Vehicle Tracking with Heading Estimation using a Mono Camera System

Master's Thesis at Veoneer

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Presentation Outline

1. Introduction
2. Theory and Methodology
   - Target Tracking
   - Feature Points
   - Homography
   - Filtering Structure
3. Results
   - Monte Carlo Simulations
   - Homography Estimation
   - Stereo Comparison
4. Conclusions

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The Traffic Situation in Sweden

Important traffic statistic from 2017[1]*:*

- Average travelled distance per day with car: 30 km
- 4400 severely injured
- 253 fatalities

[1] Trafikverket, 2018

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According to Euro NCAP, 90 % of all world-wide traffic accidents are caused by the human factor!

[1] Trafikverket, 2018

Euro NCAP

The European New Car Assessment Programme

- Performs vehicle tests and rates car models
- Vehicle tests of everyday scenarios, e.g.
  - Automatic emergency braking for vehicles and pedestrians
  - Adult and child occupant protection
- Puts requirements on the car manufacturers
- Higher requirements in the near future

Advanced Driver Assistance Systems (ADAS)

- An intelligent system to support and help the driver
- Sensors provide information, e.g.
  - Camera
  - Radar
  - LiDAR
- Software to process the data and to make decisions
- Veoneer (spin-off from Autoliv) is a leading supplier of ADAS and autonomous driving

Figure: Copyright Autoliv.

Target Tracking in Vision Systems

Detect, track and predict the movement of other vehicles.

Mono Camera System	**Stereo Camera System**
Less hardware (1 camera)	More hardware (2 cameras)
Cheaper	More expensive
Vehicle detections	Vehicle detections
No distance information	Distance information
Difficult to obtain heading information	Easy to obtain heading information

Objective of the Master's Thesis

Since depth information is available in the stereo camera, orientation and angular rate are easy to estimate. How can we do that in a mono camera system?

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Since depth information is available in the stereo camera, orientation and angular rate are easy to estimate. How can we do that in a mono camera system?

Objective

- Can the heading (orientation and angular rate) of a vehicle be estimated using a mono camera system?
- What kind of algorithms and models are suitable for solving the problem?
- How does a mono camera system performs compared with a stereo camera system?

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Method Outline

- Select a suitable vehicle model
- Select and create suitable measurements
  - Image detections of the vehicle
  - Angular rate
  - Image detections of the vehicle's corners
- Construct a filter
- Evaluate the performance
  - In simulations
  - With real-world data

Target Tracking Flow

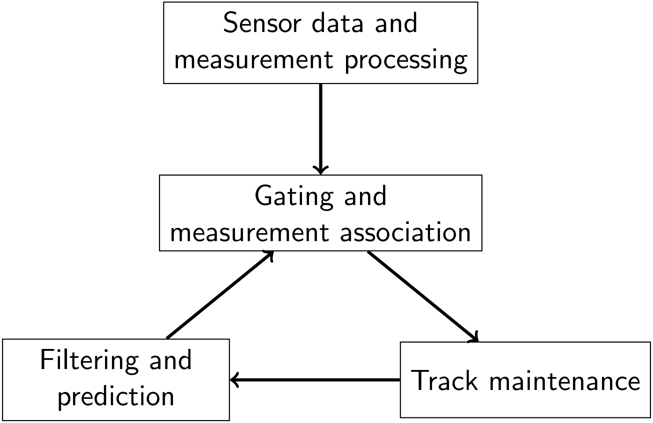


Figure: A flowchart describing a tracking system.

Feature Points

- Feature point detection
  - Harris corner detector
  - Shi and Tomasi corner detector
- Feature point tracking
  - Kanade-Lucas-Tomasi (KLT) feature tracker

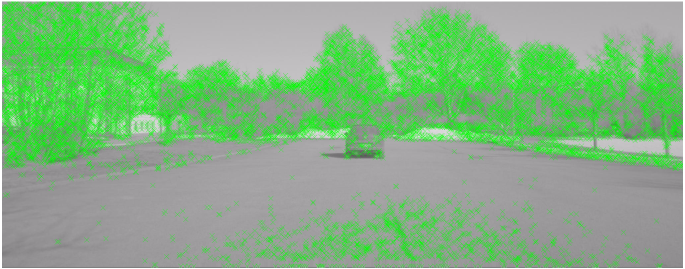


Figure: Detected feature points marked as green crosses.

