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KO-FAS

Tracking with Cooperative Sensor Systems

Tracking durch kooperative Sensorik

Horst Kloeden
BMW Group Forschung und Technik

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Introduction

Tracking is the estimation of the state of a moving object based on remote measurements.

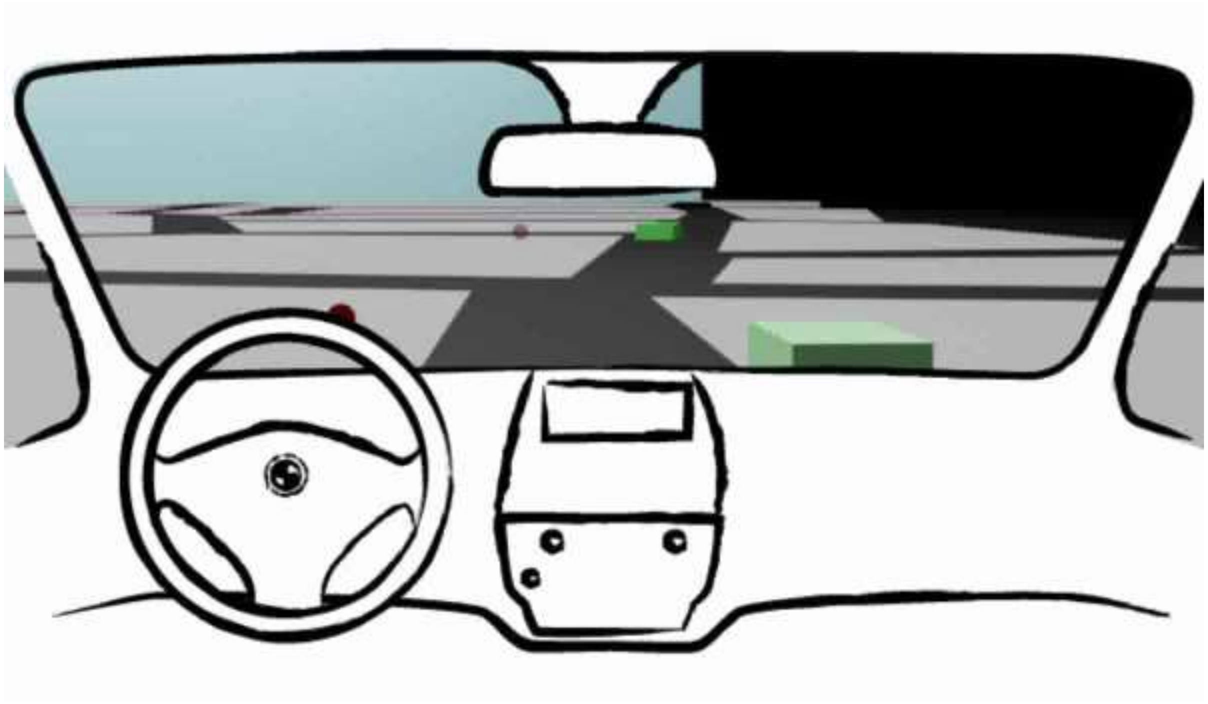
- Objectives

???

