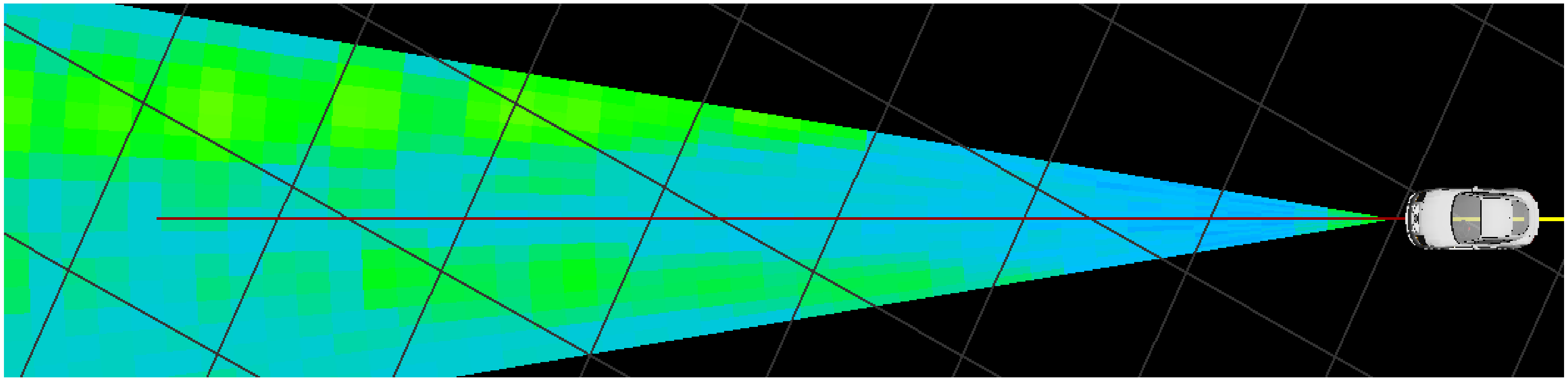
Mapping Algorithm

- Mapping with known poses (pose of vehicle is assumed to be known -> Odometry with Kalman Filter)
- One Bayes Filter per cell (cells are assumed to be independent)
- Using inverse sensor model to incorporate measurements *z*:

$$p(m_{x,y}=1 \mid z)$$

$m_{x,y}=1$	Cell reflects energy
$m_{x,y}=0$	Cell does not reflect energy

  - Static objects: The further away the detection from noise level the higher the probability
  - Dynamic objects: The more significant a detected movement (Doppler) the lower the probability



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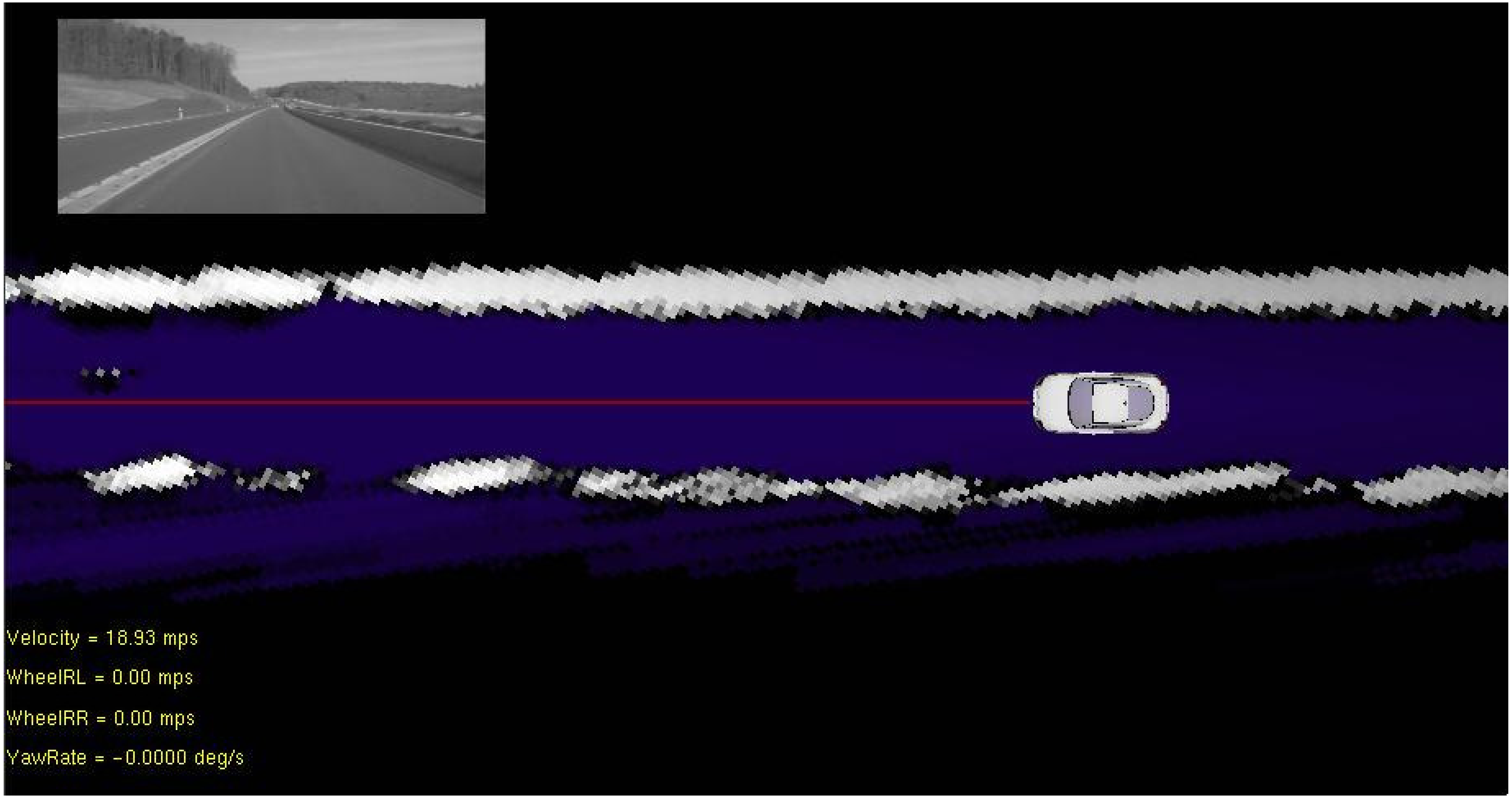
Reflectance Map



