INERTIAL-VISION NAVIGATION WITH SUPPORT FROM FLAT TERRAIN MAP

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INTRODUCTION

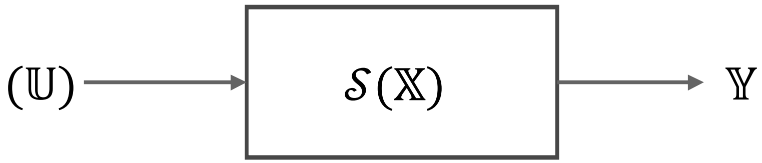
- A method to estimate position and heading of the aerial vehicle
- Focus on the concept, not many hard results (mainly due to lack of data)
- Short introduction on Particle Filter
- Short introduction on Chamfer matching
- Evaluation of the likelihood function

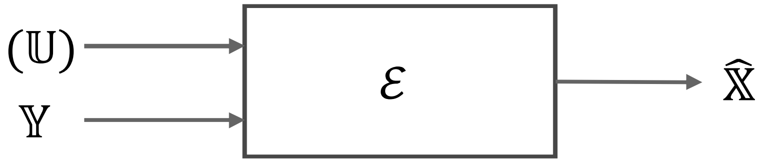
MAIN IDEA

- Use downward pointing camera images together with a flat map of the environment (represented as an image) to estimate the position and heading of the flying platform
- Flat map assumes that pitch and roll attitude of the vehicle is small – helicopter or blimp-like platform
  - Even with 3D map, the ambiguity between position and attitude is still present for this configuration
- Images and map are utilised in the likelihood function
- Estimation is performed with the Particle Filter
  - Handles likelihood function in a nice way (unlike EKF)

ESTIMATION PROBLEM

- Given a system, $\mathcal{S}$, and some observations (measurements) created from it, $\mathbb{Y}$, estimate the hidden variables the are contained in the system, $\mathbb{X}$, with an estimator $\mathcal{E}$. The observations may include inputs to the system, $\mathbb{U}$, as well.





- Navigation is an example of the estimation problem.
- Estimation can be solved in many different ways
  - Filtering (real-time)
  - Smoothing (batch-oriented)

PARTICLE FILTER

Particle Filter (PF) solves an optimal (non-linear) filtering problem

$$p(x_t|y_{1:t}) = \frac{p(y_t|x_t)p(x_t|y_{1:t-1})}{p(y_t|y_{1:t-1})}$$

$$p(x_{t+1}|y_{1:t}) = \int p(x_{t+1}|x_t)p(x_t|y_{1:t})\,dx_t$$

with a sampling method (Monte Carlo).

In the equations above:

$p(y_t|x_t)$ is the likelihood function (usually a measurement equation),

$p(x_{t+1}|x_t)$ is the state transition pdf (usually state dynamics),

$p(x_t|y_{1:t})$ is the posterior pdf (what we want to estimate),

$p(x_t|y_{1:t-1})$ is the prior pdf (prediction of the state at time *t* before measurements arrive).

PARTICLE FILTER

- pdfs from previous slide are approximated with *N* particles with corresponding weights: $\{x_t^i, w_t^i\}_{i=1:N}$
- Two main steps are iterated
  - Weight update – ”measurement update”
  - Resampling and particle transition – ”time update”
- Point estimate can be obtained as a weighted particle sum

$$\hat{x}_t = \sum_{i=1}^{N} w_t^i x_t^i$$

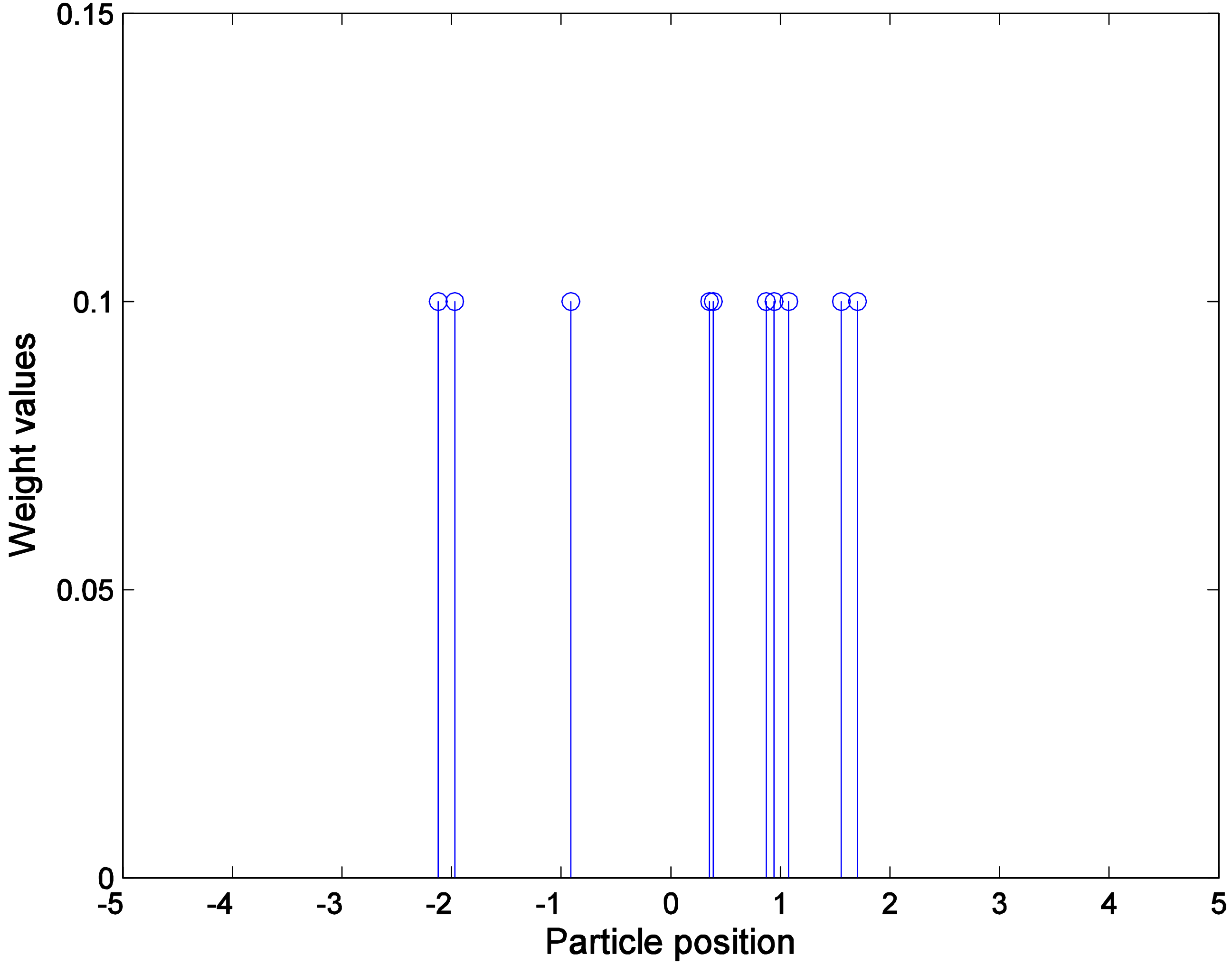
- Illustration with a toy example
  - One-dimensional
  - 10 particles
  - Simple transition pdf (state dynamics):

$$p(x_{t+1}|x_t) = \mathcal{N}(x_{t+1}; x_t + u_t, Q), (x_{t+1} = x_t + u_t + w_t)$$

