Forschungsinitiative
Ko-FAS

Vehicle localization by cooperative landmarks

Eigenlokalisierung über transponderbasierte Landmarken

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Introduction

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Introduction

Vehicle localization

- Navigation
- Advanced driver assistance systems (ADAS)
  →Lane accurate positioning
- Reference systems

Characteristics of vehicle localization systems

- availability
- low cost
- accuracy
- integrity

Navigation: GNSS

ADAS, reference systems: GNSS?

Vehicle localization in urban environments

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Principle

- Cooperative landmarks are integrated into infrastructure
- Vehicles use RF localization to determine their relative position to the landmarks (distance and angle)
- Landmarks communicate their global positions
- Vehicles combine the information with odometry sensors to perform self-localization

Advantages

- Independent of GNSS availability
- Higher localization accuracy in comparison to available mass-market solutions
- Suited for mass production → potential for low cost

Vehicle localization in urban environments

Vehicle localization in urban environments

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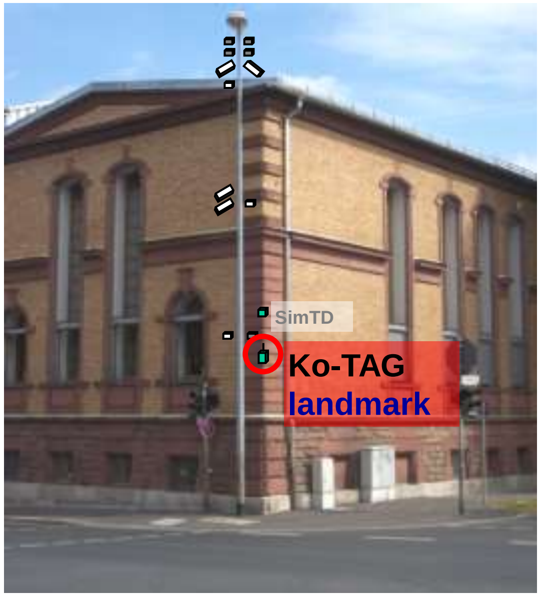
Evaluation for intersection geometry

- Ko-FAS intersection in Aschaffenburg, Germany
- Landmarks are located at diagonal corners (~26m distance)



Vehicle localization in urban environments

Localization performance depends on

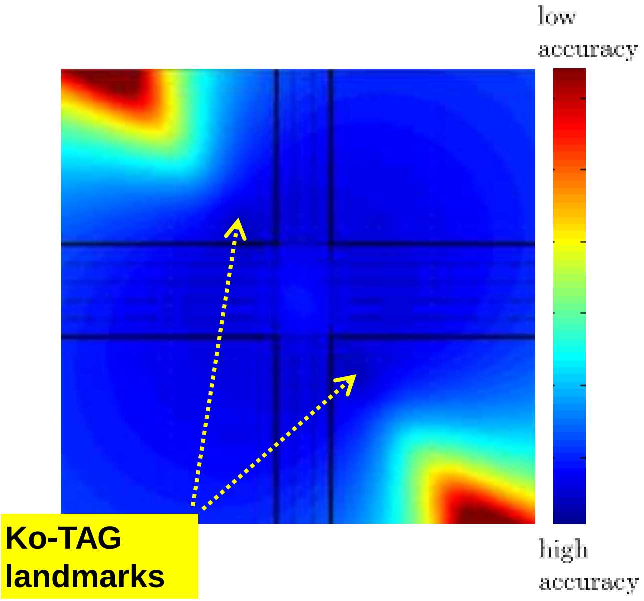
- Number of landmarks
- Geometric constellation of landmarks
- Position of the vehicle

Upper Bound on RMSE - Information obtained in a certain position

- Fisher Information Matrix

$$\mathbf{F}(\mathbf{x}) = \sum_{i \in \mathcal{H}_r} \mathbf{F}_{r_i}(\mathbf{x}) + \sum_{i \in \mathcal{H}_\phi} \mathbf{F}_{\phi_i}(\mathbf{x})$$

$$\mathrm{RMSE}(\mathbf{x}) \leq \sqrt{[\mathbf{F}^{-1}(\mathbf{x})]_{1,1} + [\mathbf{F}^{-1}(\mathbf{x})]_{2,2}}$$