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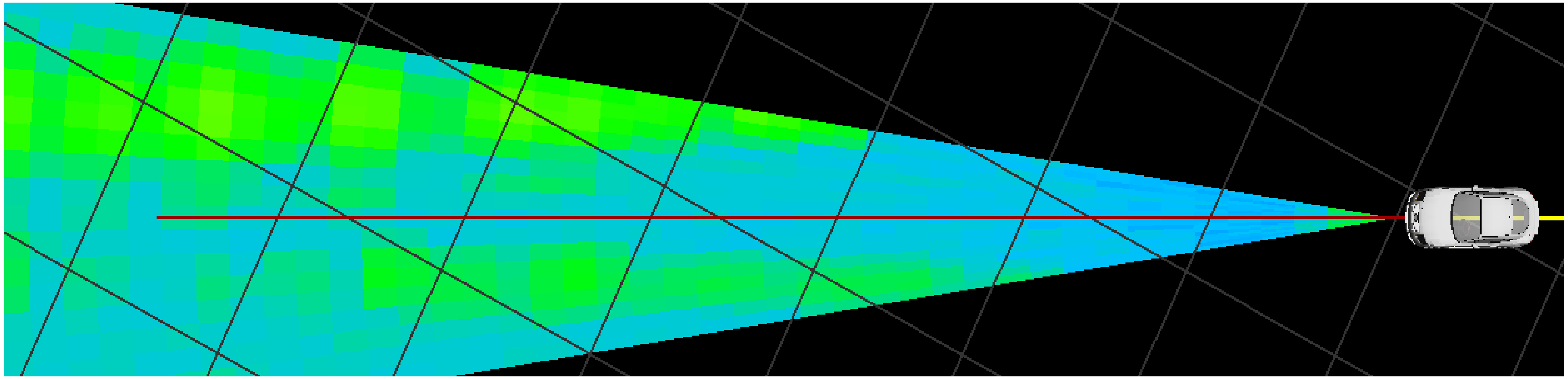
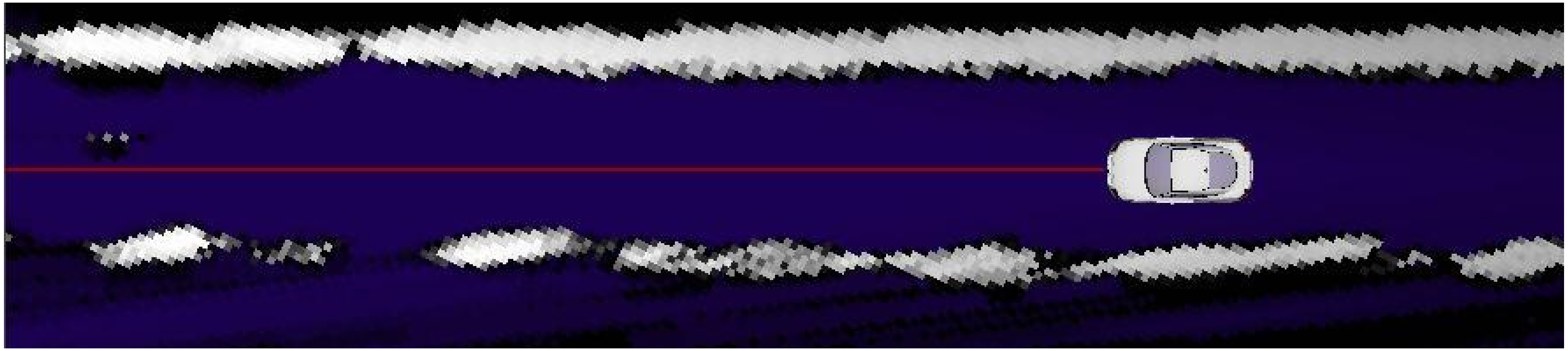
Reflectance Map: Properties

- Map contains information about structures in the environment
  - Areas which reflect energy may be traversable (e.g. bot dots)
  - Map may include artifacts (caused due to multipath effects for example)





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Mono Camera

CSF 200

- Single Image: no direct information about height/traversability of static objects
- By using at least two images 3D coordinates (relative to camera) can be reconstructed (Structure from Motion)
- ➔ Information about height of objects available ➔ Obstacle Map

$m_{x,y} = 1$ Cell is not traversable

$m_{x,y} = 0$ Cell is traversable

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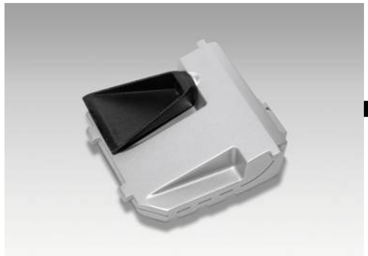
Scene Reconstruction