  - Simple likelihood (measurement equation):

$$p(y_t|x_t) = \mathcal{N}(y_t; x_t, R), (y_t = x_t + e_t)$$

PARTICLE FILTER



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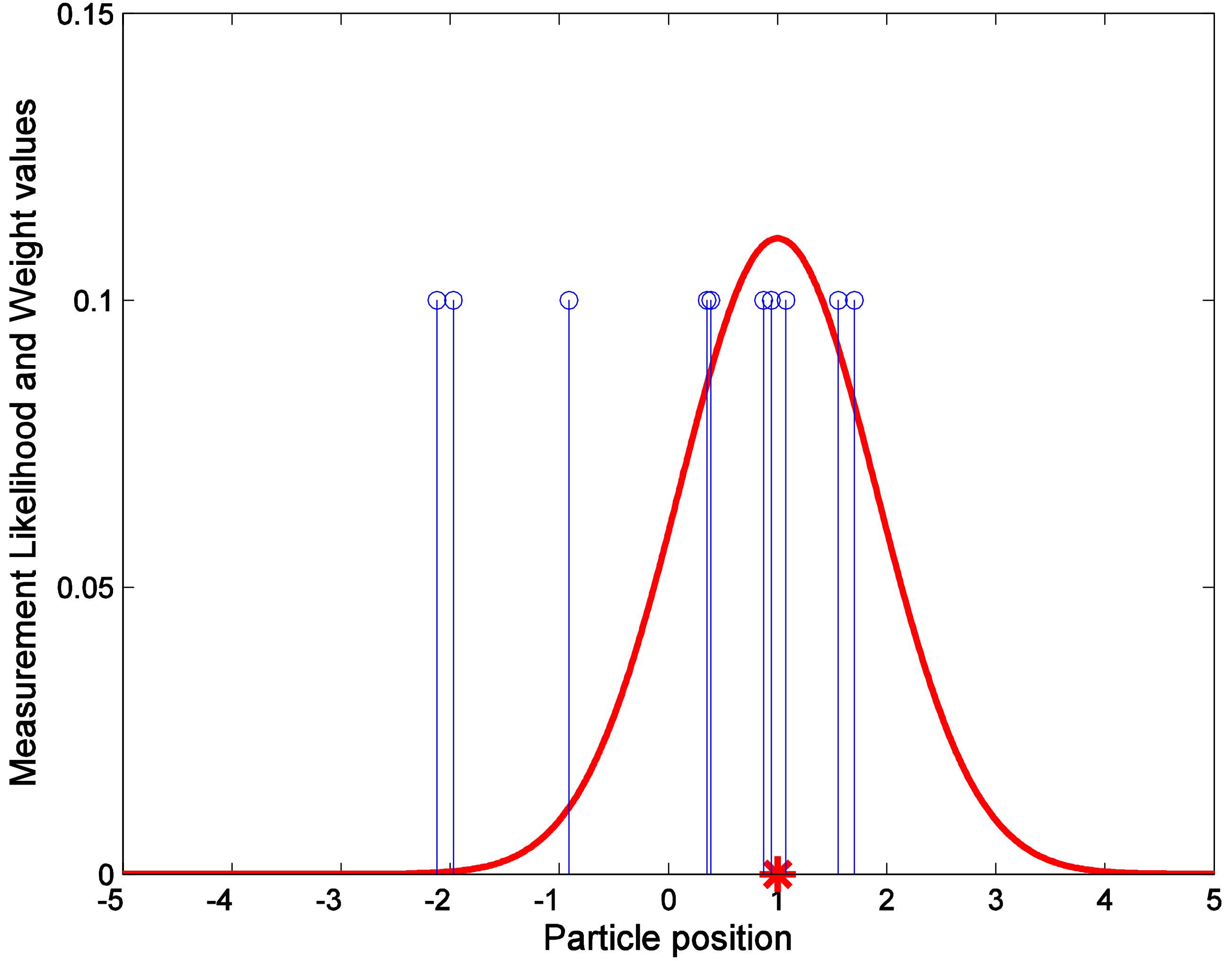

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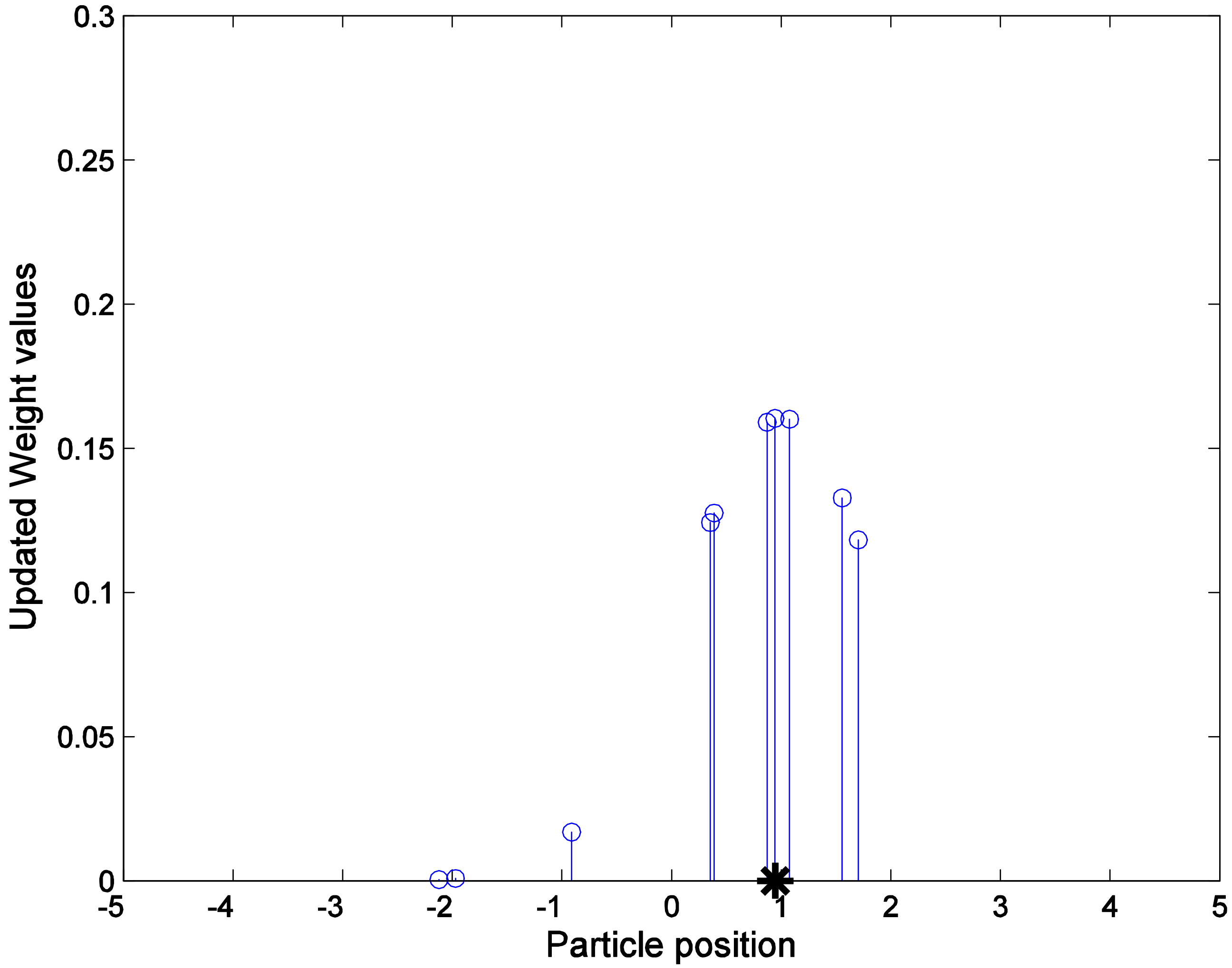