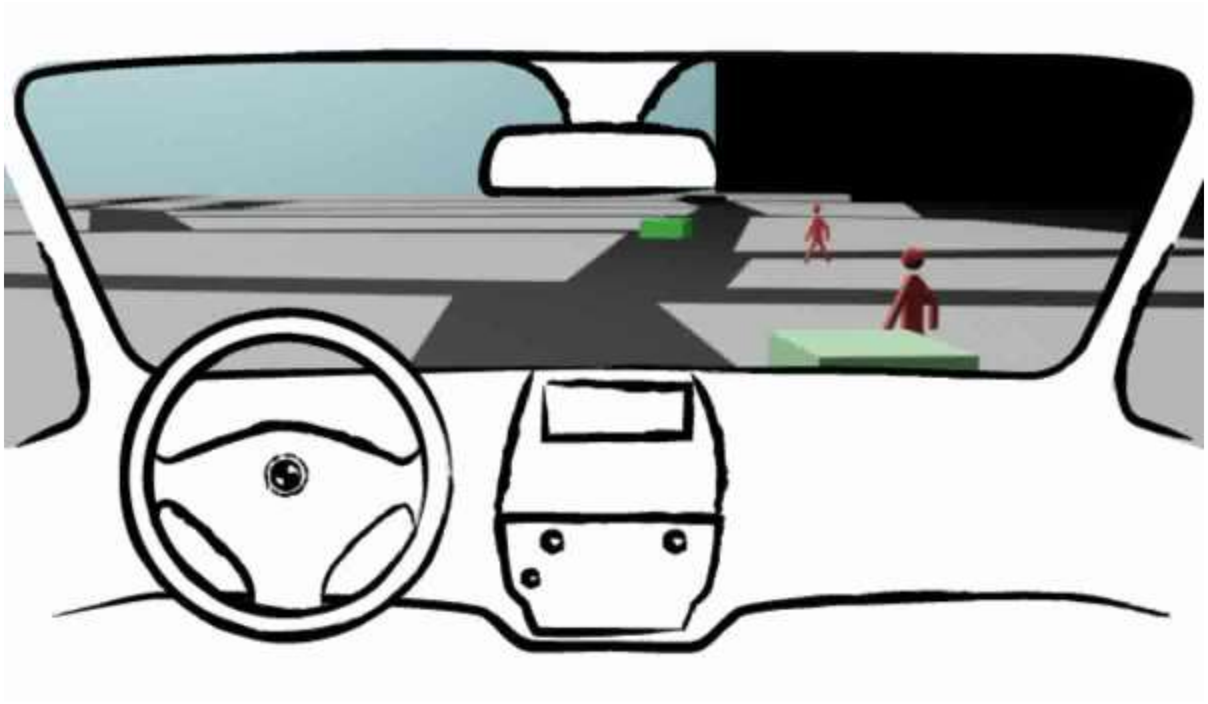
Introduction: Driver's Perspective

How does a sensor see the world?