Images

Motion Field Estimation

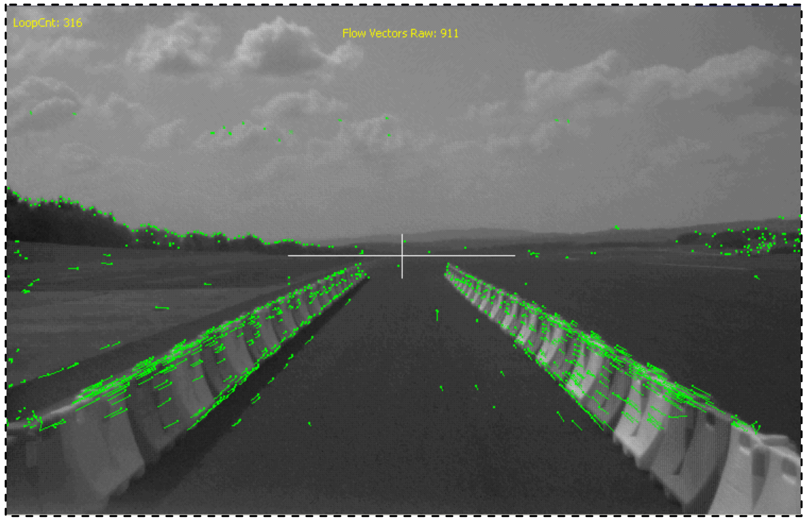
Corresponding points

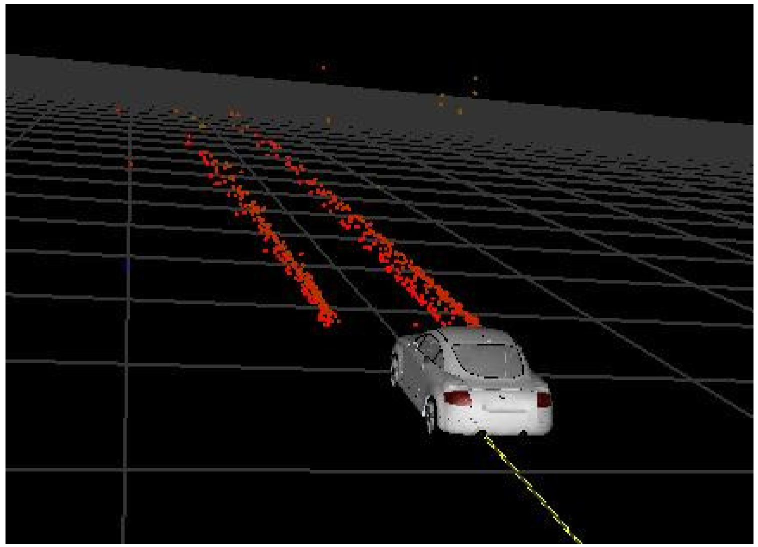
Vehicle Data

Intrinsic params

3D Scene Reconstruction

3D Point Cloud





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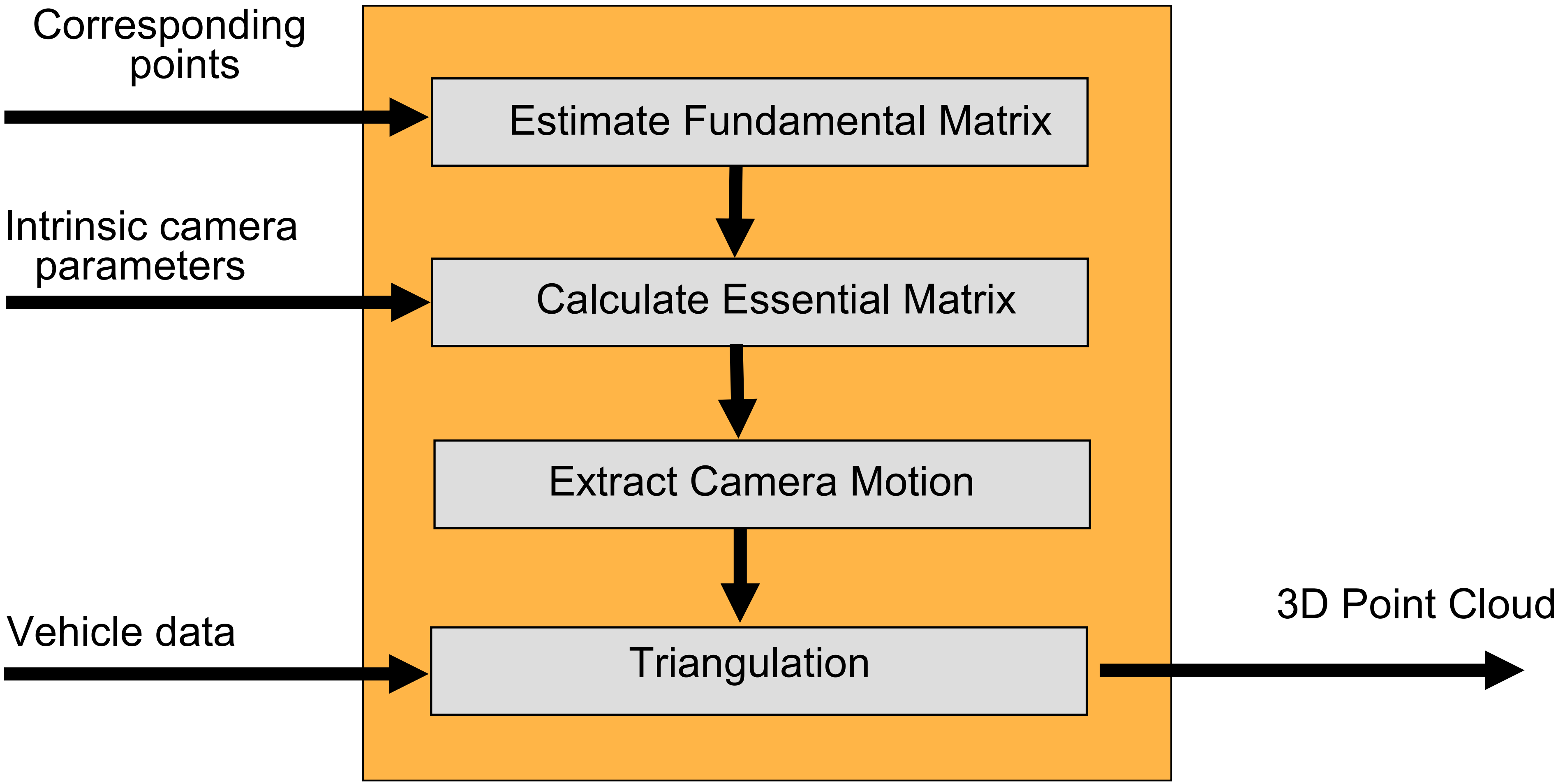
Scene Reconstruction



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Scene Reconstruction

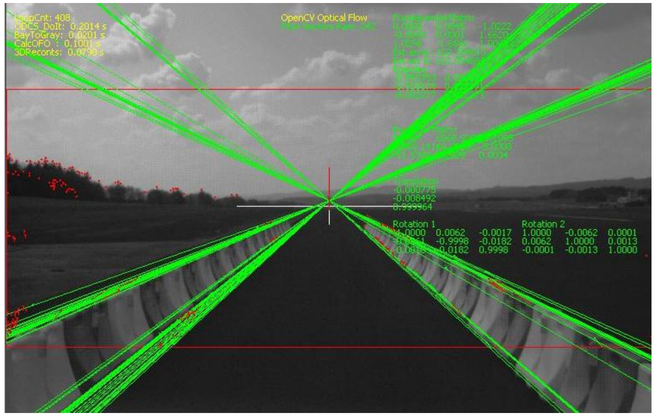
Fundamental Matrix is algebraic description of the epipolar geometry.

Corresponding points →

Classical method: 8 Point Algorithm

Robust Methods : Deal with erroneous data
Classify each data as inlier or outlier

→ Fundamental Matrix



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Scene Reconstruction

Essential Matrix encodes information of the extrinsic parameters.

Fundamental Matrix F →

Intrinsic cam params →

$$E = K^T F K$$

$$K = \begin{bmatrix} f & 0 & x_0 \\ & f & y_0 \\ & & 1 \end{bmatrix}$$

f : focal lenght

x_0, y_0 : principal point

→ Essential Matrix E

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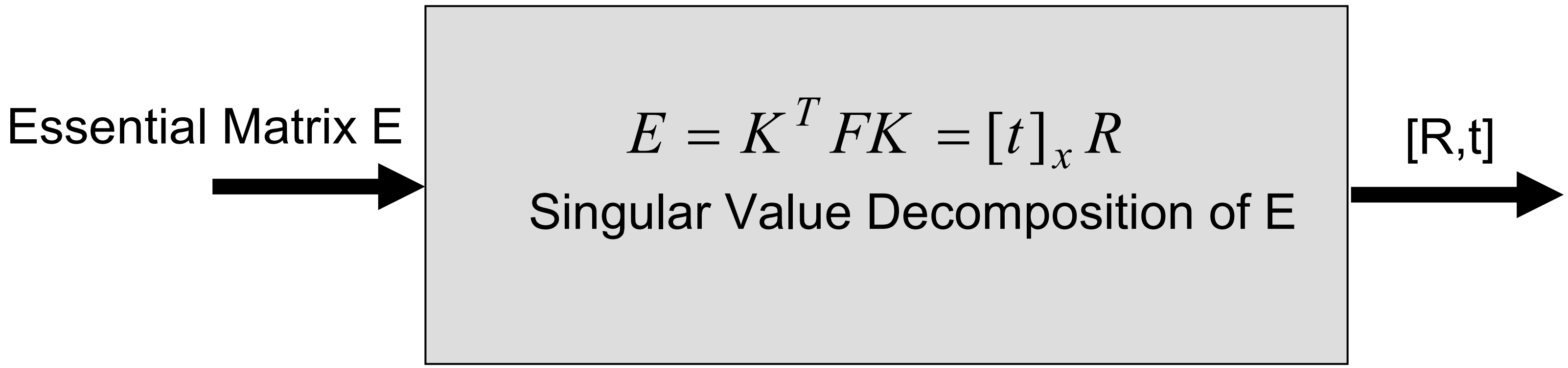
Scene Reconstruction



- 4 possible solutions, only one corresponds to positive depth values
- Translation norm is unknown => 3D reconstruction is unique only up to an unknown scaling factor.
  - ➔ translation norm is derived from vehicle motion.

