Detection- and Trajectory-Level Exclusion in Multiple Object Tracking

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Motivation and Overview

Accurate multi-target tracking requires that:
• two simultaneous detections cannot be caused by the same target, and
• two trajectories have no spatio-temporal overlap.

Dealing with both requirements is challenging. Previous work handled exclusion either only at the detection level, e.g., [3] or only at the trajectory level, e.g., [2].

We introduce simultaneous exclusion handling for both:

Detection Level

Trajectory Level

Our Contributions

• Exclusion modeling at detection level
• Exclusion modeling at trajectory level
• Novel co-occurrence label cost
• α-expansion-based energy minimization algorithm
• Statistics-based design of energy components

Discrete-Continuous Energy with Exclusion

Discrete-continuous formulation (cf. [1]):

\[ E(f, T) = \sum_{t \in T} \phi(t, T) + \sum_{t \in T} \psi(f, t) + \sum_{t \in T} \varphi(f, t) \]

Labeling

Trajectories

Detection-Level Exclusion

Goal: Enforce unique IDs for all detections in one frame.

Temporal smoothing only [1]  
Smoothing and exclusion

Apply cost \( \psi(f, t) = \begin{cases} 0, & \text{if } t_i = f \ \text{otherwise} \end{cases} \)

to all edges between simultaneous detector responses \((d, d') \in E \sum \{ (d, d') | d \neq d', |D_i - D_j| \leq s/2 \} \) allow for occasional double detection

Trajectory-Level Exclusion

Goal: Suppress solutions with incompatible trajectories.

Simple per trajectory cost \( L^D \)

Pairwise label cost \( L^P \)

A co-occurrence term penalizes a labeling \( f \) with overlapping trajectories:

\[ \phi^C(\alpha, \beta) = \begin{cases} 1, & \text{if } \exists d, d': f_d = \alpha \land f_{d'} = \beta \ \text{otherwise} \end{cases} \]

Optimization

• Discrete part has non-submodular, global terms.
• Continuous part is non-convex.

Alternate between both energy parts:

Discrete

Continuous

α-expansion augmented with greedy label removal.

Gradient-based optimization.

Statistical Analysis

Goal: Derive functional form of energy from real data.

Evaluation script [1, 3].

Publicly available ground truth, detections and individual energy components from a statistical analysis of ground-truth annotations.

Experiments

• Public, challenging datasets: PETS’09, TUD and ETH.
• Publicly available ground truth, detections and evaluation script [1, 3].

Quantitative evaluation

LOO cross-validation results on six sequences

Comparison to other methods

Our method*: 77.3% 87.2% 66.4% 8.2% 69 57

Augmented with a simple tracklet linking scheme.

Summary

We incorporated exclusion modeling into a discrete-continuous CRF
• at the detection level using non-submodular constraints,
• at the trajectory level using a co-occurrence label cost.

Moreover, we proposed an expansion move-based optimization scheme and presented a strategy to derive individual energy components from a statistical analysis of ground-truth annotations.

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