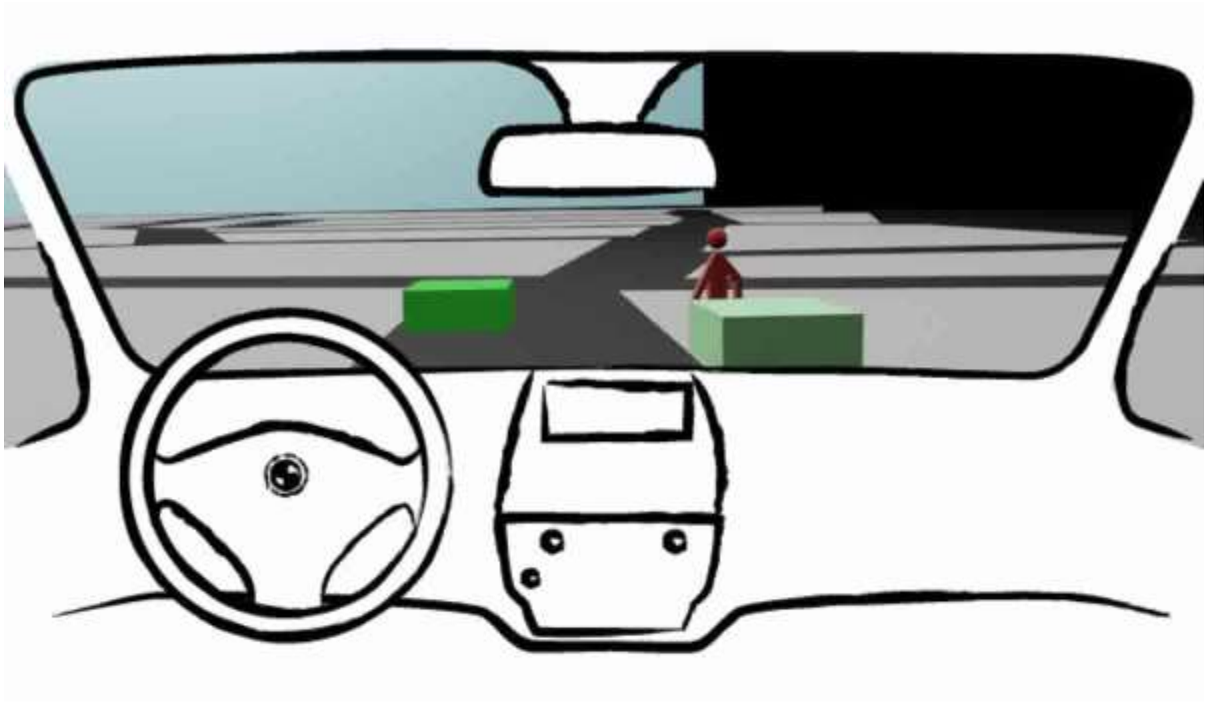
Introduction: Sensor Perspective



Introduction: Tracking Perspective



Introduction: Tracking Perspective



Introduction

Tracking is the estimation of the state of a moving object based on remote measurements.

- Objectives
  - object identification
  - improve state estimate (noise and outlier suppression)
  - recover observable object states
  - sensor independent object description
    - kinematic state: $\hat{\mathbf{x}} = [x, y, v_x, v_y]$
    - state covariance: $\mathbf{P} = \mathrm{E}[(\hat{\mathbf{x}} - \mathbf{x})(\hat{\mathbf{x}} - \mathbf{x})]$
    - static properties: size, object class

$$p(\mathbf{x}) = \mathcal{N}(\hat{\mathbf{x}}, \mathbf{P})$$

Introduction: Hierarchical Structure

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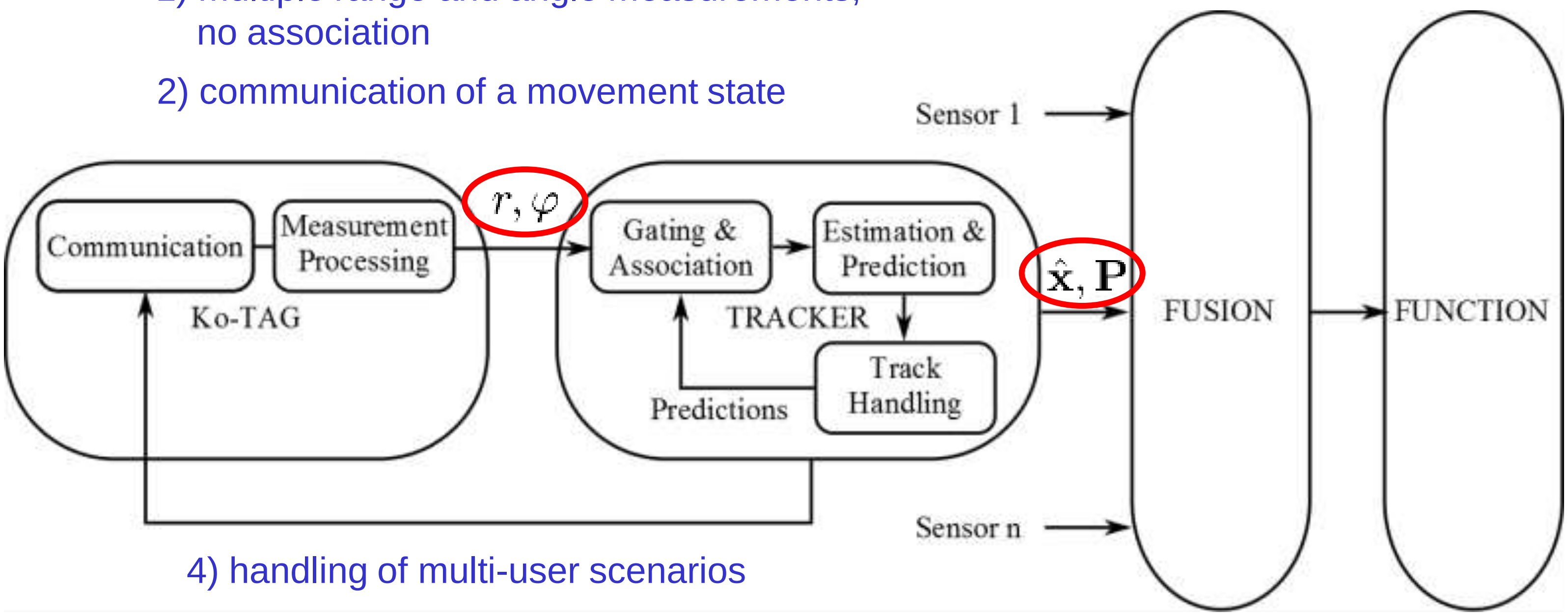
Hierarchical Structure