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Scene Reconstruction

Reconstruct all point correspondences with linear triangulation.

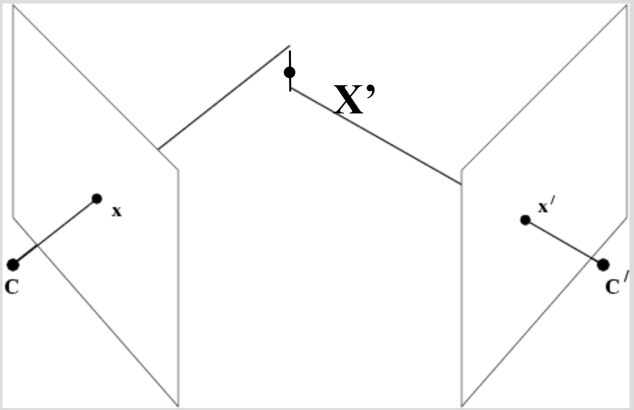
Rotation matrix R

Translation norm t

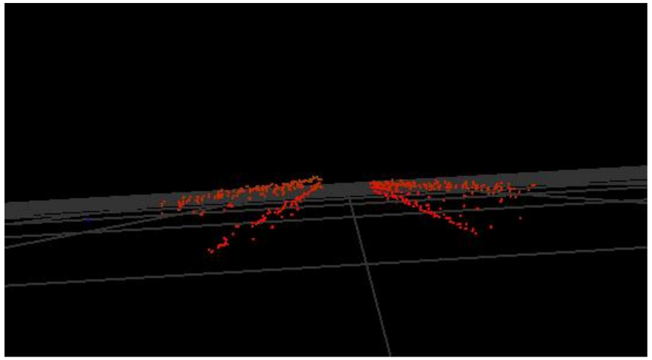
Intrinsic param K

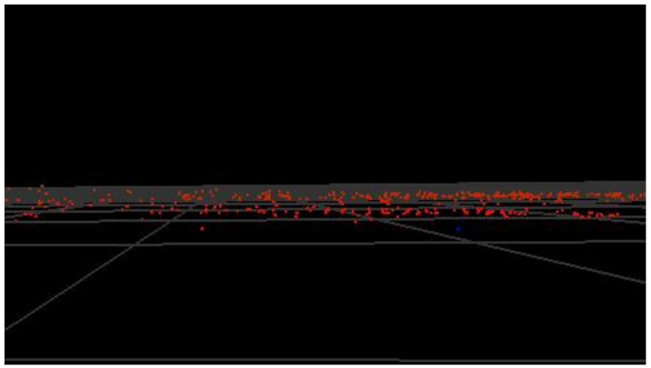
Corresponding points

$$x = PX \quad \text{mit} \quad P = K[R, t]$$



3D point cloud





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Mapping Algorithm

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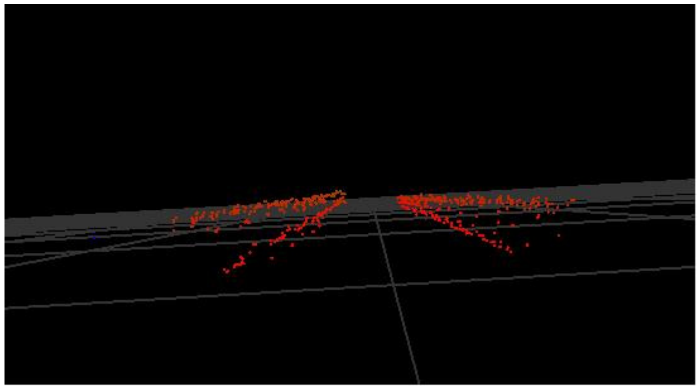
- One Bayes Filter per cell (cells are assumed to be independent)
- Using inverse sensor model to incorporate measurements *z*:

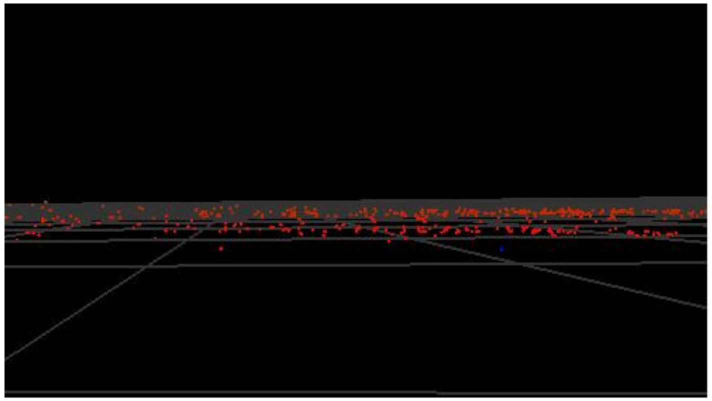
$$p\left(m_{x,y} = 1 \mid z\right)$$

$m_{x,y} = 1$ Cell is not traversable

$m_{x,y} = 0$ Cell is traversable

  - Look at 3D points within a cell (assuming flat road)
    - No 3D Point => No change in map





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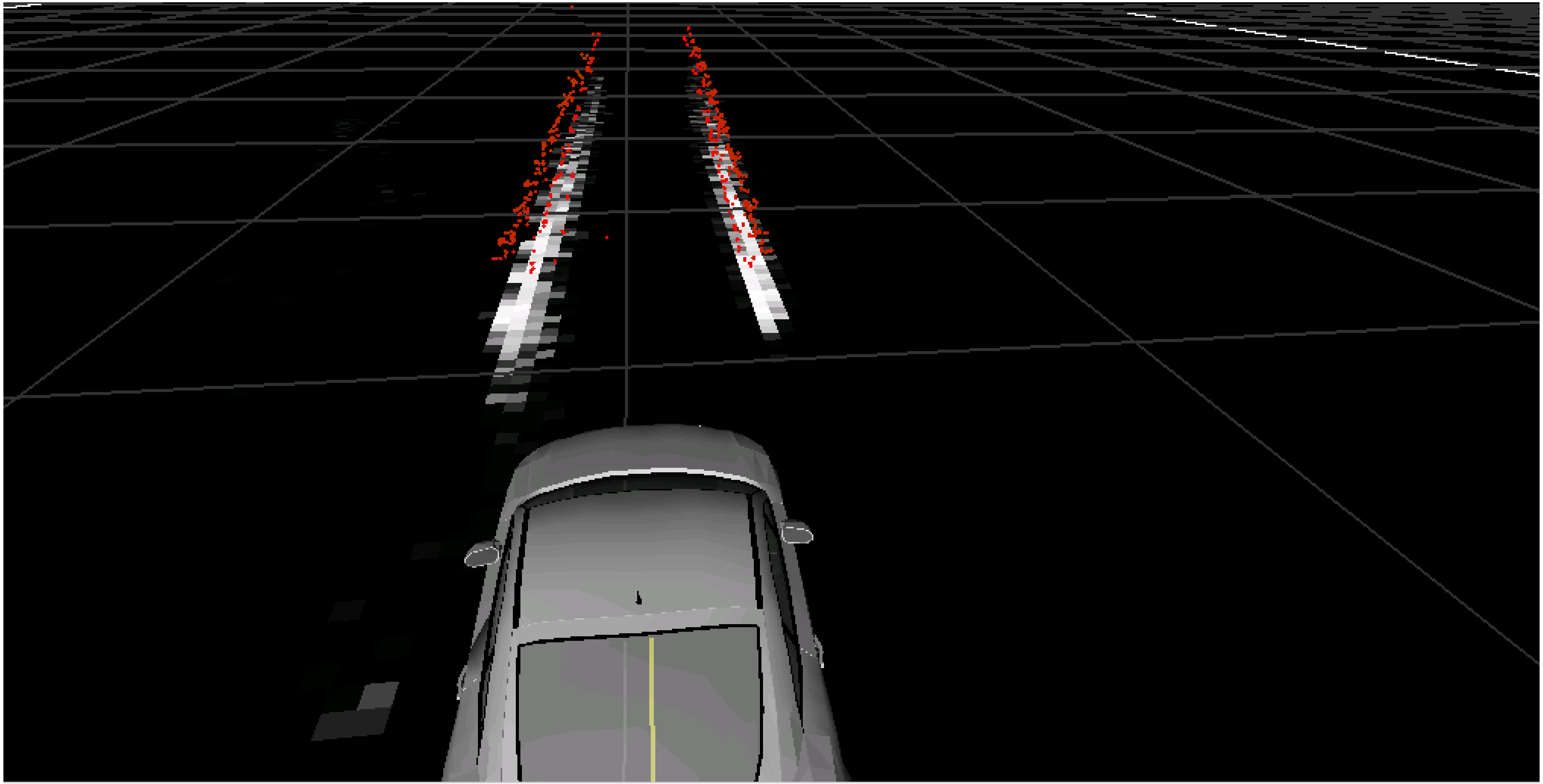
Obstacle Map