The Homography – A Geometrical View

The homography, $\boldsymbol{H}$, describes the movement of a plane from correspondence of projected points.

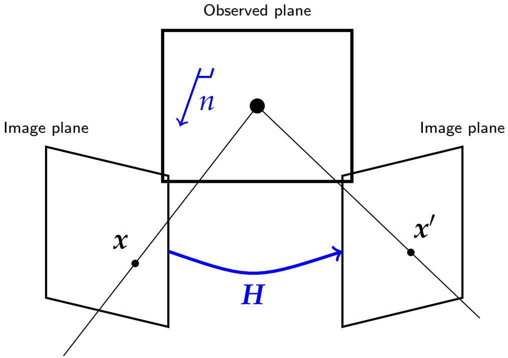


Figure: The homography describing the projective transformation between two views.

Homography for Vehicle Angular Rate

- Track feature points on the back of the target vehicle
- Find the homography between consecutive frames
- Decompose and extract the yaw rotation
- Calculate the angular rate

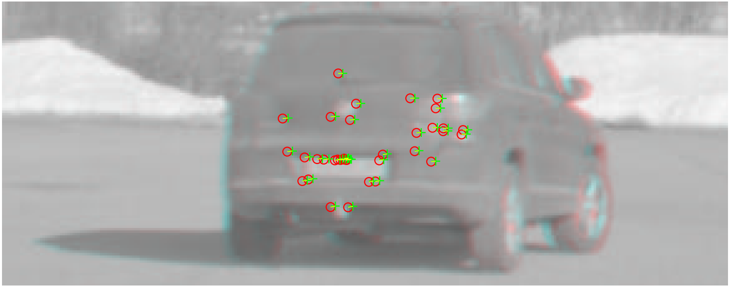
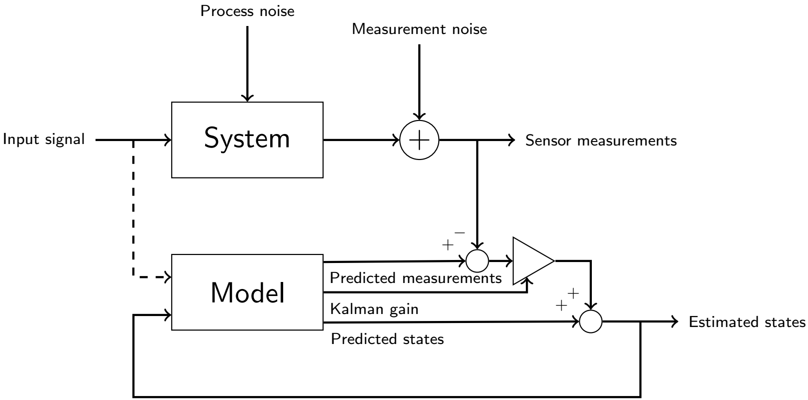


Figure: Here, feature points have moved from the 1^{st} frame (red circles) to the 2^{nd} frame (green crosses).

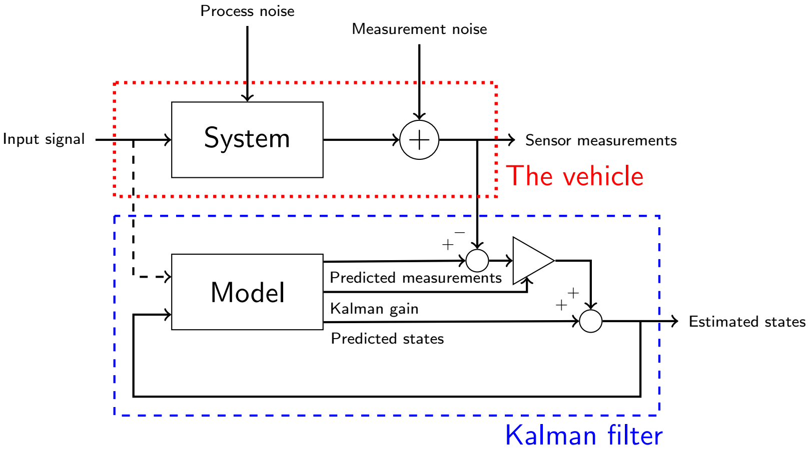
Different Image Measurements

Figure: The different image measurements used in the filter.