3) different perception:
handling of fusion rules

1) multiple range and angle measurements,
no association

2) communication of a movement state



4) handling of multi-user scenarios

Single Target Tracking with Range and Bearing Measurements and Communication of Inertial Data

Content

Tracking with Cooperative Sensor Systems

- Tracking in Multipath Environments
- Tracking in Multi-User Environments
- Conclusion

Tracking in Multipath Environments

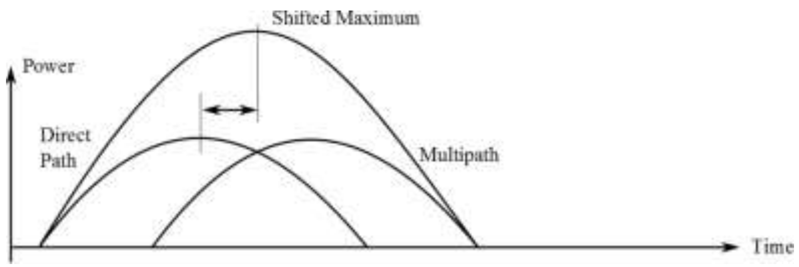
How to handle multipaths?

Tracking in Multipath Environments

Multipath Effects from a Tracking Perspective

Multipaths below resolution limit

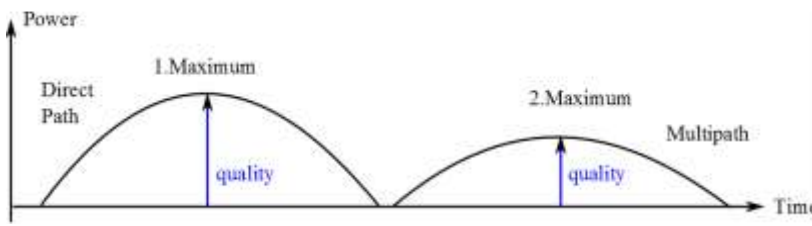
- Spatial Measurement Noise
- Destructive Interference: Misses and Outliers



→ robust filtering for colored noise
→ noise as a function of quality

Multipaths above resolution limit

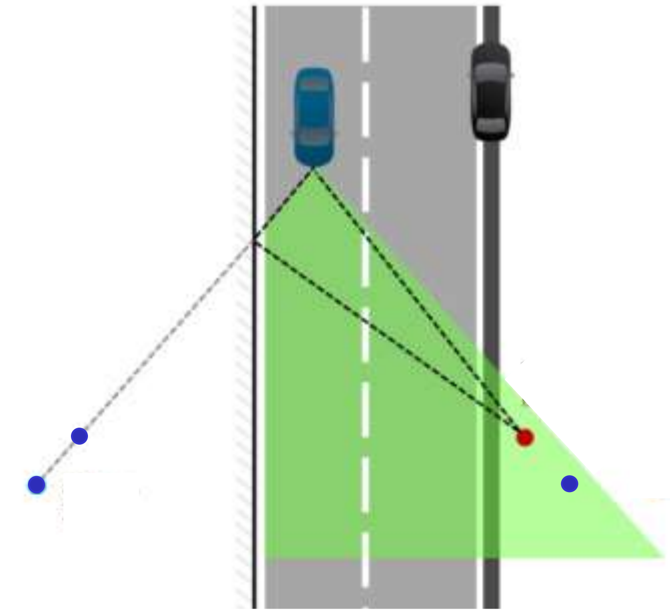
- Multiple Distance and Angle Measurements without association