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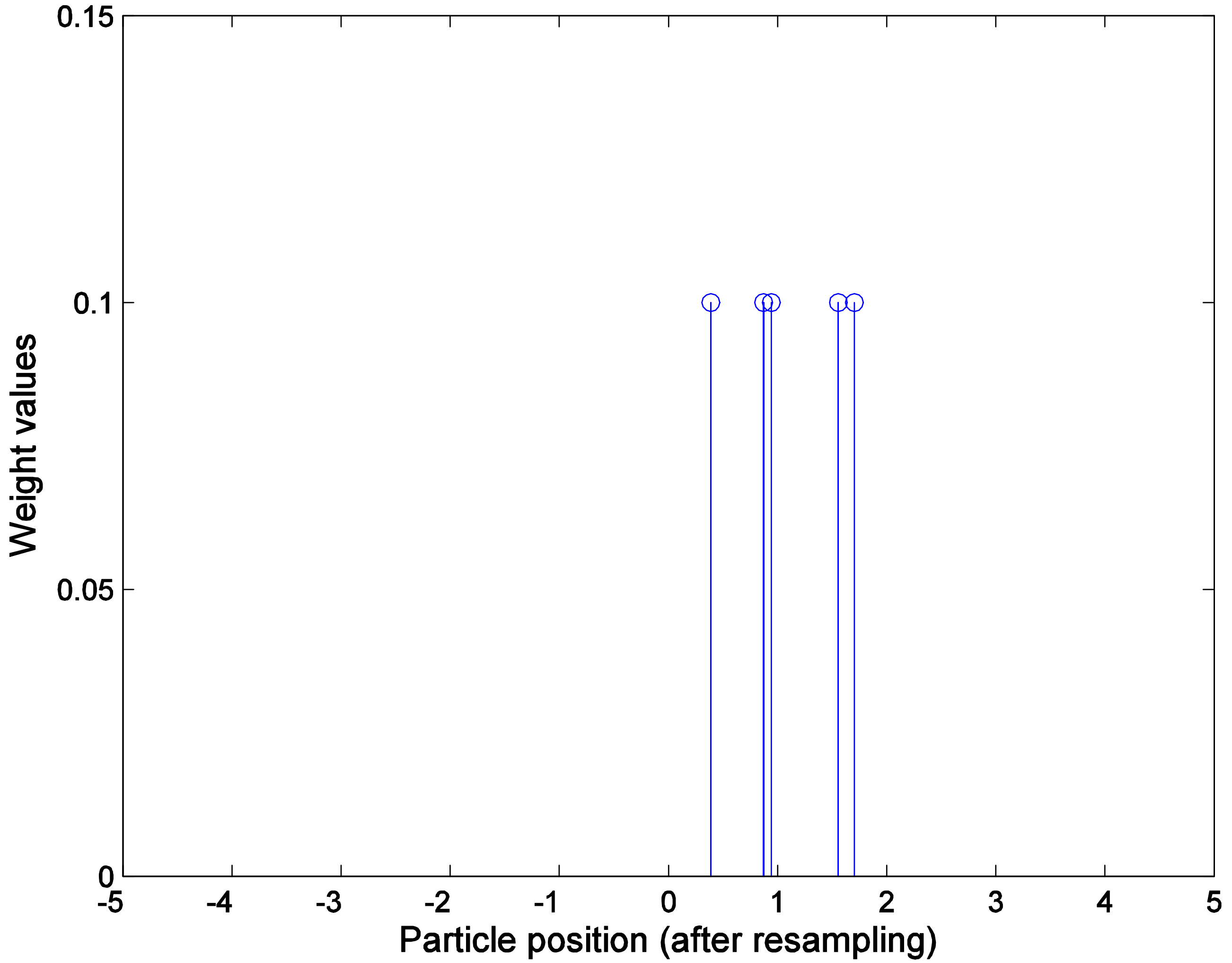

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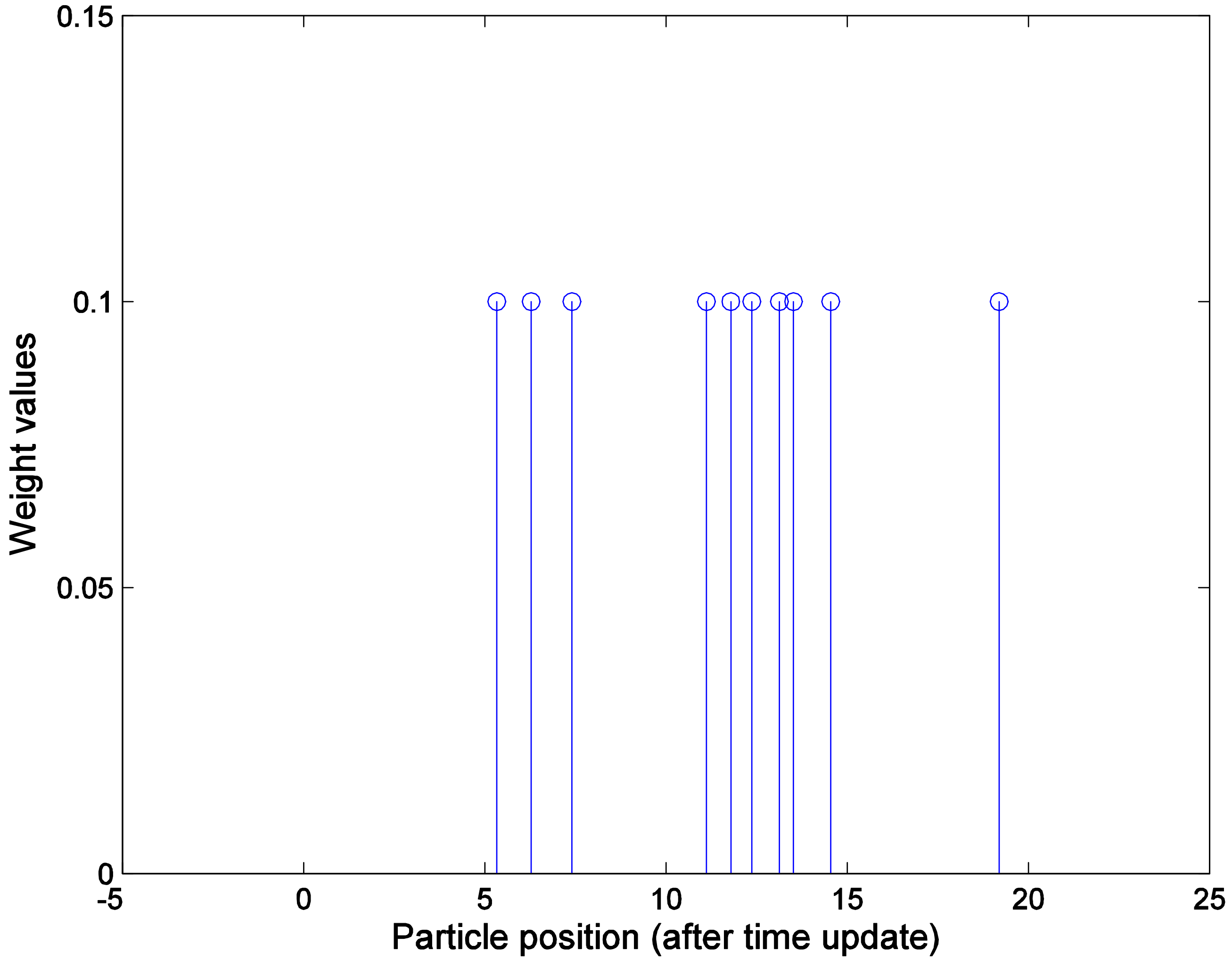