Vehicle localization in urban environments

Theoretical results for intersection geometries with two transponders

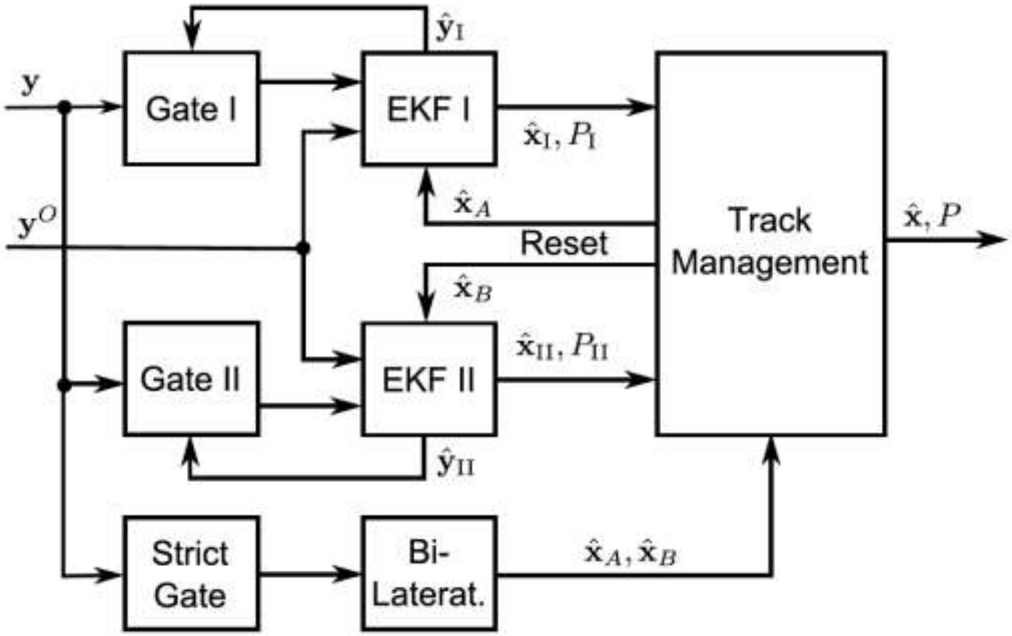
- Baseline is a strong indicator for position accuracy
- Longitudinal accuracy is better than a single distance measurement and is almost distance independent
- Lateral accuracy is much higher than longitudinal accuracy and strongly depends on distance
- Lane accuracy at Ko-FAS intersection is possible with 68% probability at least within > 40m (upper bound)
- Angle measurements have a low impact on position accuracy, but a noticeable impact on orientation estimation

Vehicle localization in urban environments

Localization Filter: Triangulation and Trilateration

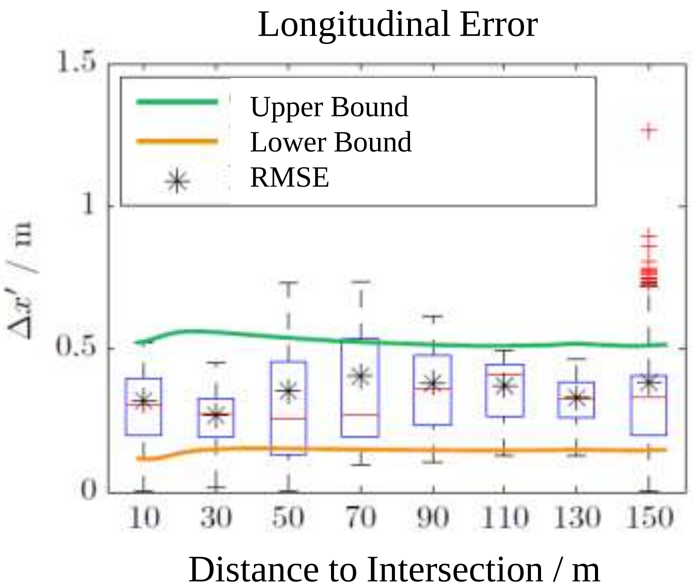
- Initialization: intersection of distances
- Gating: elemination of outliers
- State estimation: EKF
- Track management: hypothesis selection, divergence detection

