Tracking with Cooperative Sensor Systems

Tracking durch kooperative Sensorik

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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: \( \hat{x} = [x, y, v_x, v_y] \)
    - state covariance: \( P = E[(\hat{x} - x)(\hat{x} - x)] \)
    - static properties: size, object class

\[ p(x) = \mathcal{N}(\hat{x}, P) \]
Hierarchical Structure

1) multiple range and angle measurements, no association
2) communication of a movement state
3) different perception: handling of fusion rules
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
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,
    - $2 \times 2 \rightarrow 4$ possible target positions
    - $3 \times 3 \rightarrow 9$ possible target positions

Multiple Hypothesis Tracking (MHT)
- object tracking for every hypothesis
- probability of hypotheses

\[ p(x) = \sum_{l=1}^{\mathcal{H}} \mathcal{N}(\hat{x}^l, P^l) P(\exists x^l) + p'(\emptyset) \]
• Path Classification and Prediction
  • direct path / multipath (D/M)
  • existence / non-existence

Continuous Time Monte Carlo (CTMC)
  → predict state probabilities
  • birth/death processes $\lambda/\mu$
  • fading memory $\delta$

→ death rate of multipaths depends on relative speed
→ path discrimination by speed
• 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 \( P(∃D|LOS) = 1 \)
    NLOS: no information about quality \( P(∃D|NLOS) = P(∃D) \)

• Object Dynamics
direct path is a more likely object description, e.g. speed
• 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 \( P(\exists x) \)
probabilistic weighted estimate of every constellation
Tracking in Multi-User Environments

How to handle many transponders?
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 $q$
  $\Rightarrow$ try to measure every $2^{p-1}$th - cycle
  $2^{q-1}$th - cycle

TOF priority change $\Rightarrow$ 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 \((p, q)\) within constraints \(\Gamma\)
  
  • **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
    \[
    \max_{(p,q) \in \Gamma} \sum_{i=1} \left( (P_c)_i (2^{p_i-1})^{-1} + \sum_{i=1} (P_c)_i (2^{q_i-1})^{-1} \right)
    \]
  
  • **Strategy 3**: Resource allocation based on relevant information gain
    \[
    \max_{(p,q) \in \Gamma} \sum_{i=1} (P_c)_i \left[ \frac{1}{2^{q_i-1}} (\Delta H_{r,\phi})_i + \left( \frac{1}{2^{p_i-1}} - \frac{1}{2^{q_i-1}} \right) (\Delta H_r)_i + \left( 1 - \frac{1}{2^{p_i-1}} \right) (\Delta H_0)_i \right]
    \]

\(\Delta H\): 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!

Tracking with Cooperative Sensor Systems