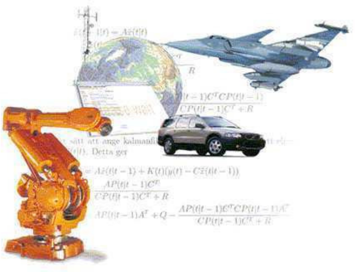
Tracking Rectangular and Elliptical Extended Targets Using Laser Measurements



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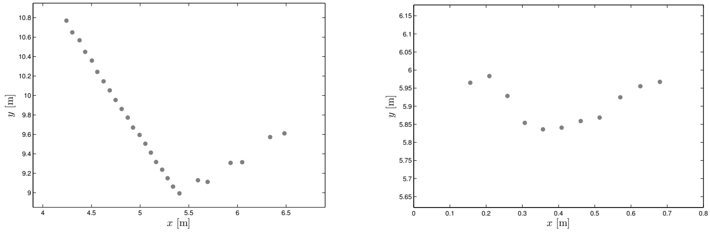
Motivation

- Extended targets $\mathbf{x}$ give rise to multiple structured meas. $\mathbf{z}$
  $\Rightarrow$ possible to estimate target size and shape.
- Laser: point meas. along target surface facing toward sensor.

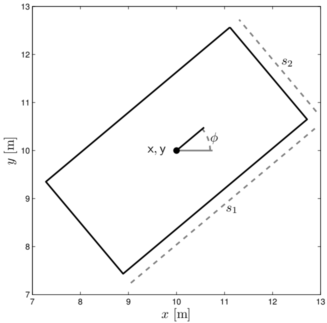


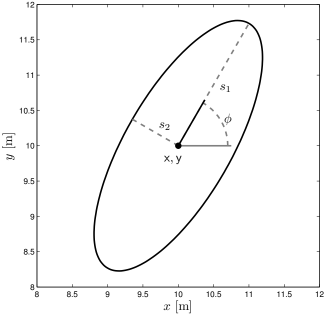
(a) Car (b) Human

- Track rectangular and elliptical extended targets.

Extended target tracking

- State vector $\mathbf{x} = \begin{bmatrix} \mathrm{x} & \mathrm{y} & \mathrm{v_x} & \mathrm{v_y} & \phi & s_1 & s_2 \end{bmatrix}^\mathrm{T}$





- Estimate state $\mathbf{x}$ using measurements $\mathbf{z}$.

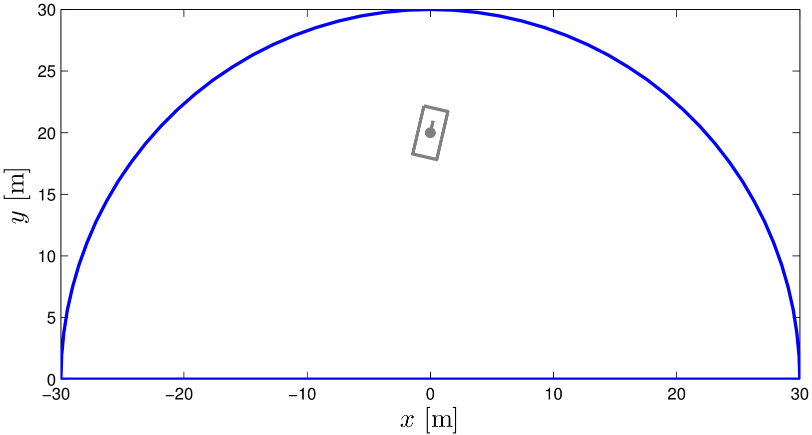
Problem defintion

- State estimate $\hat{\mathbf{x}} = \begin{bmatrix} \hat{\mathrm{x}} & \hat{\mathrm{y}} & \hat{\mathrm{v}}_{\mathrm{x}} & \hat{\mathrm{v}}_{\mathrm{y}} & \hat{\phi} & \hat{s}_1 & \hat{s}_2 \end{bmatrix}^{\mathrm{T}}$
- Prediction of $\hat{\mathbf{x}}$ in KF-framework is straightforward.
- Correction of $\hat{\mathbf{x}}$ in KF-framework requires predicted measurements and innovation covariances

