An Overview of My Thesis

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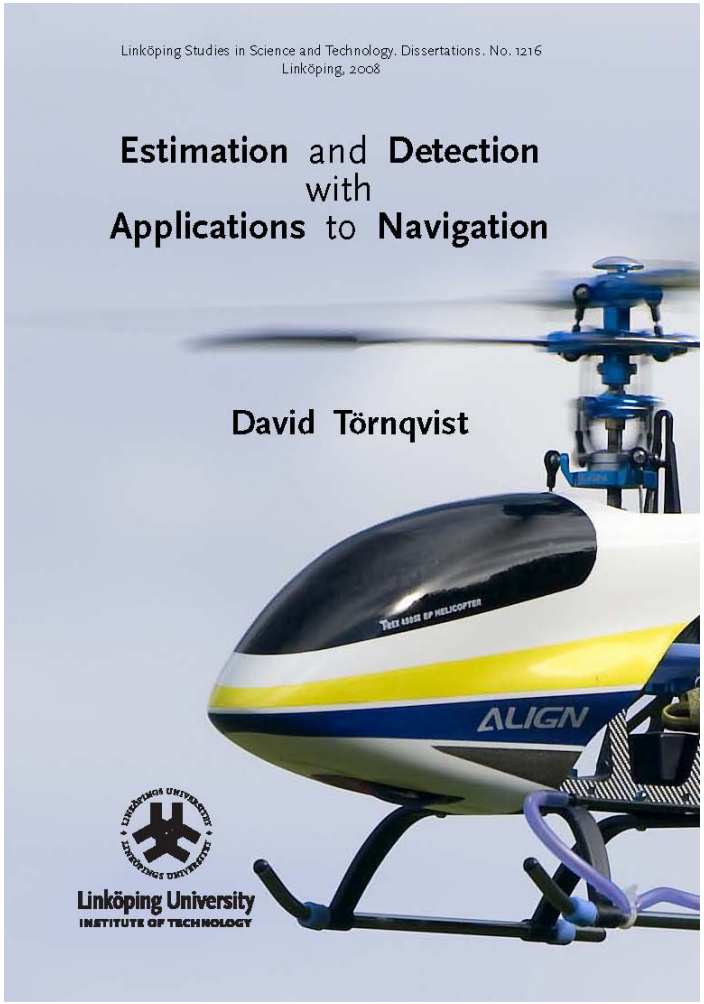


Content Summary

- Estimation
  - Estimate position and map (SLAM) with particle filter
  - Estimate target position (using positive and negative information)
  - Use of sensors with different update rate in the particle filter
- Detection
  - Extension of the parity space method
  - Detect disturbances/fault (eg magnetometer disturbances)
  - Detection of spurious features

Background

- SLAM – Simultaneous Localization and Mapping
- There is a large need in the UAV industry to have a backup navigation system, independent of GPS

Particle Filter SLAM

- Typically, the SLAM-problem has been addressed for ground vehicles with a low dimensional vehicle model (x, y, θ)
- We want to make full 3D SLAM with a particle filter and use a high dimensional vehicle model
- This allows us to:

  Make better predictions of the vehicle position and orientation.

  Filter measurements of accelerations and angular velocity rather than just integrating them.

FastSLAM

- Make the following partition of the states $x = \begin{pmatrix} x^v \\ m \end{pmatrix}$
- Estimate the vehicle model x^v with a particle filter
- For each particle, estimate the map m with a Kalman filter

$$p(x^v_{1:t}, m_t | y_{1:t}) = p(x^v_{1:t} | y_{1:t}) \underbrace{p(m_t | x^v_{1:t}, y_{1:t})}_{\prod_i \mathcal{N}(\hat{m}_{i,t}, \Sigma_i)}$$

- The last factorization lowers the complexity from quadratic to linear in the number of map entries!