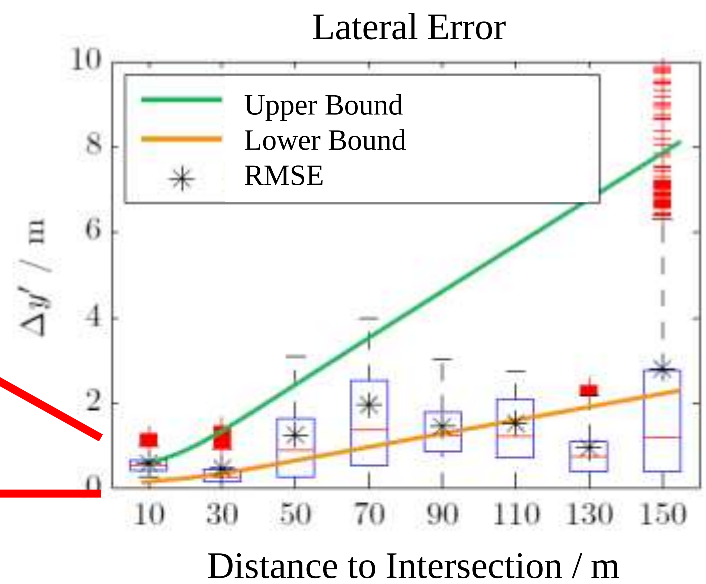
- State: $\mathbf{x} = [x, y, \gamma, v, \omega]^T$
  - position
  - orientation
  - vehicle dynamics



Vehicle localization in urban environments

Measurement results





scale

longitudinal RMSE ≈ 0.35m, distance independent

lateral RMSE ≈ 0.5 – 2.0m, significant distance dependence, lane accuracy of RMSE ≥ 50 - 60m

Vehicle localization in urban environments

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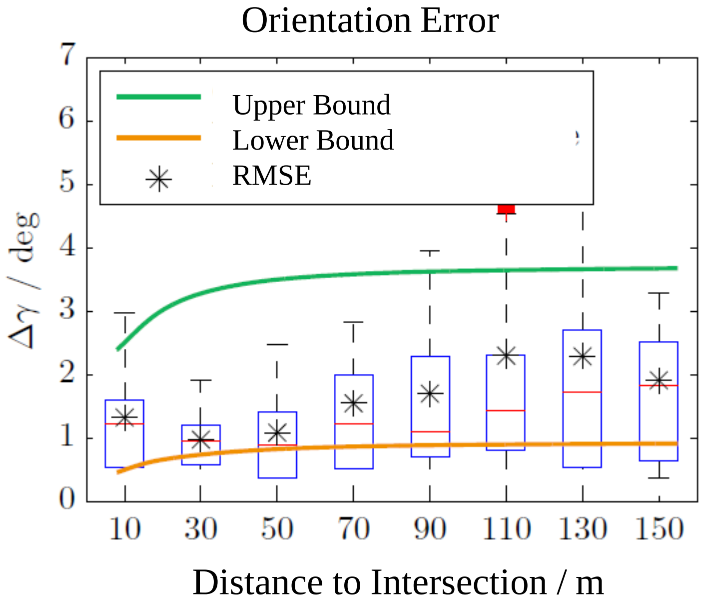
Measurement results