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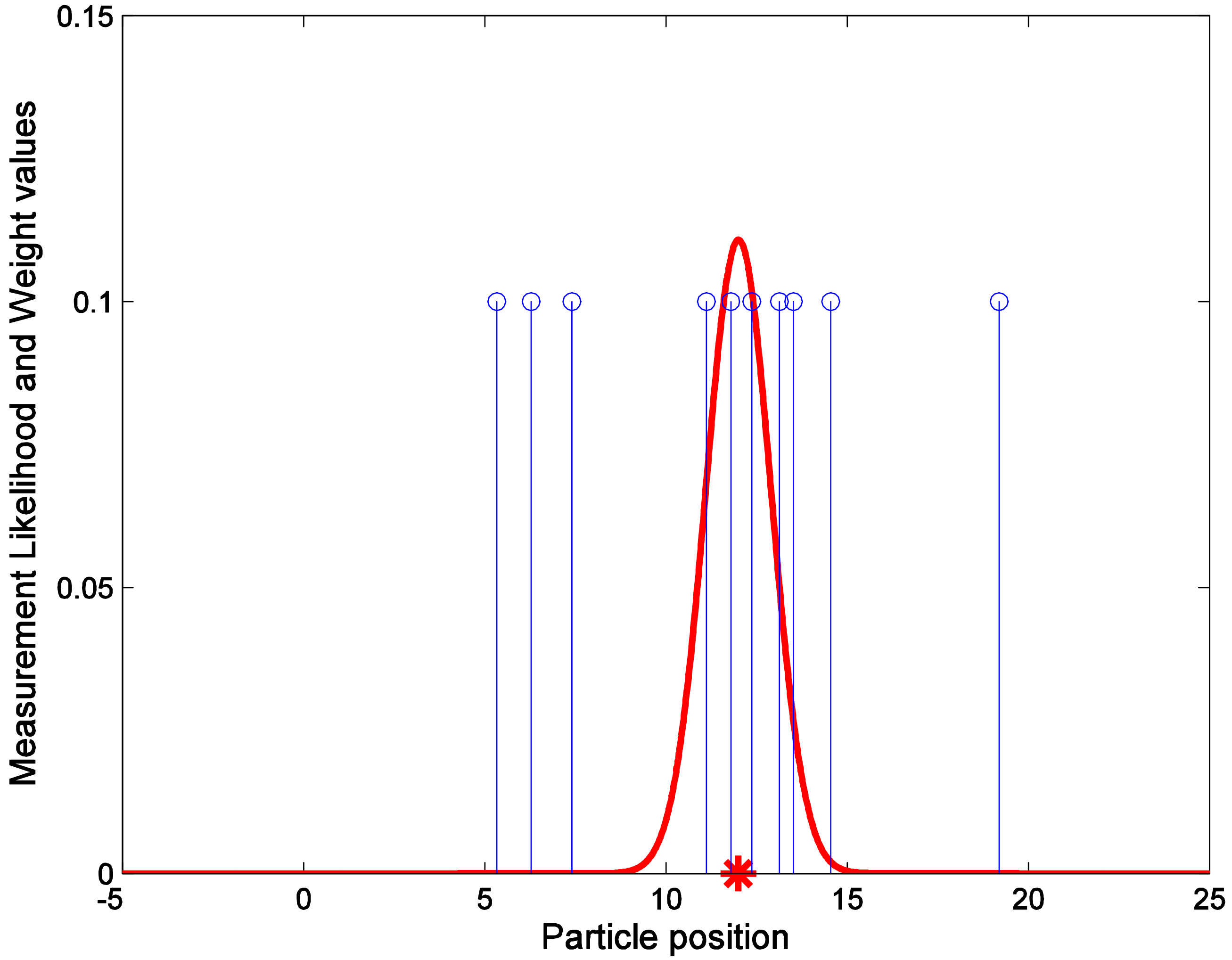

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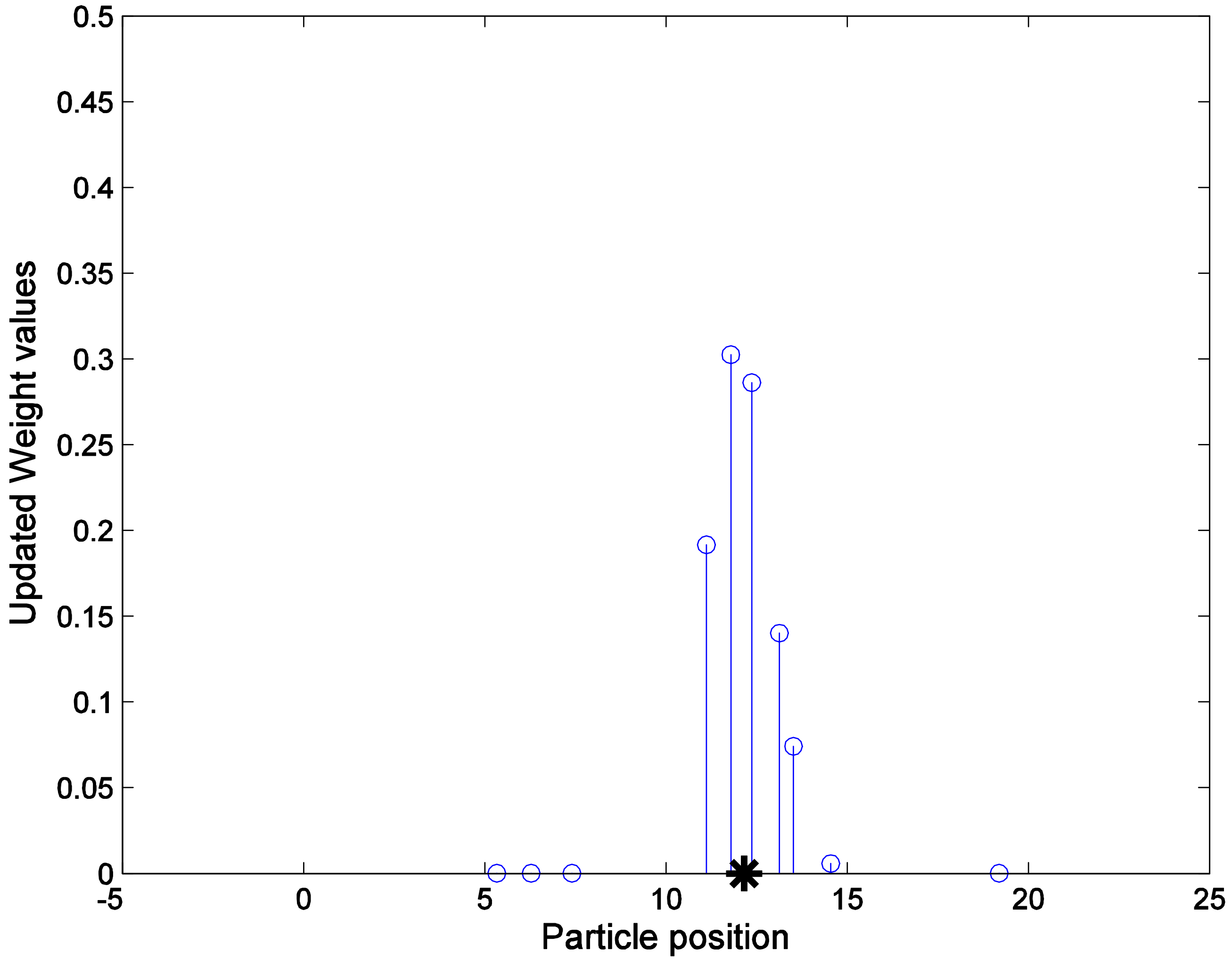


STATE TRANSITION – DYNAMICS $p(x_{t+1}|x_t)$

- Vehicle dynamics with inertial signals (accelerometers and rate gyros) as inputs in a state space form

$$p_{t+1} = p_t + T_s v_t + \frac{T_s^2}{2}\mathrm{R}(q_t)^T(a_t + w_t^a)$$
$$v_{t+1} = v_t + T_s \mathrm{R}(q_t)^T(a_t + w_t^a)$$
$$q_{t+1} = \mathrm{expm}\left(\frac{T_s}{2}\mathrm{S}(\omega_t + w_t^\omega)\right) q_t$$

where

a_t is the acceleration measurement (input),

ω_t is the gyro measurement (input),

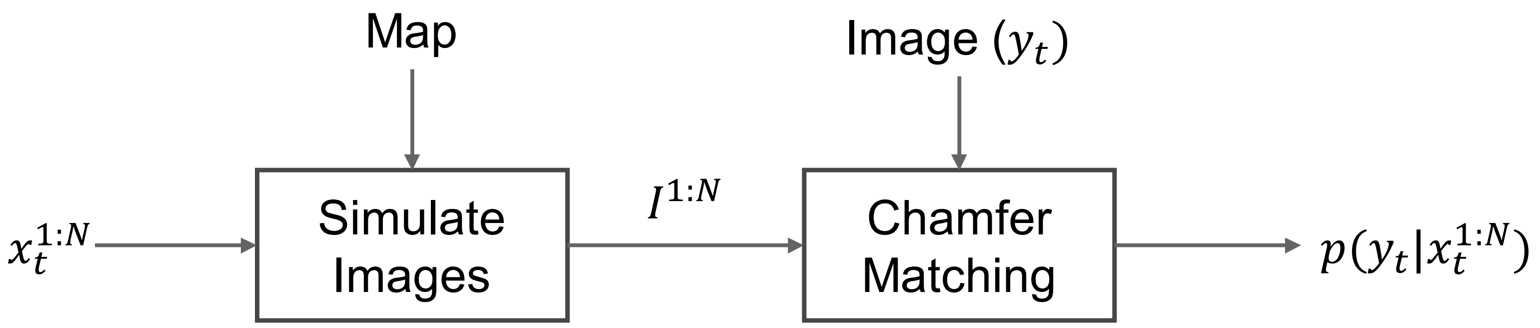
$w_t^a \sim \mathcal{N}(0, R^a)$ and $w_t^\omega \sim \mathcal{N}(0, R^\omega)$ are sensor noises,