→ Prefiltering possible but multiple peaks are remaining

Tracking in Multipath Environments

- Ground Reflection
  → typically below resolution limit
- Walls, Fences, Parking Cars, …
  → multiple distance and angle measurements without association,
  2 x 2 → 4 possible target positions
  3 x 3 → 9 possible target positions



Multiple Hypothesis Tracking (MHT)

- object tracking for every hypothesis
- probability of hypotheses

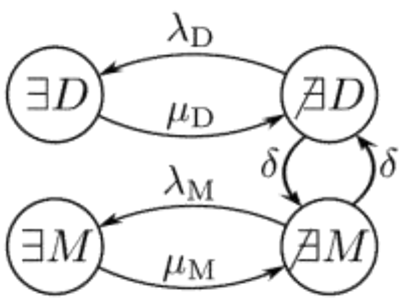
$$p(\mathbf{x}) = \sum_{l=1}^{\mathcal{H}} \mathcal{N}(\hat{\mathbf{x}}^l, \mathbf{P}^l) P(\exists \mathbf{x}^l) + p'(\nexists)$$

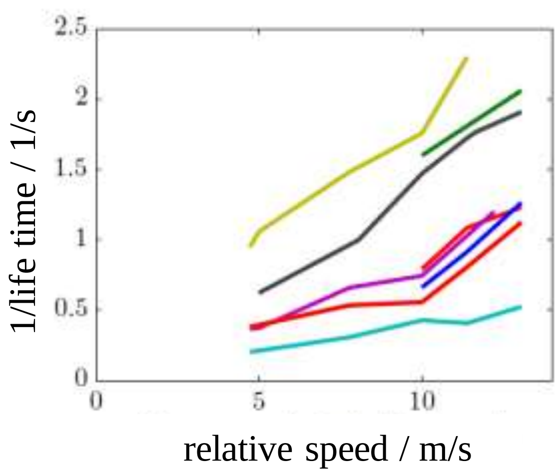
Tracking in Multipath Environments

- Path Classification and Prediction
  - direct path / multipath (D/M)
  - existence / non-existence

  Continuous Time Monte Carlo (CTMC)
  → predict state probabilities
  - birth/death processes λ/μ
  - fading memory δ

  → death rate of multipaths depends on relative speed
  → path discrimination by speed





Tracking in Multipath Environments

- Path Classification and Update by Measurements
  - Detection
    detection probabilities for direct path and multipath
  - Quality Value
    → determine probability of LOS/NLOS for a path
    LOS: implies direct path $P(\exists D|\mathrm{LOS}) = 1$
    NLOS: no information about quality $P(\exists D|\mathrm{NLOS}) = P(\exists D)$
  - Object Dynamics
    direct path is a more likely object description, e.g. speed

