OSPA Metric for Radar Extended Object Tracker

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   – MOT Accuracy
4. Assignment algorithm
5. MOTA mismatches
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Aim of the paper

- Embedded automotive RADAR sensors evolve from one-point representation per target to **multiple points per target**, with improved transmit power, SNR, phase noise and power consumption.

- The **evaluation of tracking algorithms** for multiple object tracker must consider numerous measures of effectiveness -> no standard metric available.

- This paper aims the introduction of a **new metric** for extended object tracker, that is both intuitive and easy to compute.
Problem

• **Track** = labeled temporal sequence of state estimates, associated with the same target

• **Problem** = measure the distance between two sets of tracks
  – Set of ground truth tracks
  – Set of estimated tracks

• **Measures of effectiveness (MoEs)** are to be combined:
  – Timeliness
  – Track accuracy
  – Continuity
  – False tracks

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**HOW? Correlation and transitivity of MoEs**

*Figure 1: Mapping tracker hypotheses to objects. In the easiest case, matching the closest object-hypothesis pairs for each time frame $t$ is sufficient.*

Metrics’ history

• 1914: **Hausdorff** metric \(\rightarrow\) cardinality shortcoming

\[
d_H(X, Y) = \max \left\{ \sup_{x \in X} \inf_{y \in Y} d(x, y), \sup_{y \in Y} \inf_{x \in X} d(x, y) \right\}
\]

• 2001: **Wasserstein** distance \(\rightarrow\) partly fixed the cardinality problem

• 2008: **Optimal subpattern assignment** (OSPA) \(\rightarrow\) performance evaluation of multi target filtering algorithms

• 2011: OSPA for multi target object **trackers**

“CLEAR” MOT Metrics

1. **MOTP and MOTA definition**
2. **Assignment problem** between ground truth tracks and estimated tracks
3. Key issue: **mismatch** approach in MOTA

\[
\text{MOTP} = \frac{\sum_{i,t} d_{t}^i}{\sum_{t} c_{t}}
\]

Total error in estimated position for matched object-hypothesis pairs
---------
Total number of matches made

\[
\text{MOTA} = 1 - \frac{\sum_{t} (m_{t} + f_{p_{t}} + mme_{t})}{\sum_{t} g_{t}}
\]

Misses, false positives and mismatches
---------
Total number of objects
MOT Accuracy

1. $\text{MOTA}_{\text{mean}} = 0.5116$

2. MOTA variation over time allows tracker issue detection

3. MOTA range is $(-\infty, 1)$

4. MOTA is computed for every point of the radar cluster (Closest, Left-most and Right-most)

5. Individual contributors could be separated (misses, false positives and mismatches)

Assignment problem: hungarian algorithm

1. Assign to every Truth Track the „best possible“ Radar (estimated) Track
2. Truth tracks without assigned Radar Tracks are MISSED
3. Unassigned Radar Tracks are considered FALSE ALARMS
4. Assignment must be done to minimize the total precision error (in state space, i.e. $x, y, z, v_x, v_y, v_z$)

MOTA mismatches

- MOTA counts mismatches **only once**, at the time they appear

- **FP and FN rates** are typically significantly bigger than the mismatches rate
  
  \[ \rightarrow \text{Mismatches \textit{may become invisible} in MOTA} \]
OSPA-T Concept

Ground truth tracks $\mathcal{X}_k$, estimated tracks $\mathcal{Y}_k$

$$D_{p,c}(\mathcal{X}_k, \mathcal{Y}_k) = \left[ \frac{1}{n} \left( \min_{\pi \in \Pi_n} \sum_{i=1}^{m} \left( d_c(\tilde{x}_{k,i}, \tilde{y}_{k,\pi(i)}) \right)^p + (n - m) \cdot c^p \right) \right]^{1/p}$$

where $\tilde{x}_{i,k} \equiv (\ell_i, x_{k,i})$, $\tilde{y}_{k,\pi(i)} \equiv (s_{\pi(i)}, y_{k,\pi(i)})$ and