$\mathrm{R}(q_t)$ encodes rotation between body and navigation frames,

$S(\cdot)$ is the mapping between a vector and a skew-symmetric matrix

LIKELIHOOD FUNCTION – MEASUREMENTS $p(y_t|x_t)$

- The difficult part due to its construction
- Based on image matching with Chamfer method
- No analytical gradient – EKF is hard(er) to implement



LIKELIHOOD FUNCTION – MEASUREMENTS

- A simple example image from a camera mounted on the helicopter UAV
- Map image taken from the internet

LIKELIHOOD FUNCTION – MEASUREMENTS

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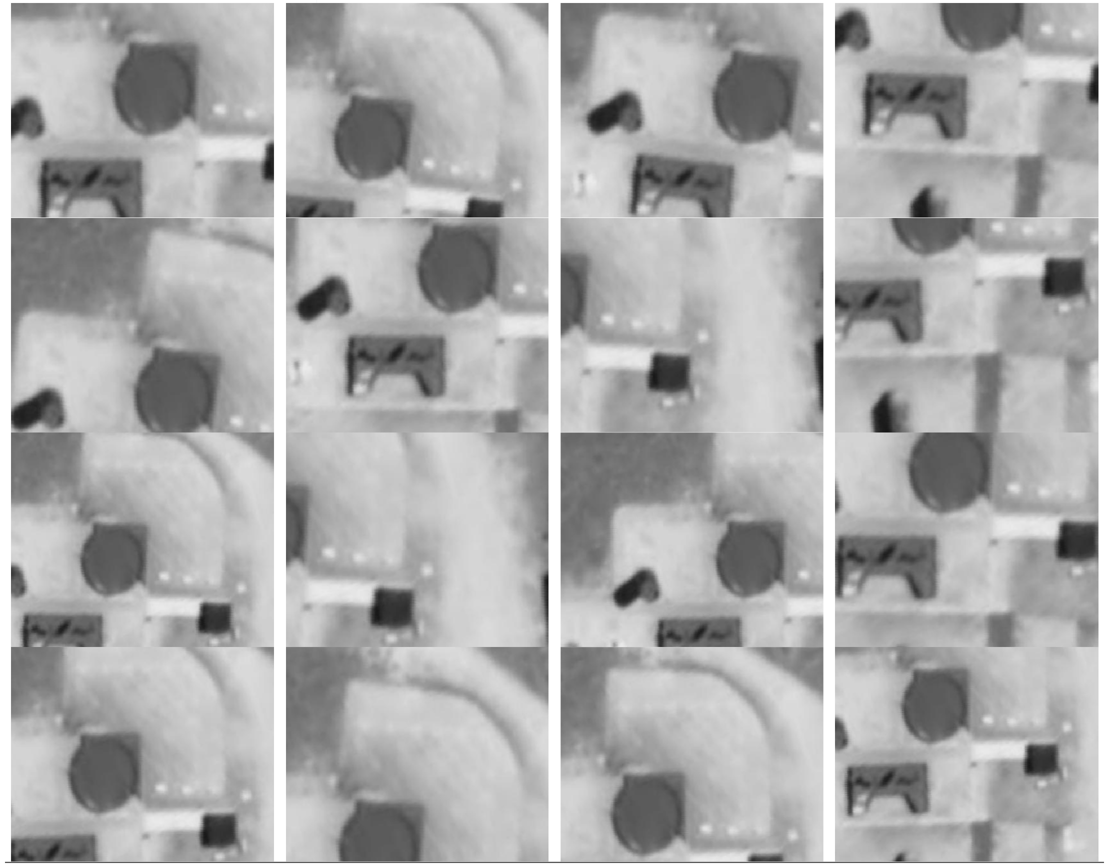
- Map image taken from the internet
- Map is used to create simulated images given the position and heading hypothesis (represented with N particles, $i = 1:N$)

$$m_C^j = \mathrm{R}(q_t^i)\left(p_t^i - m^j(1:3)\right)$$

$$\begin{bmatrix} u^j \\ v^j \end{bmatrix} = \mathcal{P}_C\left(\begin{bmatrix} \frac{m_C^j(1)}{m_C^j(3)} \\ \frac{m_C^j(2)}{m_C^j(3)} \end{bmatrix}\right)$$

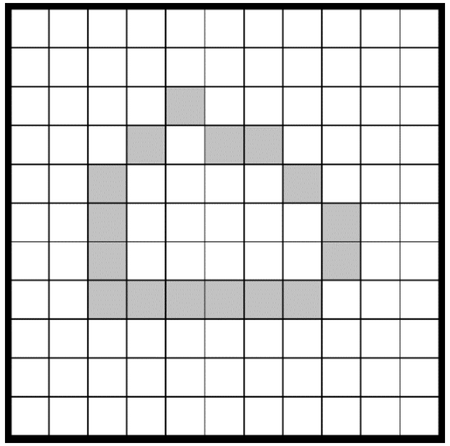
$$I^i(u^j, v^j) = m^j(4)$$



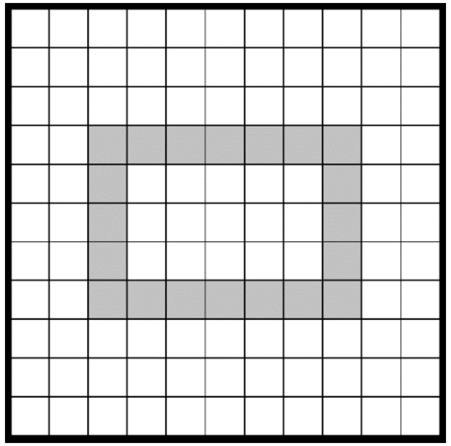
CHAMFER MATCHING

- A robust image matching method
- Based on the edge images and distance transform