Filtering Structure



Filtering Structure



Summary of the Filter Structure

- Vehicle modelled as a rectangle
- An extended Kalman filter (EKF)
- A constant velocity motion model
- State vector $\boldsymbol{x} = \begin{pmatrix} x & y & z & v & \psi & \omega \end{pmatrix}^T$
- The position and orientation are relative to the ego vehicle

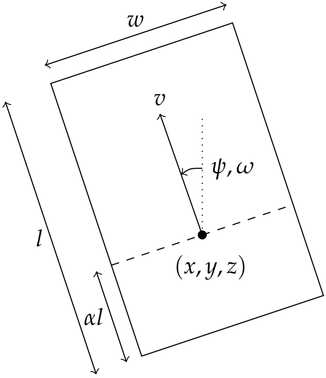


Figure: Target vehicle model.

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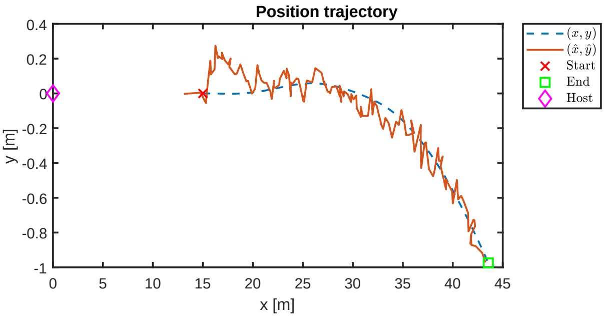
Monte Carlo Simulations – No. 1

The target is driving straight.



Monte Carlo Results – No. 1

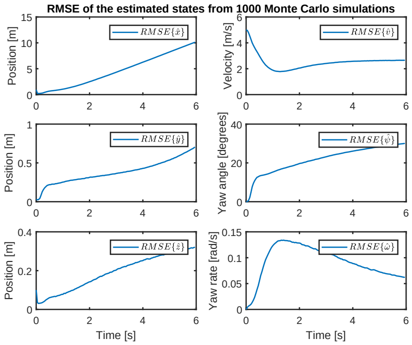


Figure: Only ROI measurements.

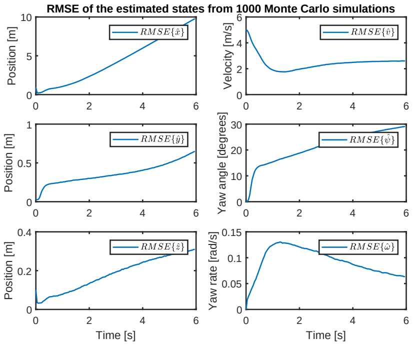


Figure: ROI and angular rate (with noise variance 1 rad/s) measurements.

Monte Carlo Results – No. 1

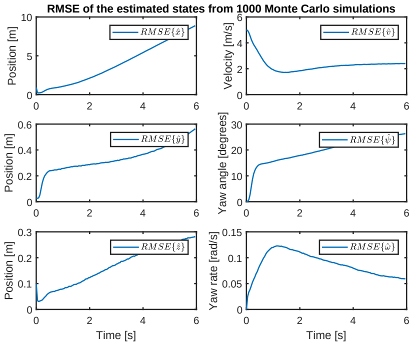


Figure: ROI and angular rate (with noise variance 0.5 rad/s) measurements.

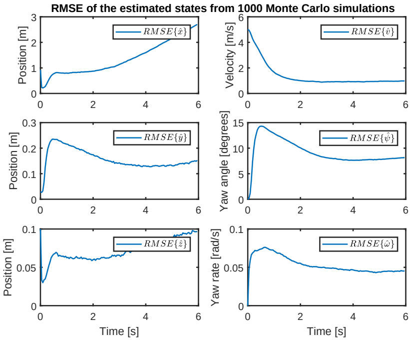
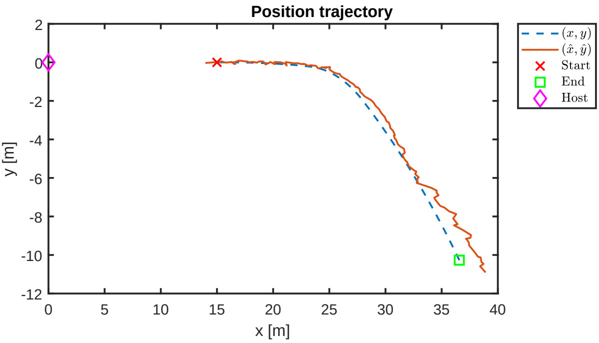


Figure: ROI and angular rate (with noise variance 0.1 rad/s) measurements.