Tracking in Multipath Environments

- Combination of Hypotheses
  - path classifications give marginal probabilities

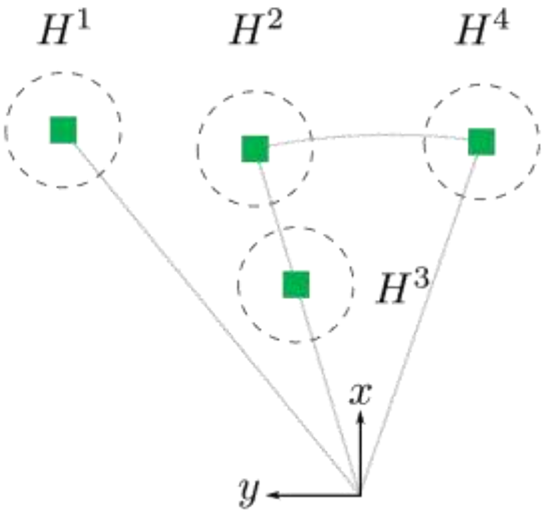
  →global constellations

  - permutation over path existence
  - permutation over path classification
  - correlated paths may not coexist

  → probability of existence $P(\exists \mathbf{x})$

  probabilistic weighted estimate

  of every constellation



$A = \{ H^1 \quad H^2 \quad H^3 \quad H^4 \}$

$\mathcal{G}_A =$

H^1	H^2	H^3	H^4
M	M	Y	Y
M	Y	M	M
D	M	Y	Y
D	Y	M	M
M	D	Y	Y
M	Y	D	M
M	Y	M	D

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix}$$

Tracking in Multi-User Environments

How to handle many transponders?

Tracking in Multi-User Environments

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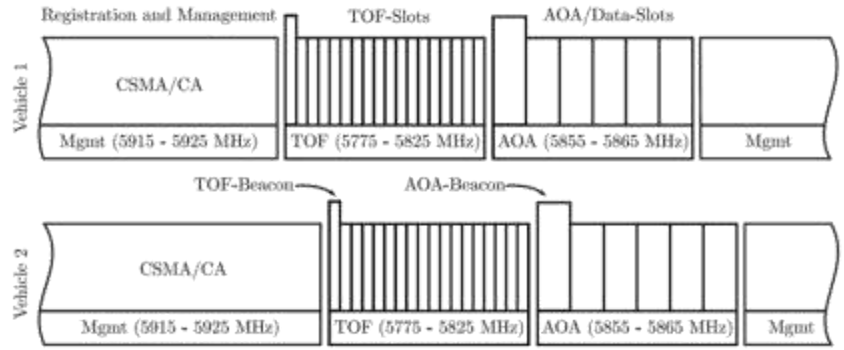
- Limited number of transponders and measurements
  - #TOF-Slots
  - #AOA/Data-Slots (≈ 1/5 #TOF-Slots)
- Protocol allows individual rates for each transponder
  - TOF-priority *p*
  - AOA-priority *q*

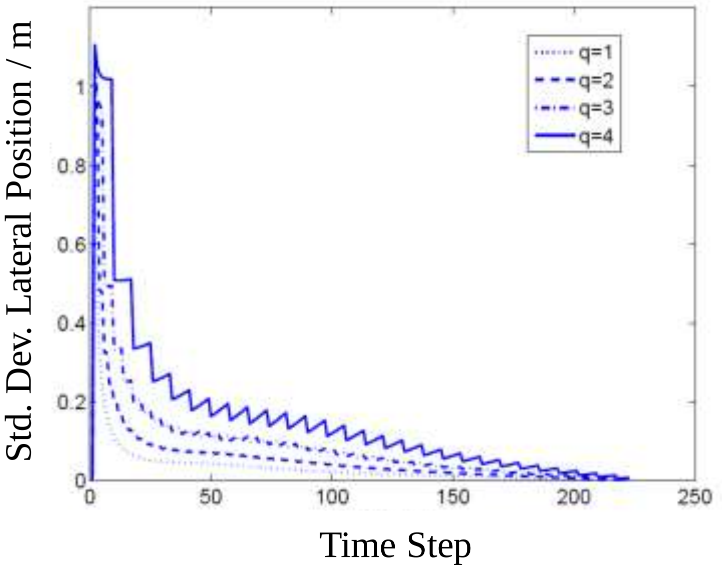
  → try to measure every
  2^{p-1}th - cycle
  2^{q-1}th - cycle