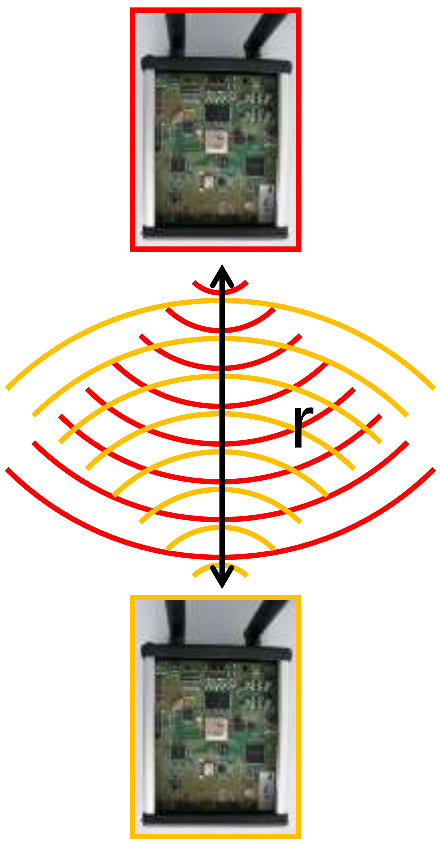


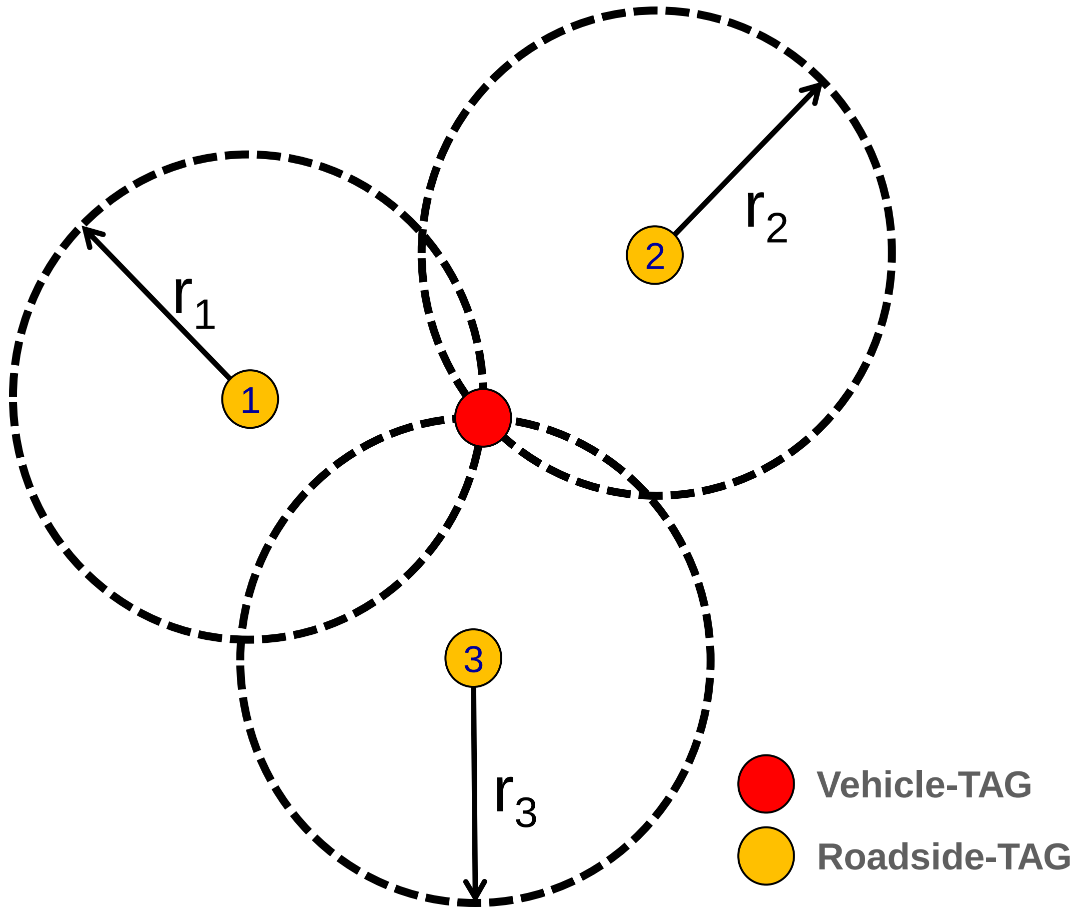
- Ground truth:
  - Generated by GNSS/INS with real-time kinematic (RTK) performance
  - Reference providing position accuracy 0.02m heading accuracy 0.1°.