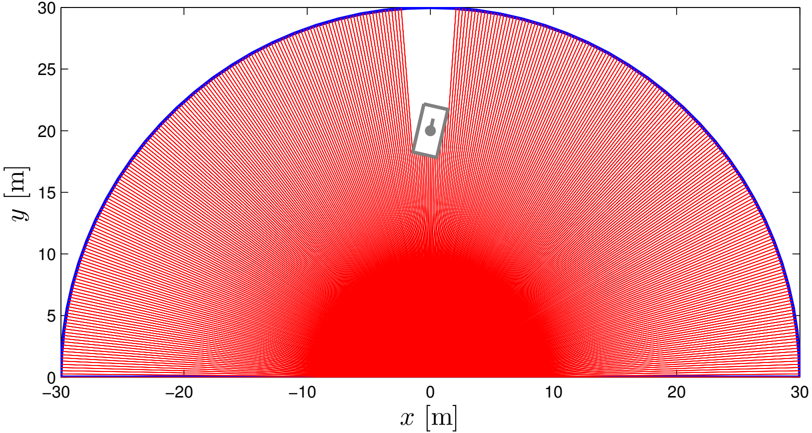
$$\hat{\mathbf{z}}_{k|k-1}$$
$$S_k$$

- This paper considers one method to obtain them.

Laser sensor functionality

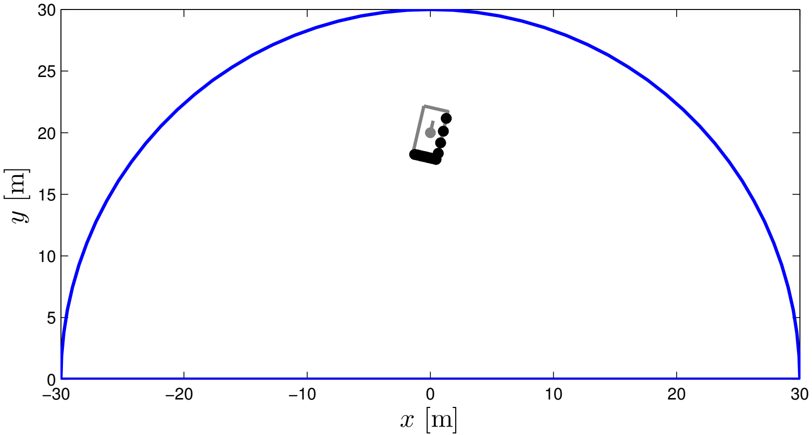


Semi-circular surveilance area with rectangular target.

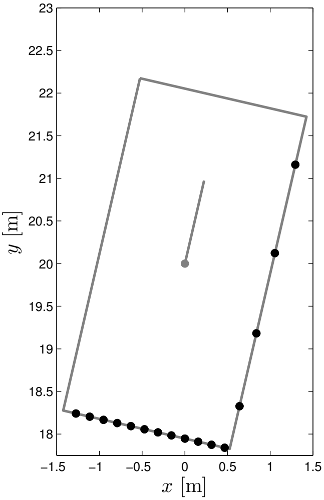


At known angles α, measure range r to closest objects (up to r_{max}).

Laser sensor functionality

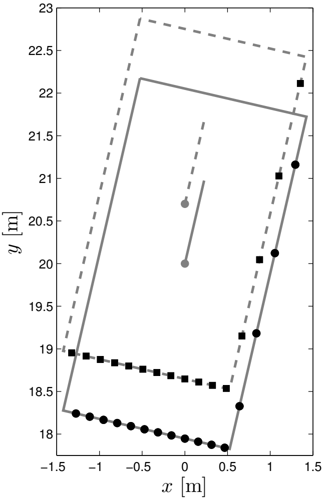


Point measurements of target surface facing towards sensor.



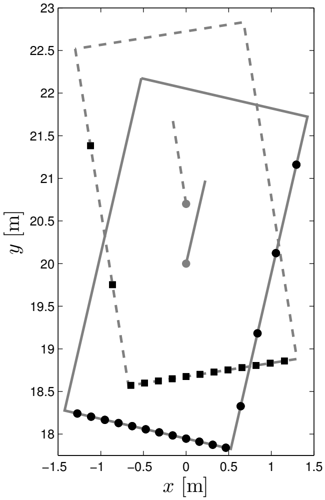
- True target $\mathbf{x}$ (solid gray rect).
- Meas. $\mathbf{z}$ in black dots.

Predicted measurements $\hat{\mathbf{z}}$



- True target $\mathbf{x}$ (solid gray rect).
- Meas. $\mathbf{z}$ in black dots.
- Pred. target $\hat{\mathbf{x}}$ (dashed gray rect).
- Pred. meas. $\hat{\mathbf{z}}$ (squares) obtained using line intersection.
- Small estimation error $\Rightarrow \hat{\mathbf{z}}$ closely resemble $\mathbf{z}$.