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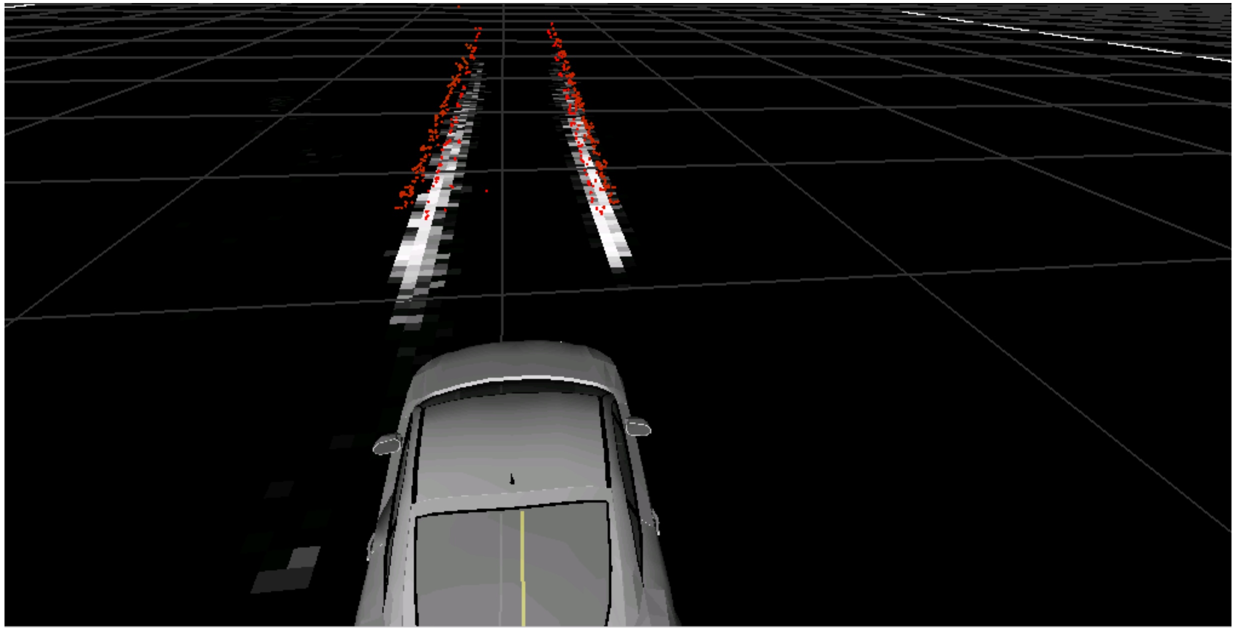
Obstacle Map: Properties

- Map contains information about *occupied areas* (obstacles) in the environment
- No information in areas without reconstructed 3D points
- ➔ Degenerated Occupancy Map



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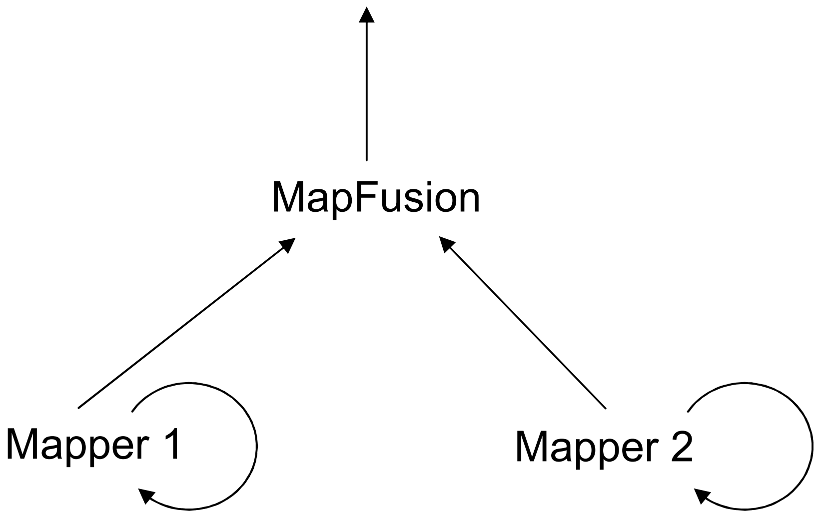
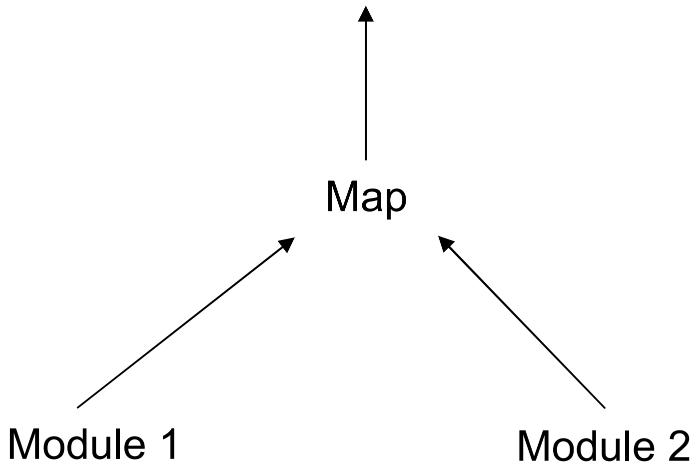
Map Fusion



- (+) Artifacts can be handled in local maps
- (+) Independent of sensor frequencies
- (--) Large amount of data