Monte Carlo Simulations – No. 2

The target is turning to the right.



Monte Carlo Results – No. 2

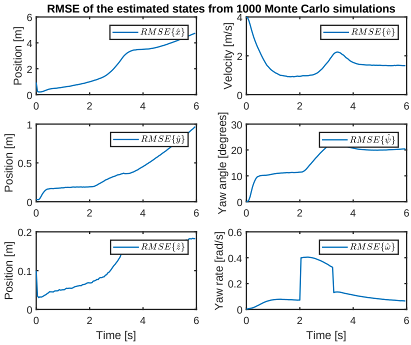


Figure: Only ROI measurements.

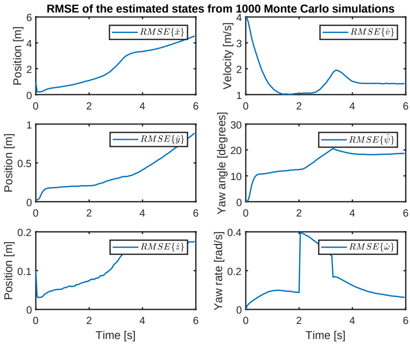


Figure: ROI and angular rate (with noise variance 1 rad/s) measurements.

Monte Carlo Results – No. 2

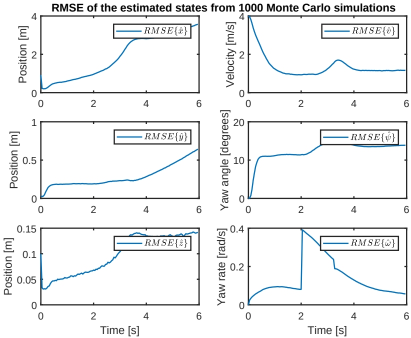


Figure: ROI and angular rate (with noise variance 0.5 rad/s) measurements.

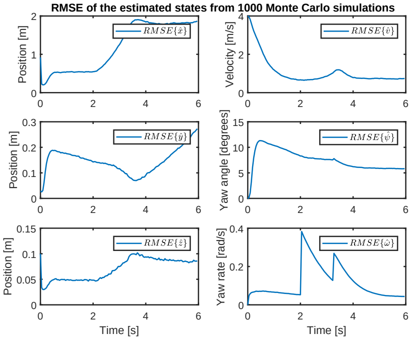


Figure: ROI and angular rate (with noise variance 0.1 rad/s) measurements.

Monte Carlo Results with Corner Measurements

Driving straight (no. 1):

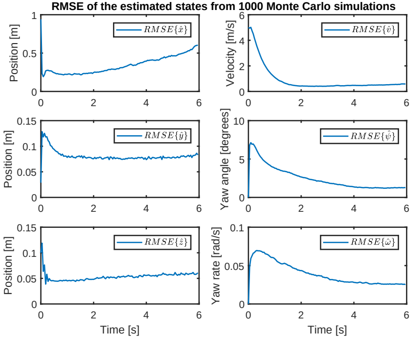


Figure: ROI, angular rate and corner measurements.

Turning right (no. 2):

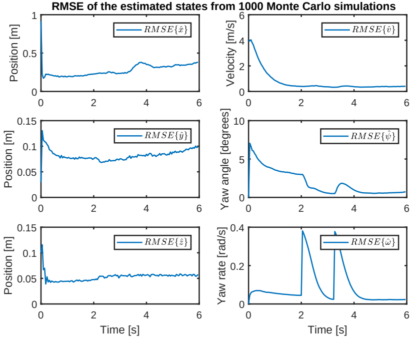


Figure: ROI, angular rate and corner measurements.

Homography Estimation Results – Simulations

Simulation of a moving rectangle with different Gaussian noise realisations.

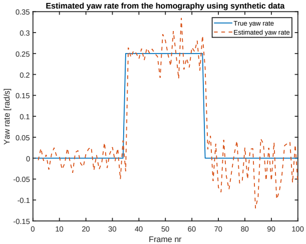


Figure: Standard deviation 0.01 [px].

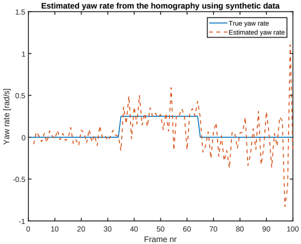


Figure: Standard deviation 0.05 [px].