Extra Rao-Blackwellizing

- An extra Rao-Blackwellizing is made for the vehicle model
- Observe that the Kalman filter is partitioned
  - One covariance matrix for the linear states in the vehicle model (blue)
  - One covariance matrix for each map entry (black)

$$p(x^p_{1:t}, x^k_t, m_t | y_{1:t})$$

$$= \underbrace{p(x^p_{1:t}|y_{1:t})}_{\text{particle filter}} \underbrace{p(x^k_t|x^p_{1:t}, y_{1:t}) \prod_{j=1}^{M_t} p(m_{j,t}|x^p_{1:t}, x^k_t, y_{1:t})}_{\text{(extended) Kalman filter}}$$

Flight Campaign

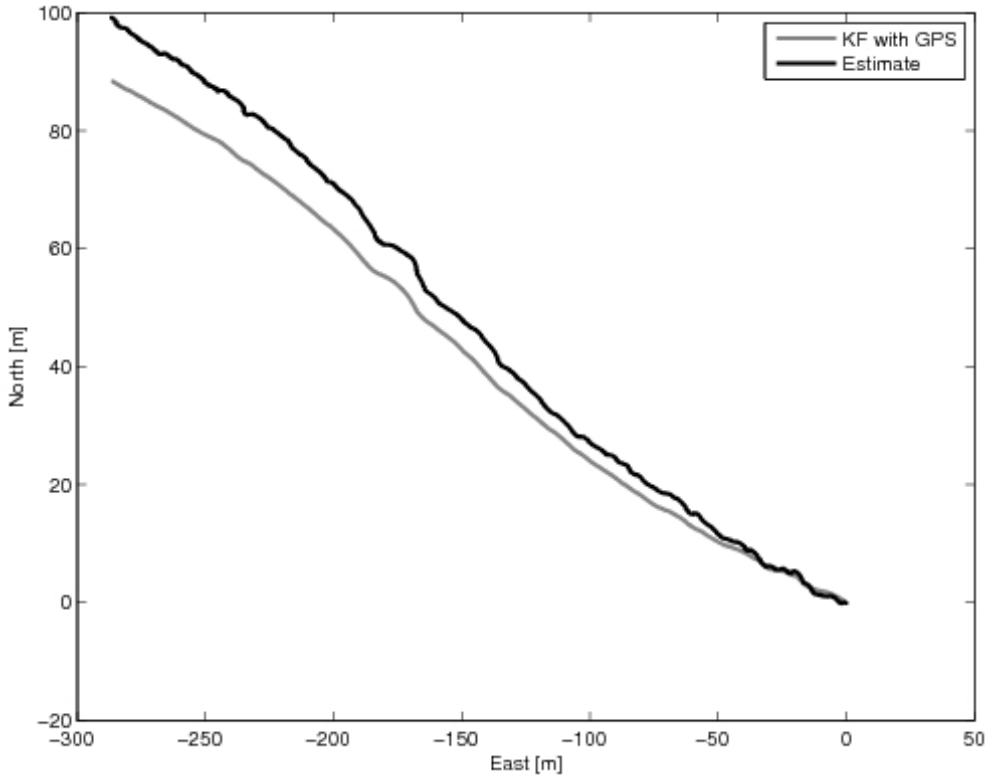
- Helicopter, Yamaha RMAX
- Revinge, Sweden