- (-) Information in map is dependent on frequency of sensors
- (-) Artifacts are not separable
- (+) Only one central map (data reduction)

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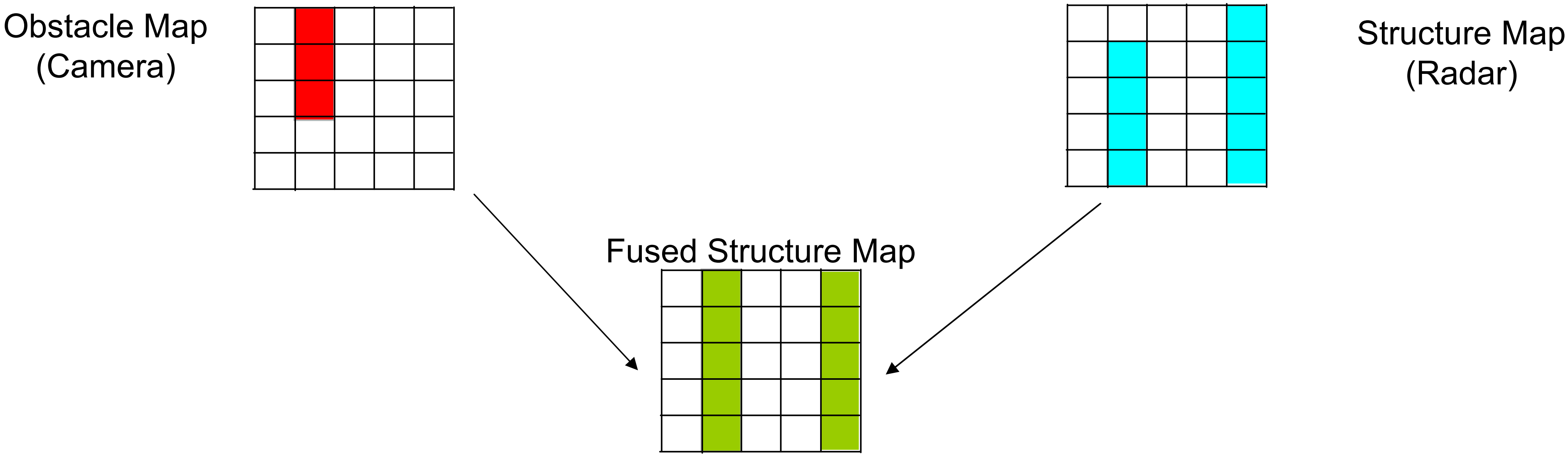
Fusion Strategy for a Fused Structure Map



- Combines information about structure
- Cells detected with only one technology contribute to fused map

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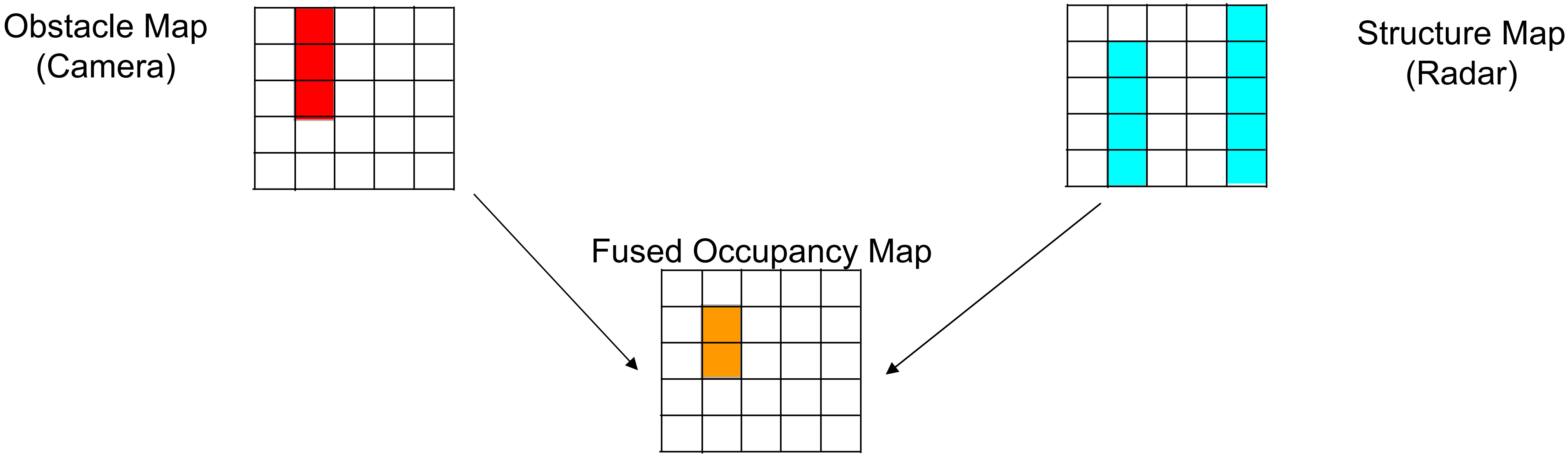
Fusion Strategy for a Fused Obstacle Map



- Combines information about non traversable areas
- Higher certainty for cells detected with both technologies