orientation RMSE ≈ 1-2.5°, approx. distance independent

Object localization for ADAS testing: Working principle

Lateration based on Ko-TAG 1.0 distance measurements





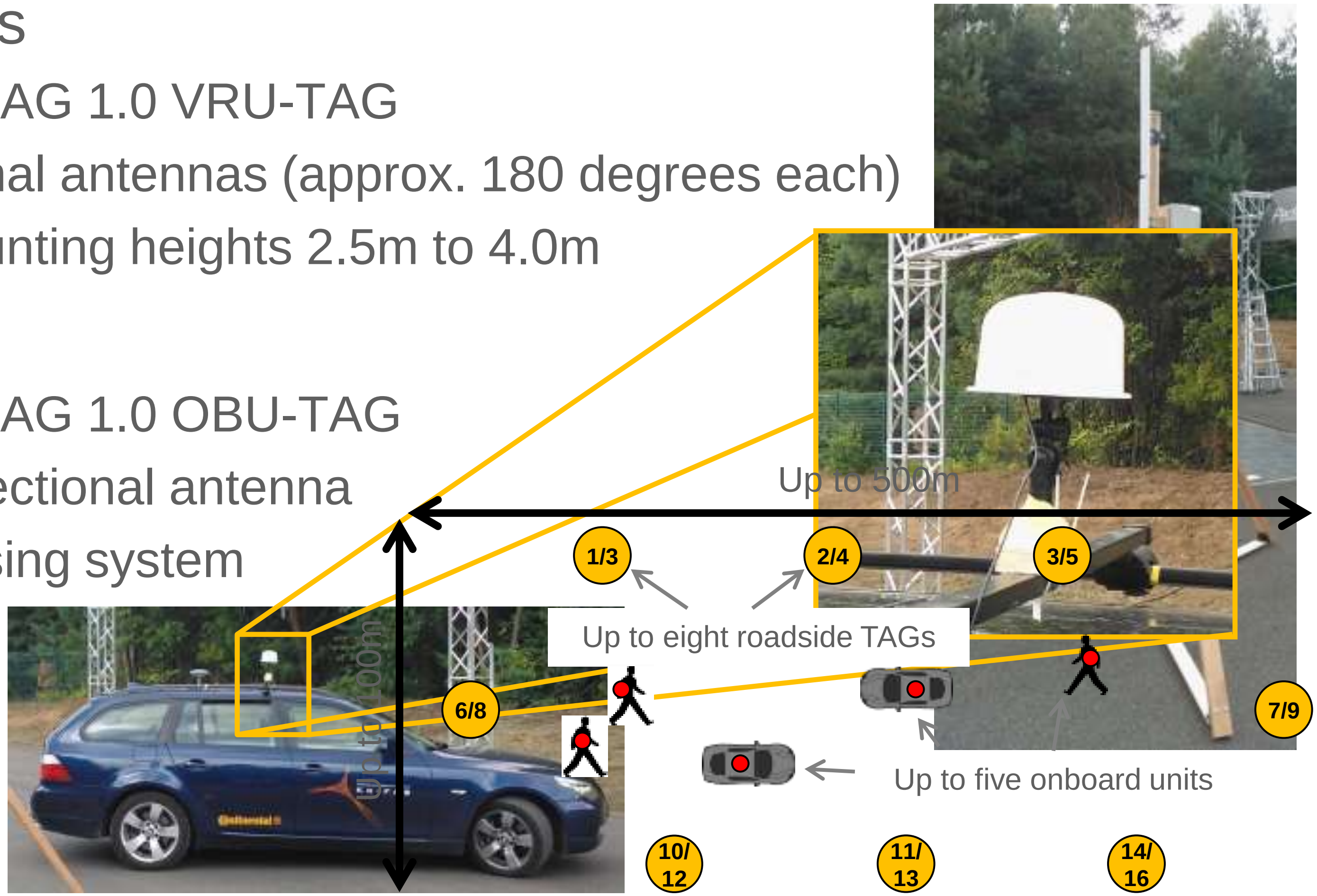
Object localization for ADAS testing: System setup

Roadside TAGs

- 2.4GHz Ko-TAG 1.0 VRU-TAG
- Two directional antennas (approx. 180 degrees each)
- Antenna mounting heights 2.5m to 4.0m

Onboard Unit

- 2.4GHz Ko-TAG 1.0 OBU-TAG
- One omnidirectional antenna
- Data processing system