- $d_c(\tilde{x}, \tilde{y}) = \min(c, d(\tilde{x}, \tilde{y}))$ is the **cut-off distance** between two tracks at $t_k$, with $c > 0$ being the cut-off parameter;
- $d(\tilde{x}, \tilde{y})$ is the **base distance** between two tracks at $t_k$;
- $\Pi_n$ represents the **set of permutations of length** $m$ with elements taken from $\{1, 2, \ldots, n\}$;
- $1 \leq p < \infty$ is the **OSPA metric order** parameter.

$c \rightarrow$ gives relative weighting given to the cardinality error component against the base distance error component

$p \rightarrow$ a higher value of $p$ increases sensitivity to outliers

Extended object tracker

- **Advantages** vs. point tracker
  - Single track for single object
  - Stable velocity vector during tracking
  - Faster initialization in near range
  - No velocity drop at end of FOV
  - Less ghost objects
OSPA-T vs. MOTA

- **Scenario 6**: MOTA identical, OSPA differentiates between closest, left-most and right-most points due to *localization errors*

- **Scenario 8**: MOTA identical, OSPA differentiates between representative points in case of *mismatches*

-> **OSPA** combines on one hand *precision and accuracy* and on the other hand intuitive characterization of the *mismatched* hypothesis-object pairs

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>MOT Accuracy</th>
<th>OSPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>L</td>
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<td>1_5crossTrgts_30degrees</td>
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<tr>
<td>8_5crossTrgts_alfa12.5</td>
<td>0.88</td>
<td>0.89</td>
</tr>
</tbody>
</table>

*OSPA Metric for Radar Extended Object Tracker*
Proposed form factor

- OSPA computation is done for every representative point (e.g. C, L, R)
- First, compute the Euclidian distances between all pairs of closest points $\|x_i, x_j\|
- If the main representatives of the target approach significantly, enlarge estimates set, within the optimal assignment is performed, to all available datasets $\prod_{n'}$.

If $\min_{i,j} \|x_i, x_j\| \geq f$ then

$$D_{p,c,f}(\mathcal{X}_k, \mathcal{Y}_k) = \left[ \frac{1}{n} \left( \min_{\pi \in \Pi_n} \sum_{i=1}^{m} \left( d_c(\tilde{x}_k, i, \tilde{y}_k, \pi(i)) \right)^p + (n - m)c^p \right) \right]^{1/p},$$

else

$$= \left[ \frac{1}{n'} \left( \min_{\pi \in \Pi_{n'}} \sum_{i=1}^{m'} \left( d_c(\tilde{x}_k, i, \tilde{y}_k, \pi(i)) \right)^p + (n' - m')c^p \right) \right]^{1/p}$$

We selected the **form factor** $f = 3m$, representing half of the diagonal length of a mid-class limousine and the cutoff parameter $c = 10m$
Simulation of parking

- 4 cars driving in a **low-range** (20x40m) and **low-speed** (9 to 27 km/h) scenario
- Radar with **40 ms cycle** and **GM-PHD** filter
- $\Delta$-target enters field of view
- $\bigcirc$-target exits field of view

Experimental results

- Around cycle 50, the deteriorated OSPA becomes **more evident** when using the form factor.

- In the interval [80, 90] cycles, wrongly assessed OSPA localization shortcomings are eliminated.

- Mean values of 100 simulations showed an execution time of **50ms** (OSPA) vs. **40ms** (OSPA with form factor).

Conclusions

• Intuitive metric for multiple object tracker, covering
  – Localization errors in the N dimensional state-space
  – Cardinalization errors like false alarms or misses
  – Labelling errors

• Computing method definition for extended object tracker (multiple points per object)

• 20% faster than reference OSPA, without considering the form factor
  – Suitable for big data applications (with several Petabytes of raw sensor data)