Predicted measurements $\hat{\mathbf{z}}$



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- Pred. meas. $\hat{\mathbf{z}}$ (squares) obtained using line intersection.
- Small estimation error
  $\Rightarrow$ $\hat{\mathbf{z}}$ closely resemble $\mathbf{z}$.
- Not true for larger estimation error.

- Using line intersection to compute $\hat{\mathbf{z}}$ is insufficient.
- $\mathbf{z}$ used when computing $\hat{\mathbf{z}}$ and S, i.e. the measurement model depends on the current set of measurements.

$$\hat{\mathbf{z}}_{k|k-1} \approx \hat{\mathbf{z}}_{k|k-1}\left(\mathbf{z}, \hat{\mathbf{x}}_{k|k-1}\right)$$
$$S_k \approx S_k\left(\mathbf{z}, \hat{\mathbf{x}}_{k|k-1}\right)$$

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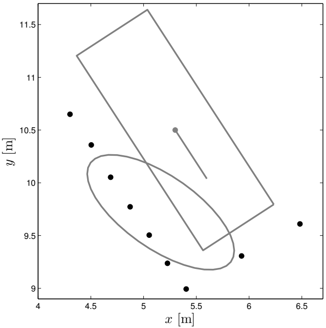
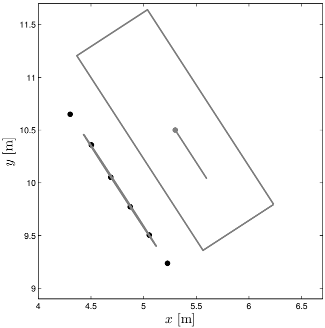
Contributions:

- Functions to compute predicted meas. $\hat{\mathbf{z}}$ and innov. cov. S
- Intregration into extended target GM-PHD filter.
- Evaluation in simulations and experiment.

1. Find number of sides measured in data.

Let e_1 and e_2 be eigenvalues of data covariance matrix.

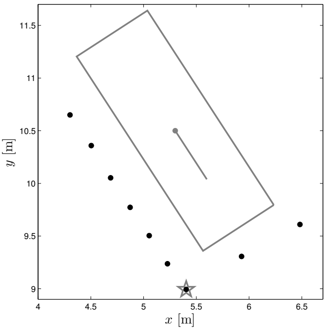


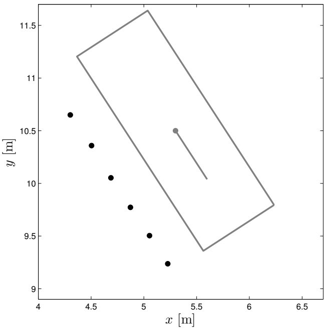


$$\frac{e_2}{e_1} = \frac{0.6629}{0.1198} = 5.5327$$

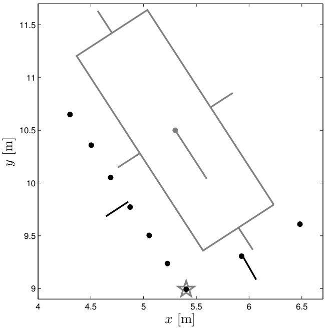
$$\frac{e_2}{e_1} = \frac{0.5146}{4.5760 \cdot 10^{-5}} = 1.1246 \cdot 10^4$$

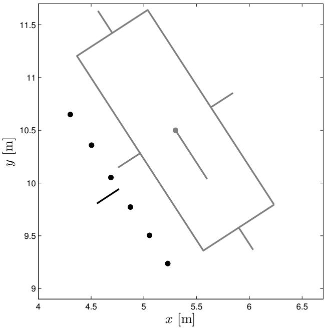
2. If two sides are shown, find breakpoint.



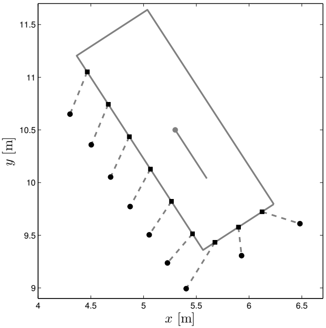


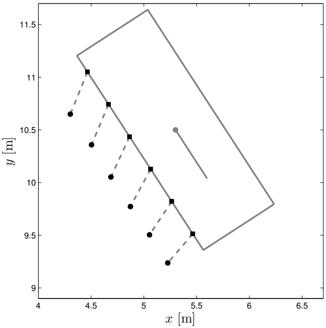
3. Find normal angles of measurements and of predicted target surface, associate nearest neighbours.