Object localization for ADAS testing: Data processing steps

Preprocessing

Distance plausibility check:
- Min/Max Values

Signal quality check:
- Minimum threshold

Height correction:
- Correct offset for different antenna heights

→

Position calculation

Lateration:
- $\dim(dist_{pre})$ equations

Find optimum position:
- least squares method

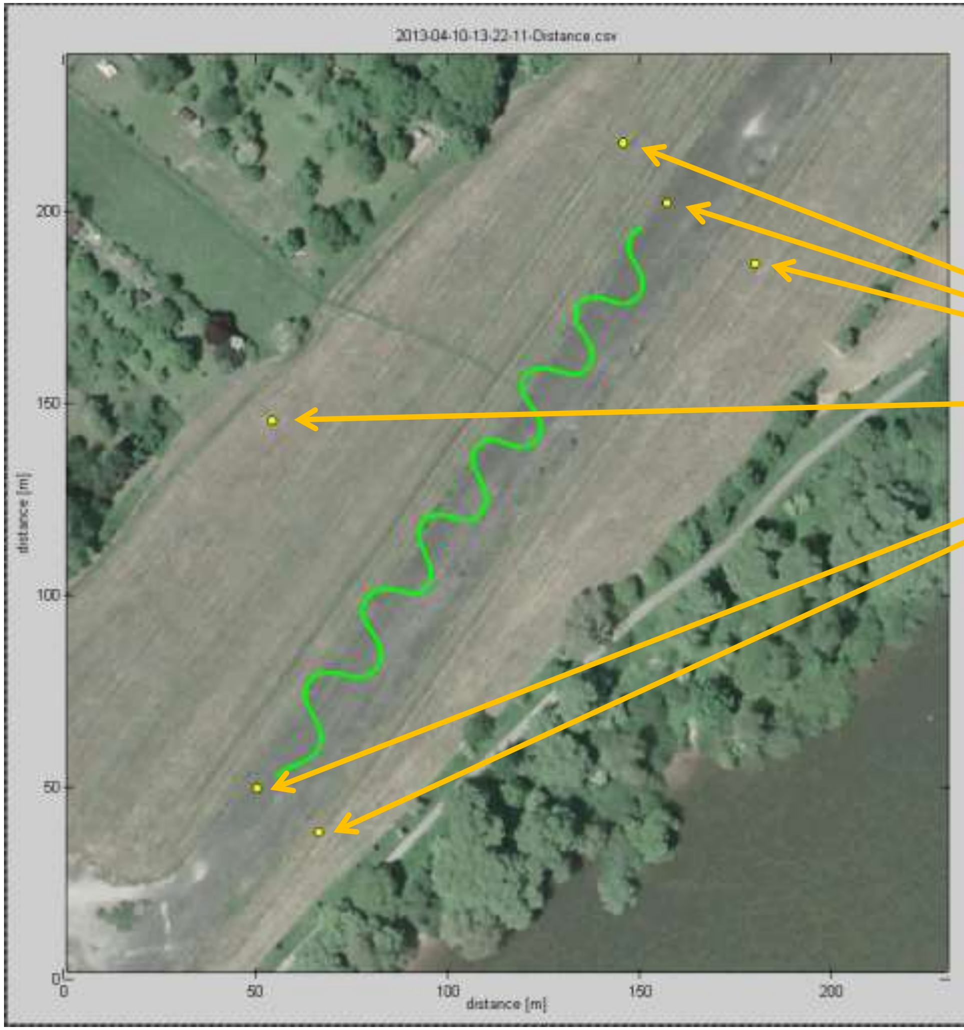
→

Filtering

Extended Kalman Filter:
- Smoothing position
- Speed estimation
- Moving direction estimation
- Prediction of new state if no measurement data available
- CV-model (constant velocity)

$$dist_{raw} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_7 \\ r_8 \end{bmatrix} \qquad dist_{pre} = \begin{bmatrix} r_n \\ \vdots \\ r_m \end{bmatrix} \qquad pos_{raw} = \begin{bmatrix} x \\ y \end{bmatrix} \qquad state = \begin{bmatrix} x \\ v_x \\ y \\ v_y \\ \psi \end{bmatrix}$$

Object localization for ADAS testing: Demonstration video



Green:	RTK D-GPS Path
Red:	Ko-TAG Path
Yellow dots:	Position of roadside TAGs
Blue:	Distance circles