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Continental

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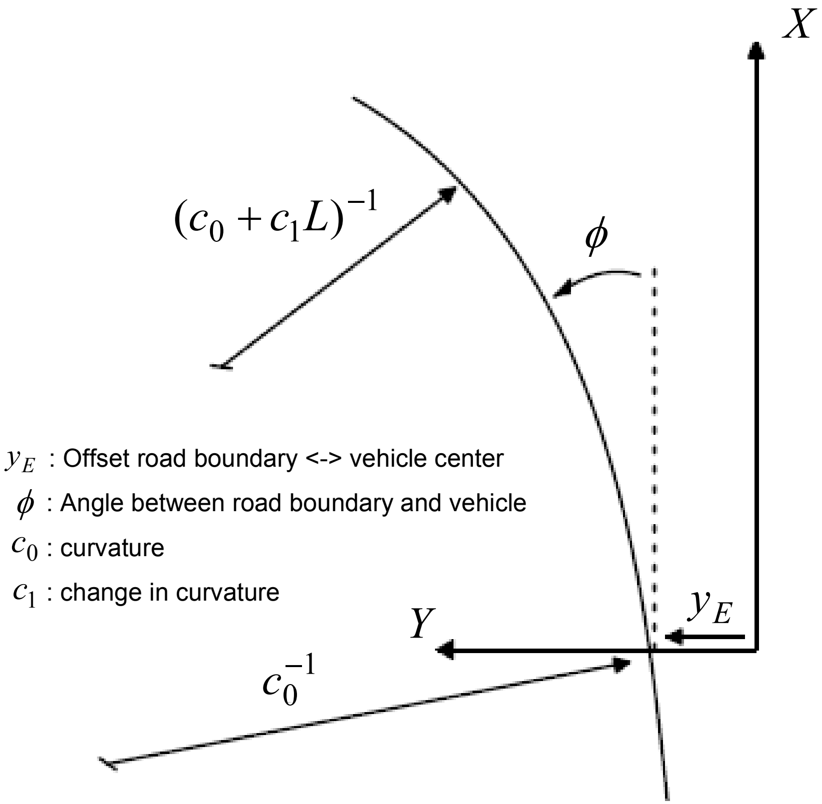
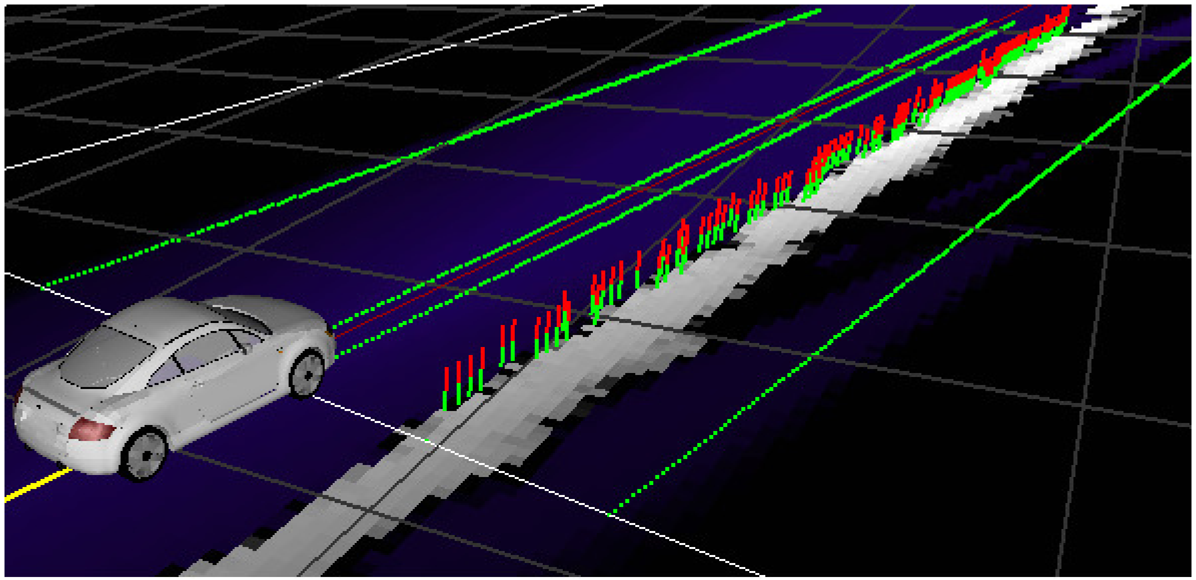
Road Boundary Estimation

- Boundary is modeled as clothoid in vehicle coordinates
- A Kalman filter is used for estimation
  (Compare lane tracking with monocular cameras)
- Multiple hypothesis are tracked





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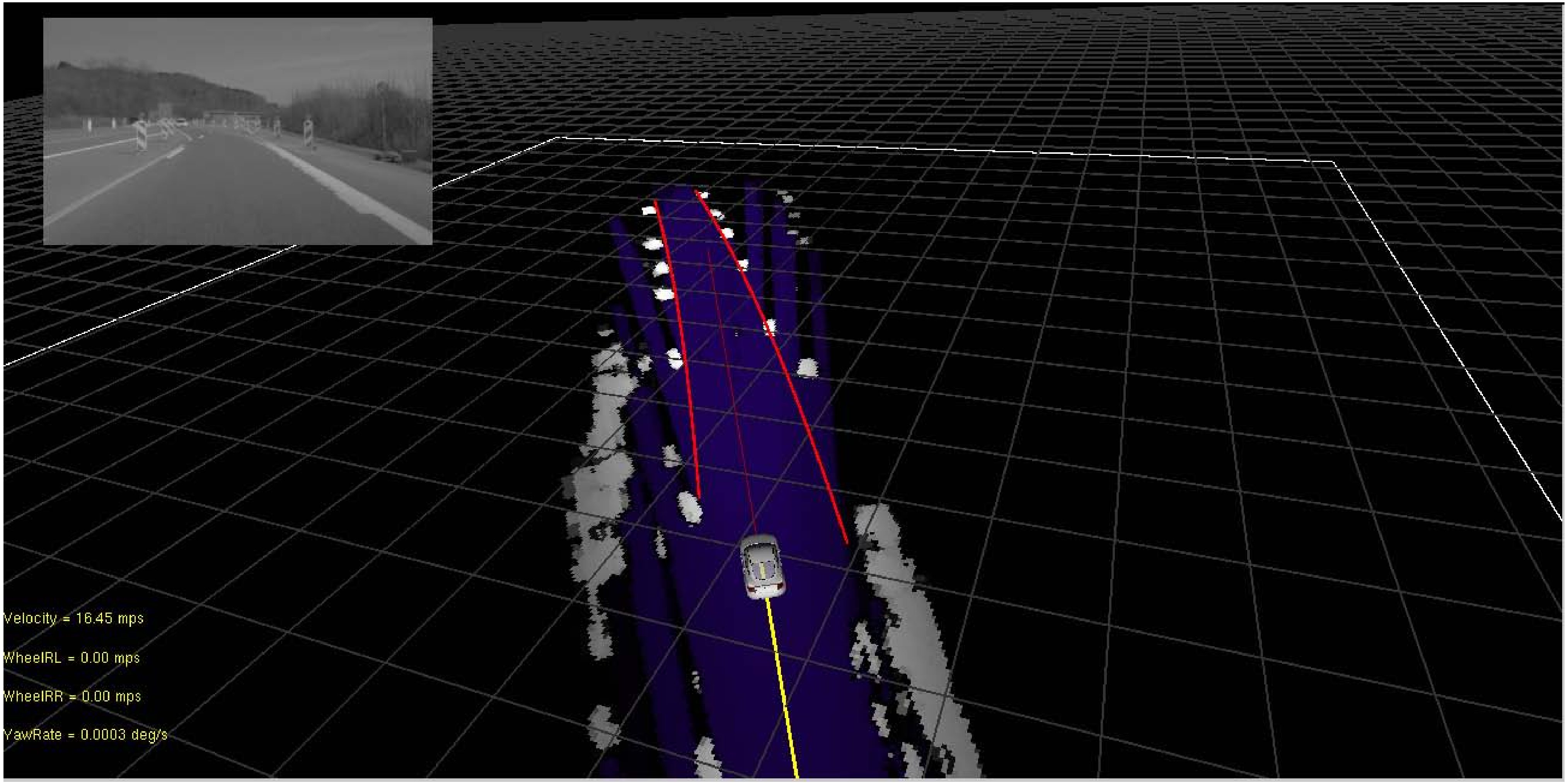
Road Boundary Estimation



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Resulting Road Boundaries

- Extracted from Fused Structure Map
  - High certainty for a structuring element (guidance wall, bot dots)
- Extracted from Fused Obstacle Map
  - High certainty for a non traversable element (guidance wall)

- Information can now be combined with detected lane markings
  - ➔ independent information to verify lane markings and as such lane
  - ➔ additional information to decide about system reaction in different scenarios

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Situation Assessment

Interpreted as invalid
(Lane marking next to guidance wall takes precedence)