Pattern



Template



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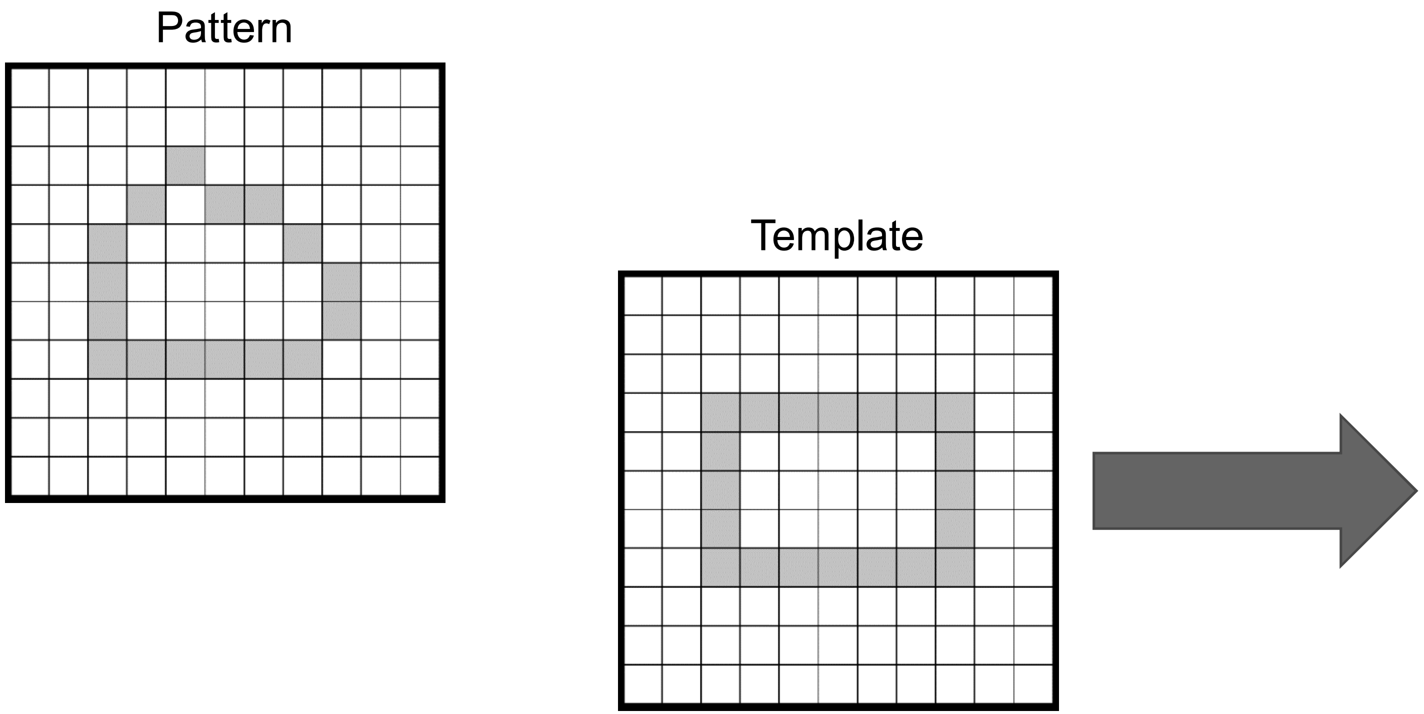

Distance Transform

5	4	3	3	3	3	3	3	3	4	5
4	3	2	2	2	2	2	2	2	3	4
3	2	1	1	1	1	1	1	1	2	3
2	1	0	0	0	0	0	0	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	1	2	2	2	1	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	0	0	0	0	0	0	1	2
3	2	1	1	1	1	1	1	1	2	3
4	3	2	2	2	2	2	2	2	3	4
5	4	3	3	3	3	3	3	3	4	5

CHAMFER MATCHING

- Example of two matching cases
- Likelihood is obtained with the transformation
  $p(y_t|x_t) = e^{-V(y_t,x_t)}$

V = 24/16 = 1.5

5	4	3	3	3	3	3	3	3	4	5
4	3	2	2	2	2	2	2	2	3	4
3	2	1	1	1	1	1	1	1	2	3
2	1	0	0	0	0	0	0	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	1	2	2	2	1	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	0	0	0	0	0	0	1	2
3	2	1	1	1	1	1	1	1	2	3
4	3	2	2	2	2	2	2	2	3	4
5	4	3	3	3	3	3	3	3	4	5

V = 2/16 = 0.125

5	4	3	3	3	3	3	3	3	4	5
4	3	2	2	2	2	2	2	2	3	4
3	2	1	1	1	1	1	1	1	2	3
2	1	0	0	0	0	0	0	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	1	2	2	2	1	0	1	2
2	1	0	1	1	1	1	1	0	1	2
2	1	0	0	0	0	0	0	0	1	2
3	2	1	1	1	1	1	1	1	2	3
4	3	2	2	2	2	2	2	2	3	4
5	4	3	3	3	3	3	3	3	4	5

EVALUATION OF THE LIKELIHOOD – GOOD CASE

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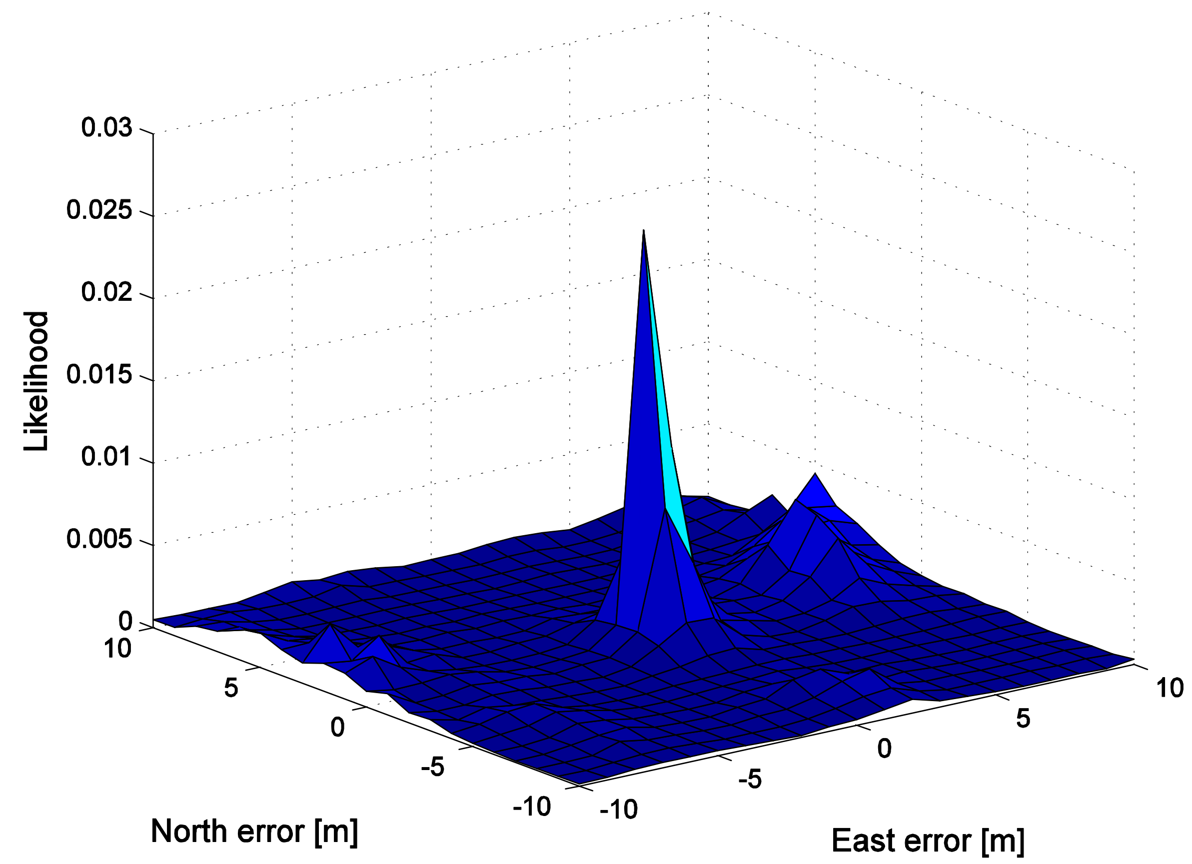