Object localization for ADAS testing: System performance

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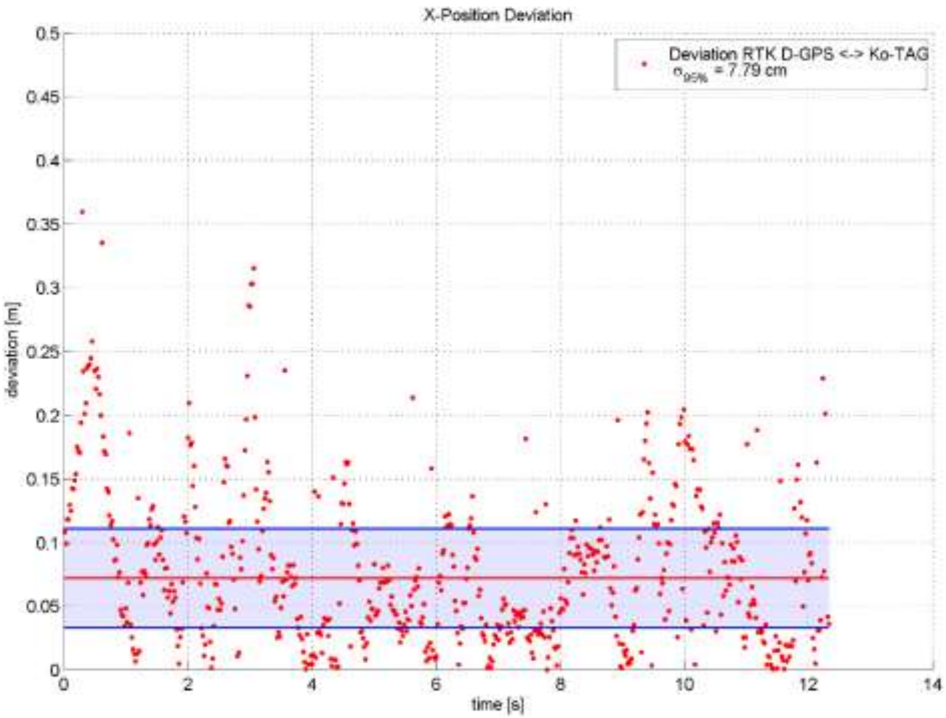
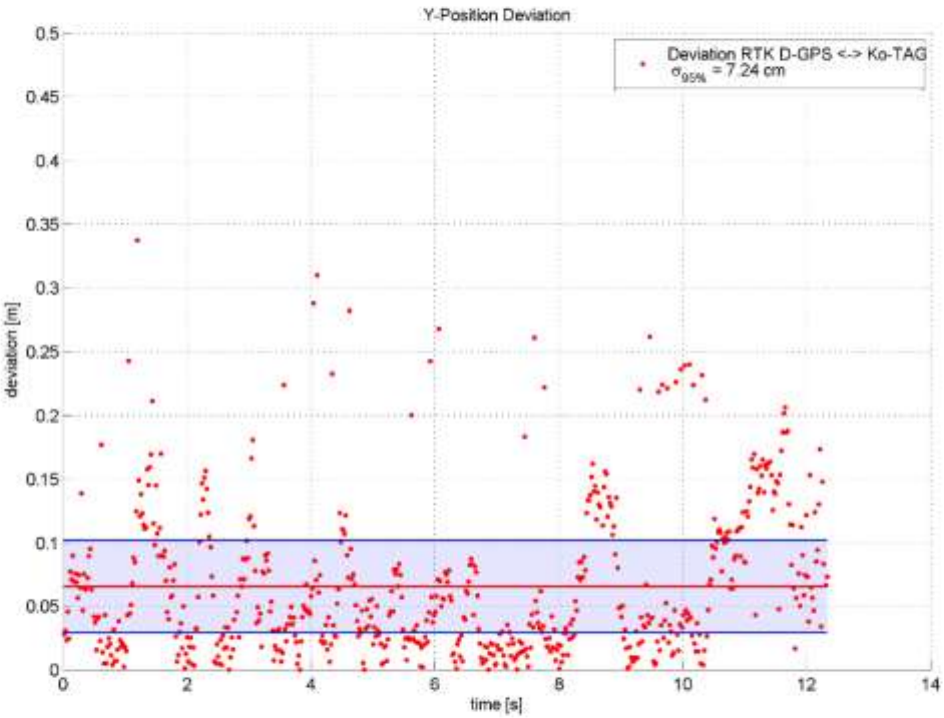
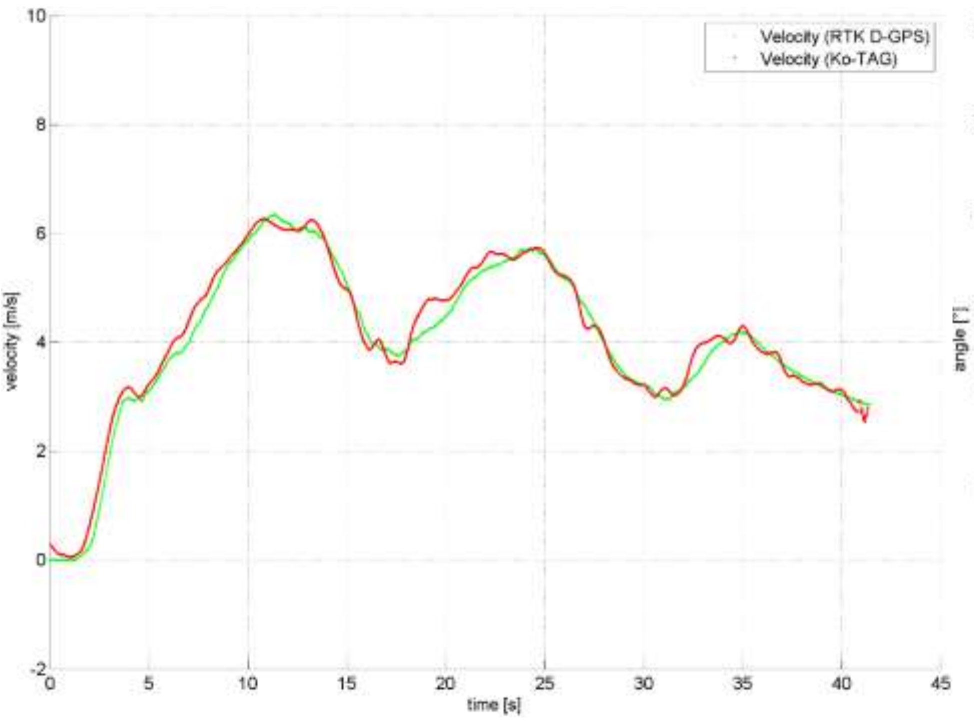
Positioning: Mean deviation X/Y to RTK D-GPS below 0,08m