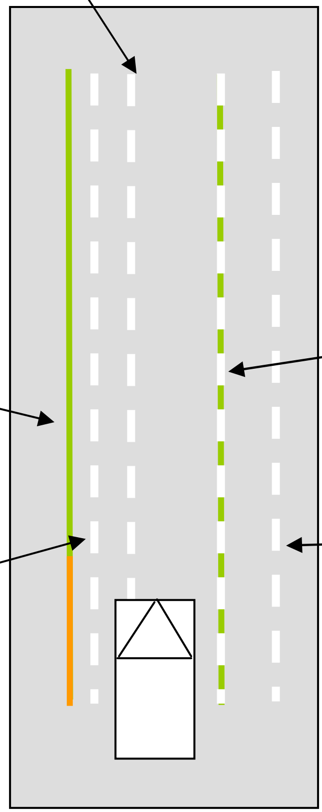
Lane Marking

Boundary from Structure Map

Boundary from Occupancy Map

Interpreted completely as guidance wall
Note: only first part is present in Occupancy Map

Interpreted as special line
(may be oncoming traffic on other lane)



Interpreted as lane marking next to untraversable object

Interpreted as unimportant
(other lane)

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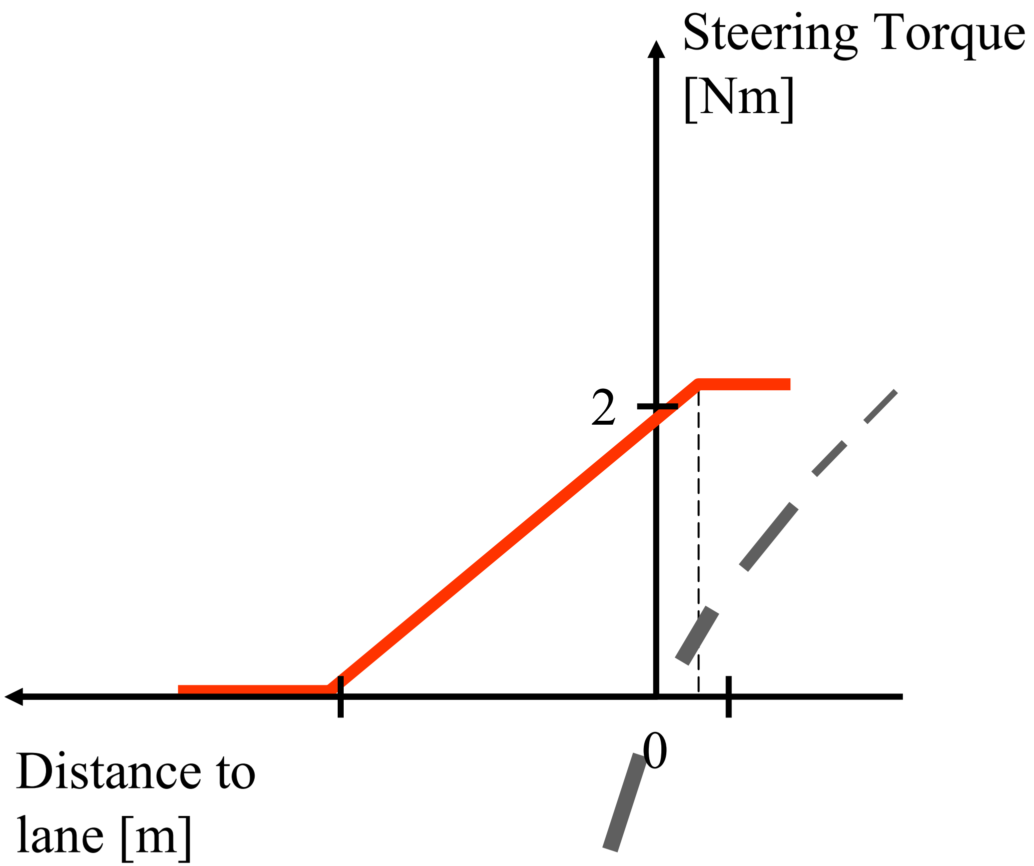
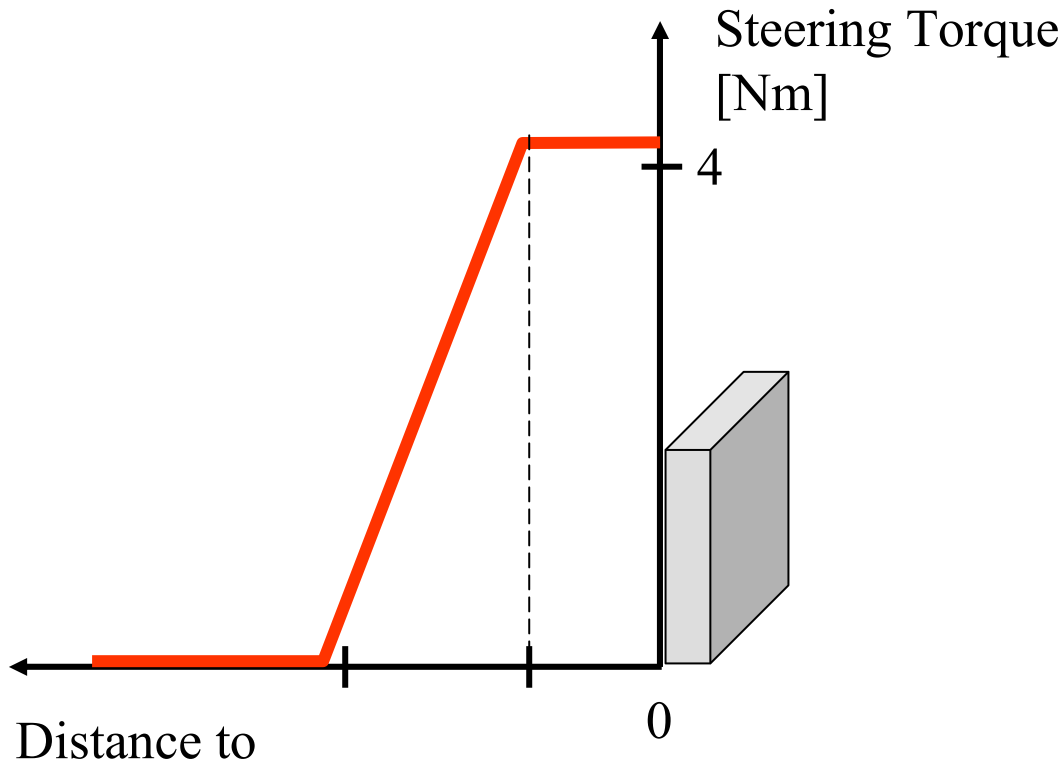
Examples for different assistance strategies

Lane marking



Lane marking next to guidance wall



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Example Video

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Conclusions

- Often static objects define the road shape in construction sites
- Location based maps can be used to model static objects efficiently
- Location based maps have discretization effects
- Single plane scanning sensors can be used to estimate a map which contains structuring elements
- A mono camera can be used to estimate a map containing information about non traversable areas
- By fusion of maps the certainty of information can be increased
- Information about road boundaries can be extracted from location based maps
- The information about the road boundaries can be used in situation assessment algorithms to interpret complex scenarios like construction sites better
- This allows increasing driving comfort and safety in more situations

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Thank you for your attention!

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Die Arbeiten erfolgten zu Teilen im Rahmen des Förderprojektes AKTIV AS.
(Teilprojektleiter ist Stefan Scholz, VW)

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