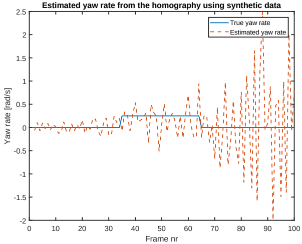


Figure: Standard deviation 0.1 [px].

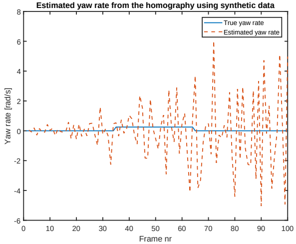


Figure: Standard deviation 0.5 [px].

Homography Estimation Results – Real-world Data

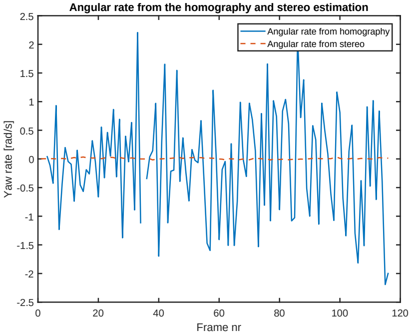


Figure: Target driving straight and has a variance of 0.8 rad/s on the angular rate data.

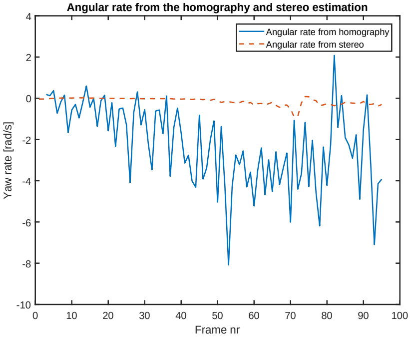


Figure: Target turning right and has a variance of 2 rad/s on the angular rate data.

Stereo Comparison – No. 1

The target is driving straight.

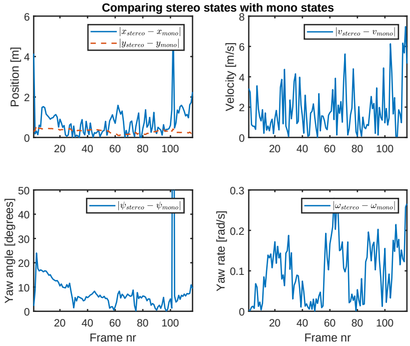


Figure: ROI and angular rate measurements.

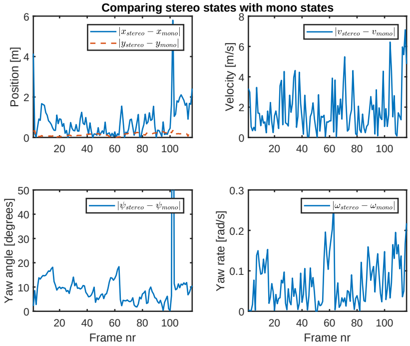


Figure: ROI, angular rate and corner measurements.

Stereo Comparison – No. 2

The target is turning to the right.

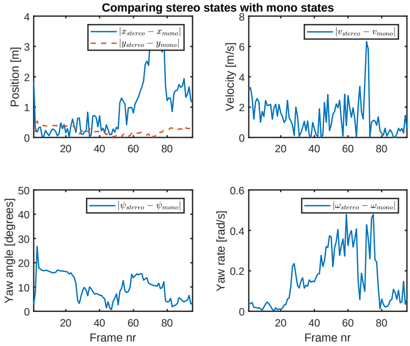
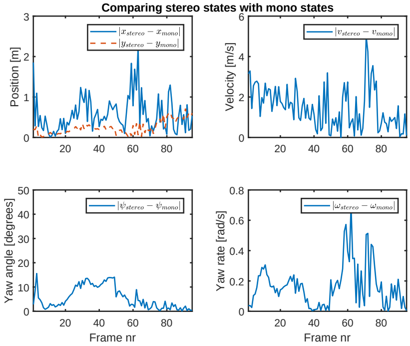


Figure: ROI and angular rate measurements.



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Conclusions

- The heading can be estimated in a mono camera system
  - Given the proper measurements
  - Measurements with high enough accuracy
- The extended Kalman filter is a suitable filter structure
- Still some performance difference compared to stereo
  - Homography estimation method
  - Feature point tracking
  - Corner detector