Results

- New map entry
- Measured map entry
- Particle for position

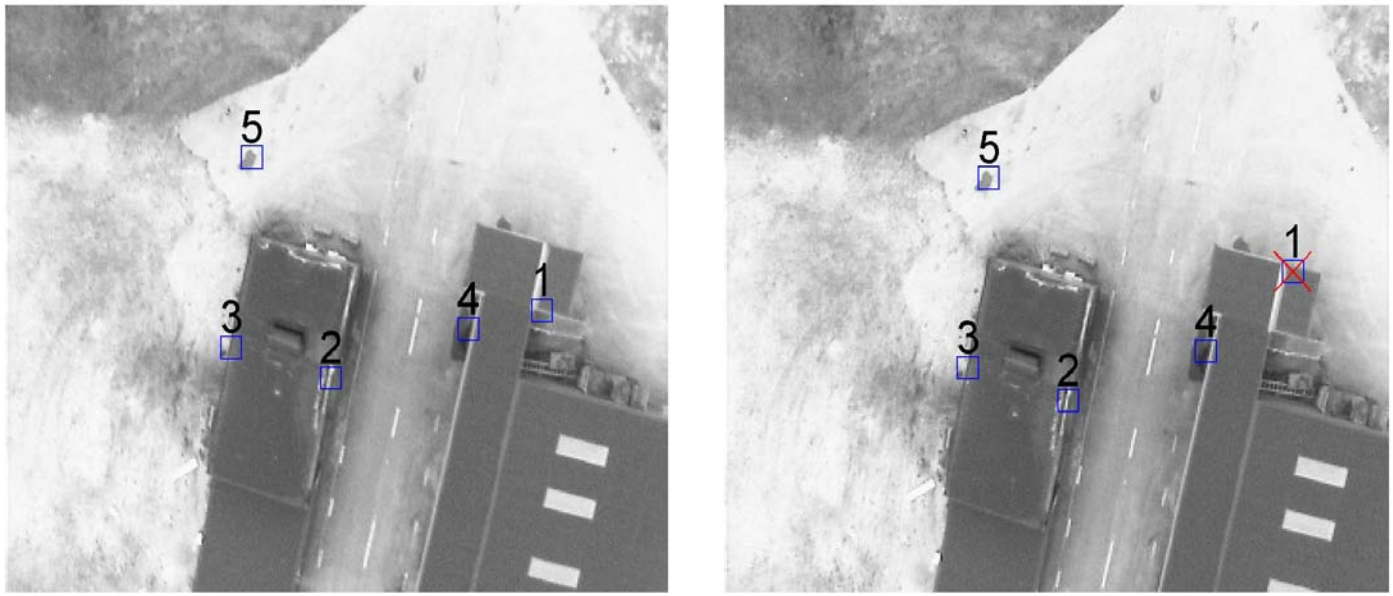
Results

- Low drift in position over a 300m distance.



Feature Detection for SLAM

- Features are detected in the image
- Corresponding features should be found in the next image



- Correspondence sometimes faulty, must be detected!

Parity Space – Idea

- Is output data consistent with the model over a time-window?

- Algorithm:

  A projection removes outputs consistent with the model

  Only noise and faults are left

  GLR-test determines if there are faults

Parity Space – Projection

- Eliminate influence of the initial state by projection, standard method (Chow and Willsky, 1984).
- Model description over time-window

$$\mathbb{Y} = \mathcal{O}x + \bar{H}_f\mathbb{F} + \bar{H}_v\mathbb{V} + \mathbb{E}$$

  x is the initial state, can also include unknown parameters.
- The residual is formed as

$$r = \mathcal{P}_{\mathcal{O}^\perp}\mathbb{Y} = \mathcal{P}_{\mathcal{O}^\perp}(\bar{H}_f\mathbb{F} + \bar{H}_v\mathbb{V} + \mathbb{E})$$

Parity Space – GLR Test

- Form the following hypothesis test

$$\mathcal{H}_0 : \; r \sim N(0, S),$$
$$\mathcal{H}_1 : \; r \sim N(\mathcal{P}_{\mathcal{O}^\perp} \bar{H}^f \mathbb{F}, S).$$

- If the noises are Gaussian a Chi-square variable results from the GLR-test

$$L = \bar{r}^T \mathcal{P}_{W^T \bar{H}^f} \bar{r} \sim \chi'^2_\nu(\lambda)$$

- Central or non-central Chi-square distribution determines if a fault is present or not.