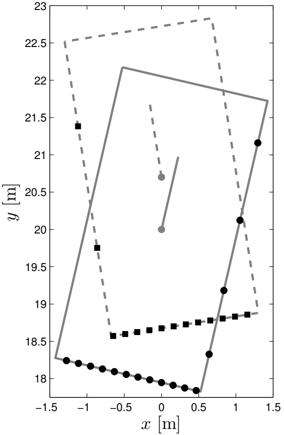


4. Distribute predicted measurements over estimated target surface.

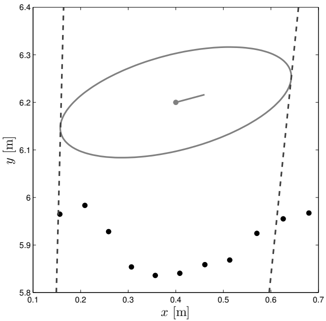




Comparison: line intersection (left) vs. our method (right).



1. Find angles within which target is located.



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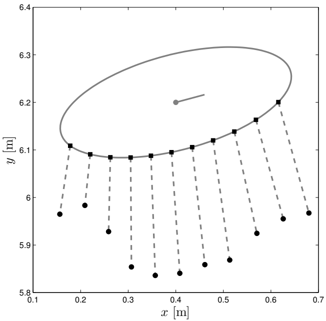
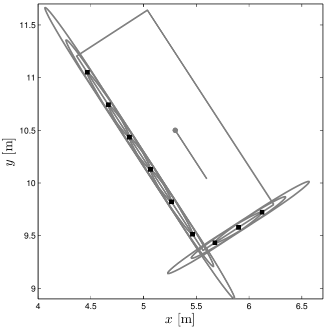
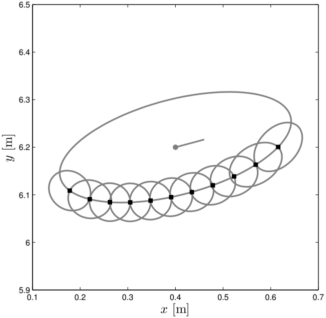
2. Distribute $\hat{\mathbf{z}}$ in between angles on side of surface facing sensor.



Innovation covariances

- Align measurement noise covariances along surface.
- Cover part that was measured.
- Measurement model Jacobian computed numerically.





Performance evaluation

- Estimation error for x and y position.

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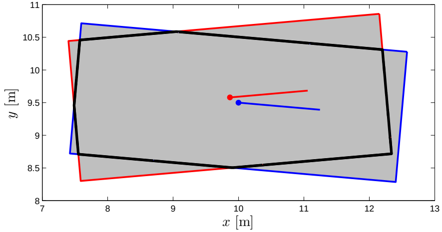
- Intersection-Over-Union (IOU) for extension ϕ, s_1, s_2
  - $\hat{A}$ - extension of estimate. A_0 - extension of the true target.



$$\frac{\hat{A} \cap A_0}{\hat{A} \cup A_0} \in [0\ 1]$$

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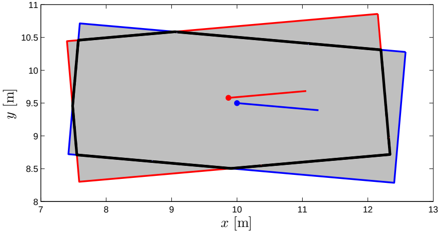
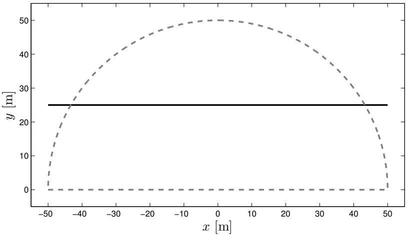
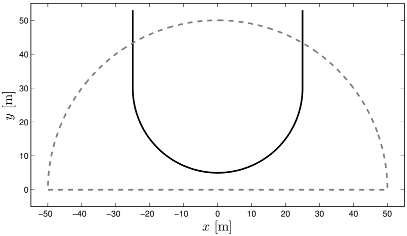


$$\frac{\hat{A} \cap A_0}{\hat{A} \cup A_0} \in [0\ 1]$$

- Shape type, rectangle or ellipse?
  - Give birth to one GM-PHD component of each kind.
  - Compare corresponding component weights.

Two trajectories, one linear and one curved.