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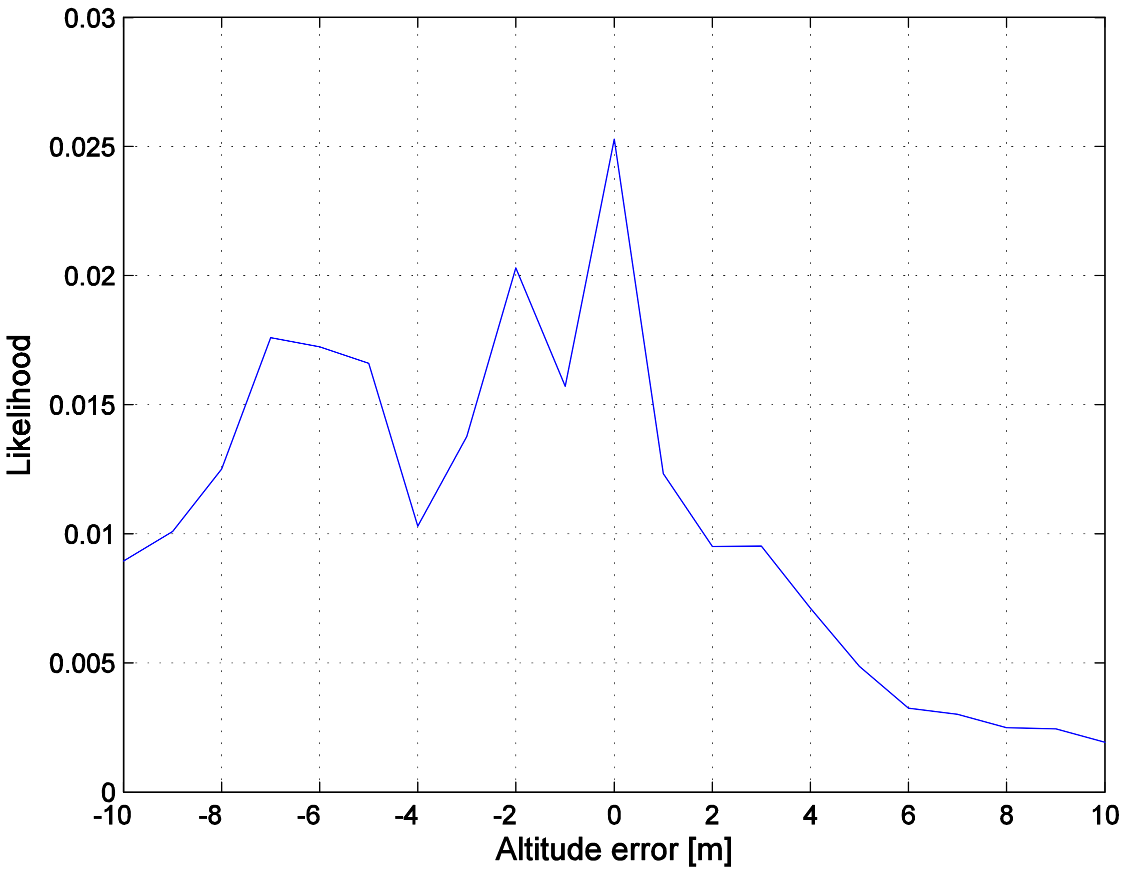

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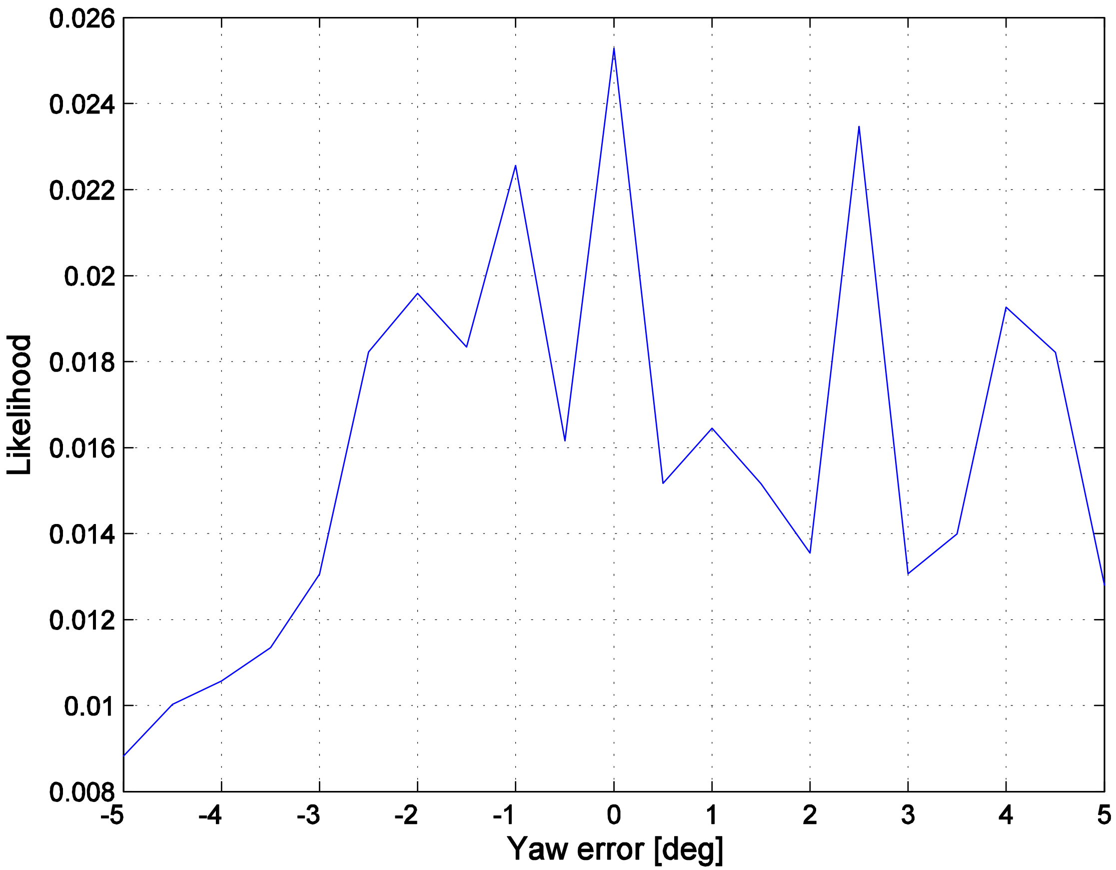