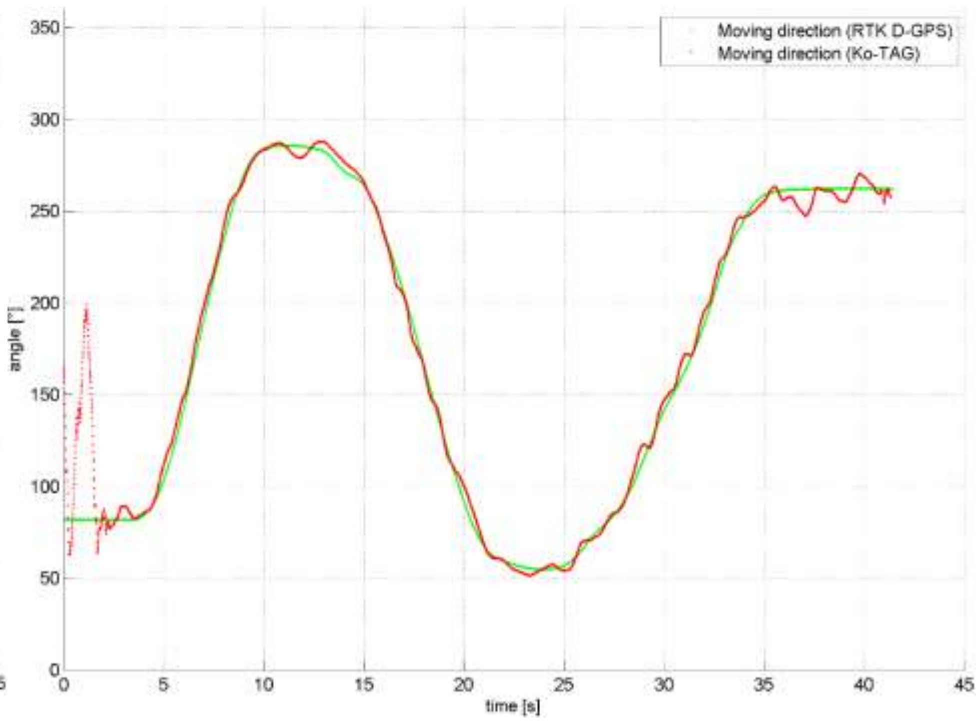




Object localization for ADAS testing: System performance

Good performance for speed and moving direction estimation





Conclusion & Outlook

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Vehicle localization in urban environments:

- Vehicle localization system without additional modifications
- Independent of satellite navigation systems (GNSS) and digital maps
- Suited for local areas with a need for a higher precision and robustness, such as urban intersections

Object Localization for ADAS testing:

- System is working with high accuracy
- Low cost multi localization possible
- Independent of GPS
- Prototype system is working

  → Importation of algorithms into embedded hardware to reduce complexity

Thank you for your attention!

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