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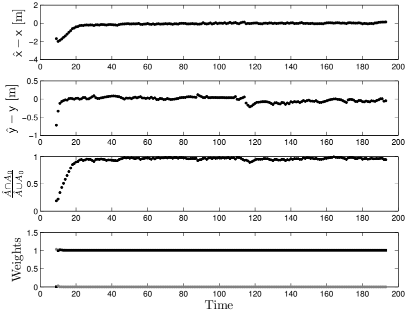
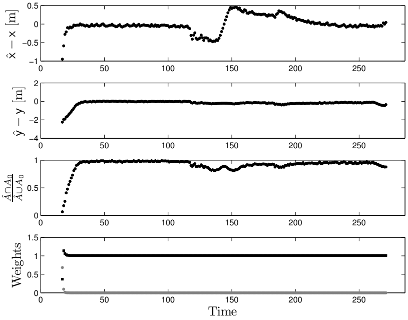
Simulations

Results for rectangular target.





Linear motion

Curved motion

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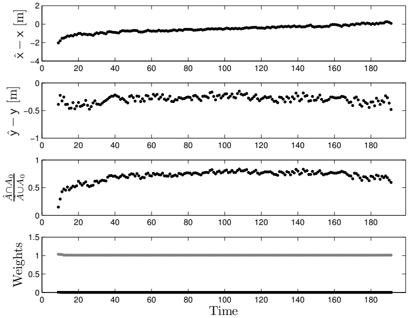
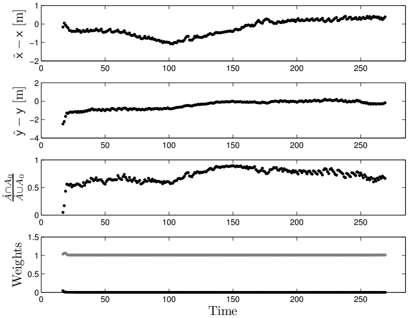
Results for elliptical target.

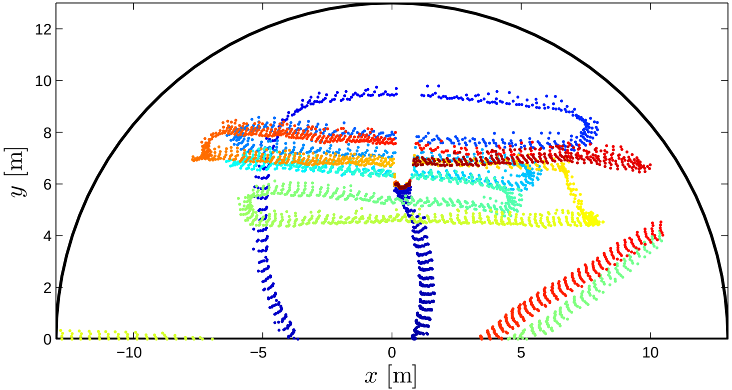


Linear motion

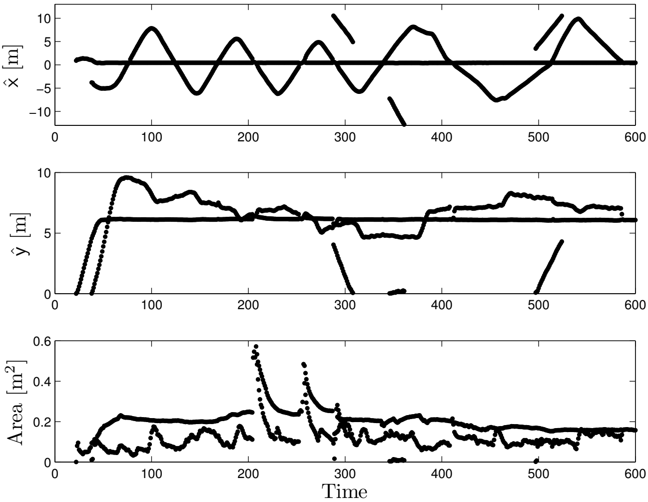


Curved motion

- SICK laser range sensor used to collect data.
- Multiple human targets, at most 3 at the same time.
- Measurements of stationary objects removed beforehand.



Experiment


x̂ [m]
10
5
0
−5
−10
0
100
200
300
400
500
600
ŷ [m]
10
5
0
Area [m²]
0.6
0.4
0.2
0
Time

Contributions:

- Functions to compute predicted meas. $\hat{\mathbf{z}}$ and innov. cov. S
- Intregration into extended target GM-PHD filter.
- Evaluation in simulations and experiment.

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Summary and future work

Contributions:

- Functions to compute predicted meas. $\hat{\mathbf{z}}$ and innov. cov. S
- Intregration into extended target GM-PHD filter.
- Evaluation in simulations and experiment.

Future work:

- Investigate underestimation of size of elliptical targets.
- Compare to UKF and PF solutions.
- Integrate with variable probability of detection.
- Experiments with rectangular and elliptical targets.

Thank you for listening!

Any questions?