  - TOF priority change → network traffic
  - AOA priority change with beacon

Tracking in Multi-User Environments

- Measurement Priorities
  - steady state accuracy
  - transient behaviour
  - maximum number of tracks



- Objectives:
  - object relevance - collision probability
  - track condition - covariance matrix
  - multiple sensors
  - minimum number of TOF priority changes

Tracking in Multi-User Environments

- Possible Strategies: Optimal ($\underline{p}$, $\underline{q}$) within constraints *Γ*
  - **Strategy 1:** Uniform resource distribution

$$\max_{(p,q)\in\Gamma} N(2^{p-1})^{-1} + N(2^{q-1})^{-1}$$

  - **Strategy 2:** Resource allocation based on the collision probabilities

$$\max_{(\underline{p},\underline{q})\in\Gamma} \sum_{i=1} (P_\mathrm{c})_i (2^{p_i-1})^{-1} + \sum_{i=1} (P_\mathrm{c})_i (2^{q_i-1})^{-1}$$

  - **Strategy 3:** Resource allocation based on relevant information gain

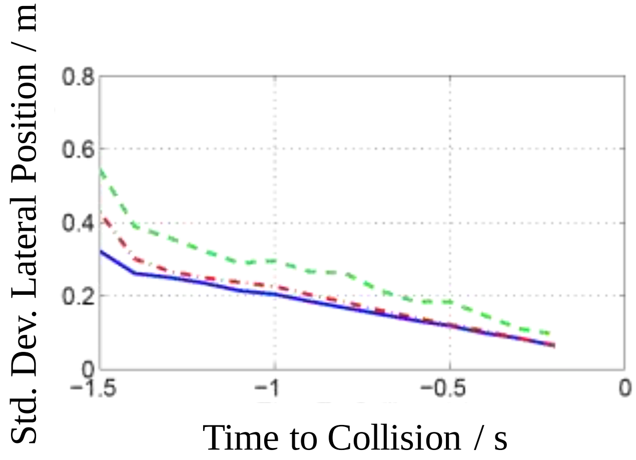
$$\max_{(\underline{p},\underline{q})\in\Gamma} \sum_{i=1} (P_\mathrm{c})_i \left[\frac{1}{2^{q_i-1}} (\Delta H_{r,\phi})_i + \left(\frac{1}{2^{p_i-1}} - \frac{1}{2^{q_i-1}} \right) (\Delta H_r)_i + \left(1 - \frac{1}{2^{p_i-1}} \right) (\Delta H_0)_i \right]$$

ΔH: entropy difference between current and expected following state

Tracking in Multi-User-Environments

- Simulation results for a pedestrian safety system:
  - uniform allocation: significant disadvantages
  - collision based and uniform:
    comparable performance in most scenarios

  - advantages of information based approach:
    - tracks with different conditions
    - optimize over multiple sensors
    - higher robustness in with systematic errors
  - advantages of collision based approach
    - lower computational cost



Conclusions

- Tracking with Cooperative Sensor Systems:

  "single target tracking with range and bearing measurements"

  - multipath handling
    - colored spatial and temporal noise
    - multiple measurement hypotheses without association
    - misses and outliers
  - strategies for multi-user environments
  - adaption of fusion rules to cooperative objects
    - detection of occluded objects, transponders
    - multiple hypothesis description
  - integration of inertial sensor data
    - coordinate conversion of dynamic data
    - integration of a semantic movement behavior

Thank you for your attention!

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- Kloeden, H.; Rauch, A.; Klanner, F.; Schwarz, D.; Rasshofer, R. H.: Kooperative Ansätze zur Fahrzeugumfeldwahrnehmung. In: 8. VDI-Tagung Fahrzeugsicherheit, 2011, S. 261–274
- Kloeden, H.; Schwarz, D.; Biebl, E. M.; Rasshofer, R. H.: Fusion of Cooperative Localization Data with Dynamic Object Information using Data Communication for Preventative Vehicle Safety Applications. In: Advances in Radio Science 11 (2013)