Feature Modeling

- Model with stationary features
- Pinhole camera model
- The measurement model is linearized

"Unknown" parameters

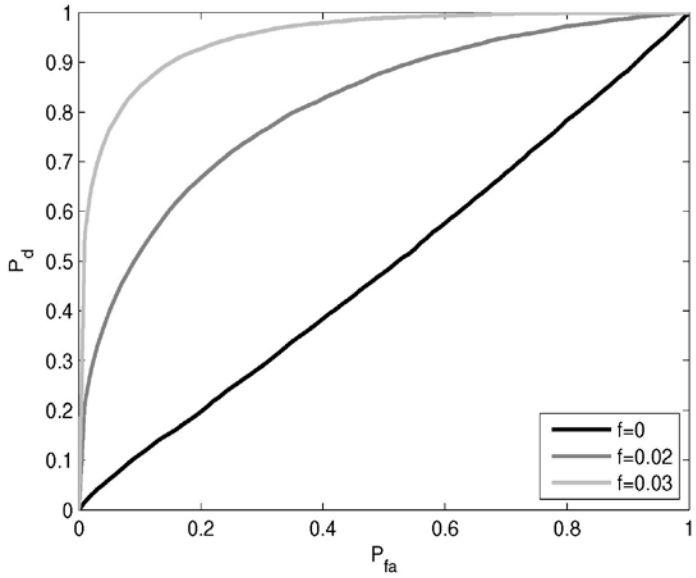
$$m_{i,t+1} = m_{i,t}$$

$$y_{i,t} = \frac{1}{z^c_{i,t}} \begin{pmatrix} x^c_{i,t} \\ y^c_{i,t} \end{pmatrix} = \frac{1}{z^c_{i,t}} \begin{pmatrix} I & 0 \end{pmatrix} R_t(m_{i,t} - p_t) + e_{i,t}$$

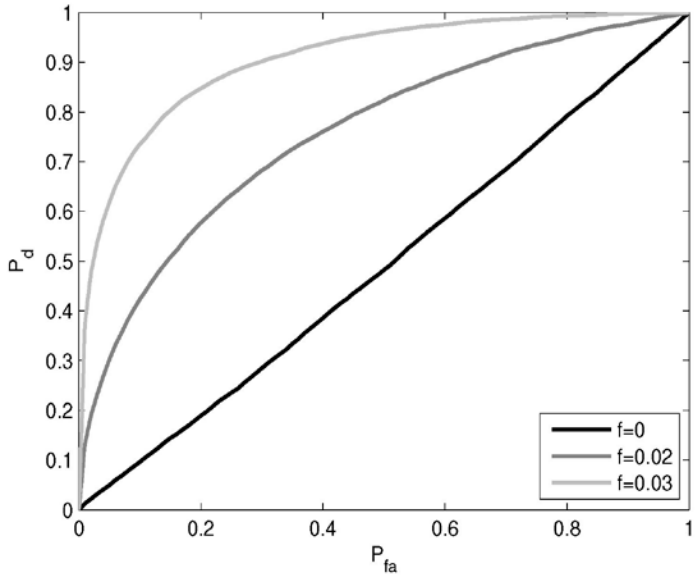
where $$m^c_{i,t} = \begin{pmatrix} x^c_{i,t} \\ y^c_{i,t} \\ z^c_{i,t} \end{pmatrix} = R_t(m_{i,t} - p_t).$$

Simulation Example –
Detection Performance

- Receiver Operation Characteristics (ROC)
- More powerful test when the position is accurately estimated



Position estimated



Position projected away

Real-World Example –

Autonomous Helicopter

- Simultaneous Localization and Mapping (SLAM)
- Flying a 300m distance at 60m altitude
- Divergence without spurious feature detection

Advantages with this Method

- Rejects spurious features with *statistical methods*
- A *combination* of IMU and camera is used
- A time window of *several images* can be used
- Successful implementations

Thank you for listening!

Questions?