EVALUATION OF THE LIKELIHOOD – BAD CASE

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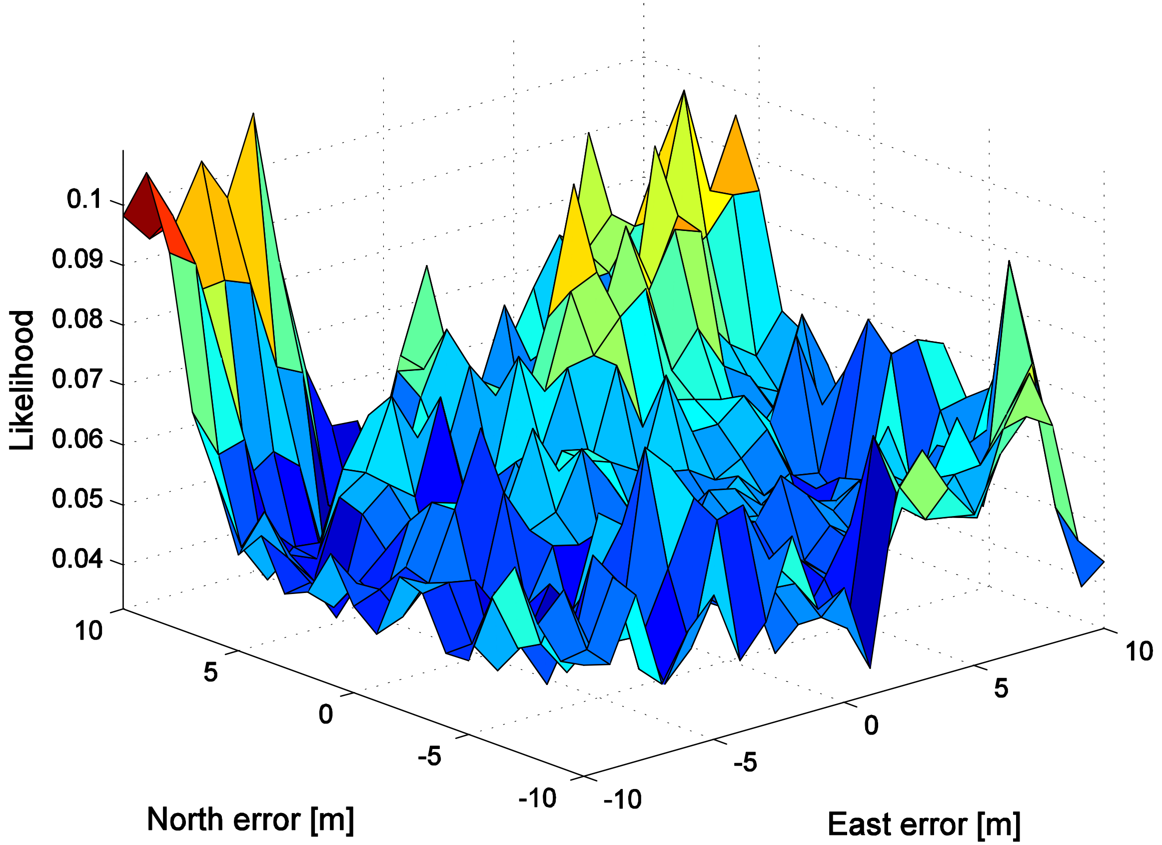
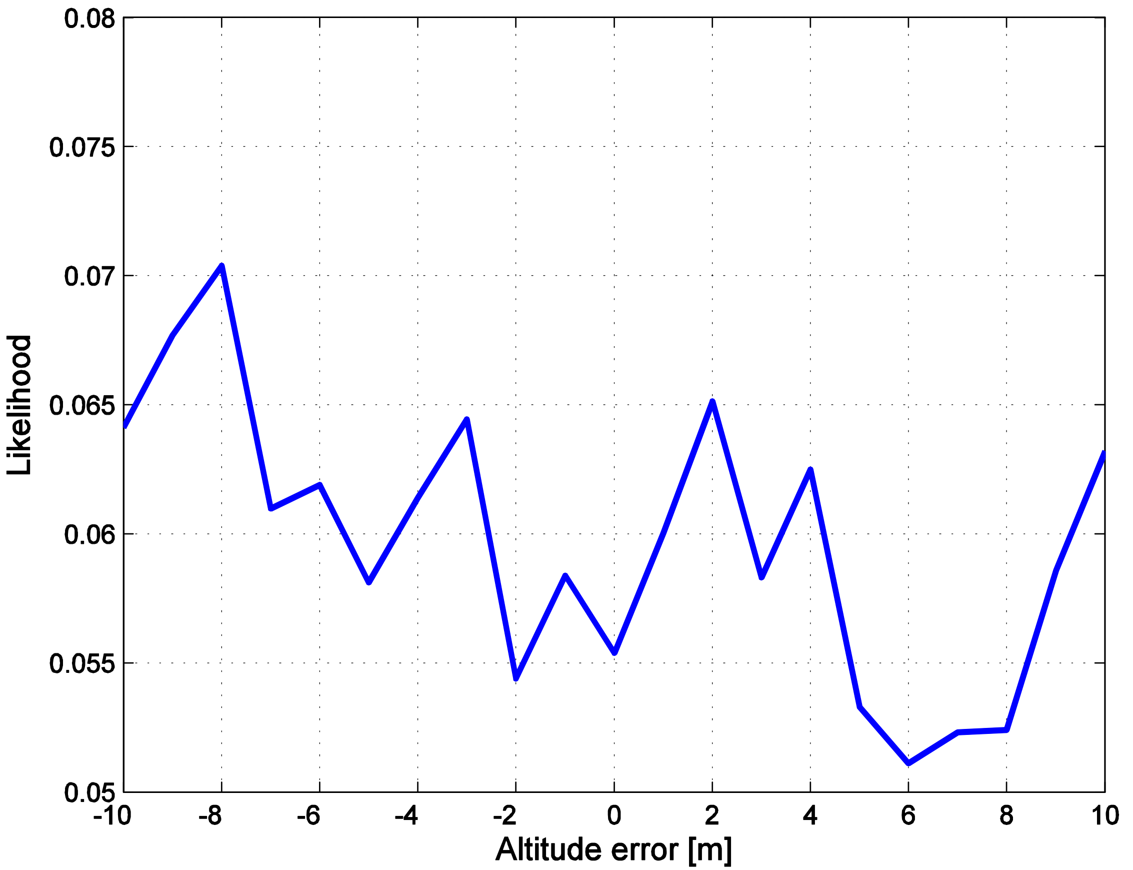


EVALUATION OF THE LIKELIHOOD – BAD CASE



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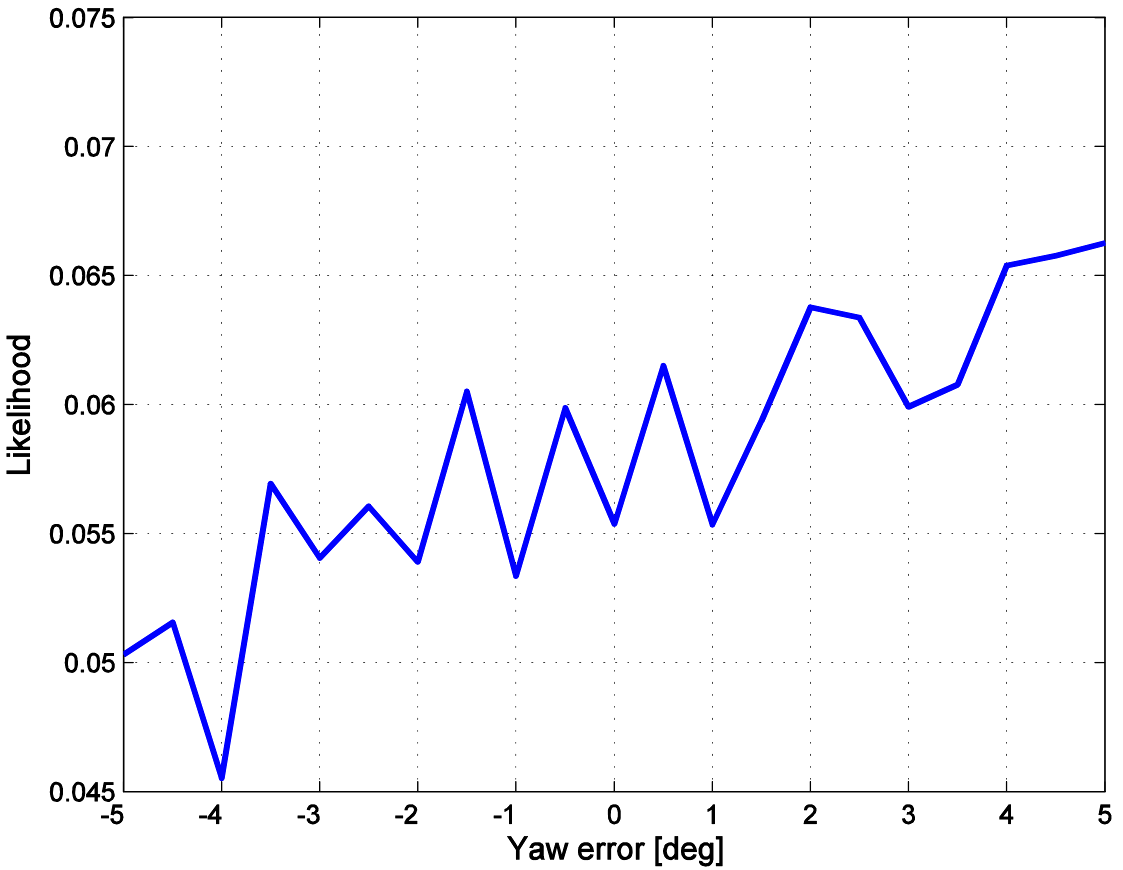

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CONCLUSIONS AND FUTURE WORK

- A method for estimation of an aerial vehicle's 3D-position and heading without GNSS is presented
- Evaluation concentrated on likelihood function
- Results are promising for now – informative images(!)
- Sensitivity to pitch and roll deviation form zero shall be studied
- Evaluation of the whole filter on real UAV data

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