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Hybrid-driven Gaussian process online learning for highly maneuvering multi-target tracking

Key words: Target tracking; Gaussian process; Data-driven; Online learning; Model-driven; Probabilistic data association

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Motivation

1. The performance of existing maneuvering target tracking methods for highly maneuvering targets in cluttered environments is unsatisfactory.
2. Traditional model-driven methods face several application limitations: (1) poor tracking ability and environmental adaptability; (2) state estimation delay; (3) high computational complexity.
3. In response to the constraints of the model-driven approaches, data-driven methods have been proposed, but they also have some problems: (1) poor interpretability; (2) estimation instability.

Method

•The fundamental idea is to integrate the time-varying constant velocity (CV) model into Gaussian process motion tracker (GPMT), thereby enhancing predictive abilities to effectively track extremely maneuverable targets amidst cluttered surroundings.

Algorithm 1 Hybrid-driven GPMT

Input: $\mathbf{X}_t, \mathbf{T}_t, \theta$

Output: $\hat{\boldsymbol{\mu}}_t^f, \hat{\mathbf{C}}_t^f, \boldsymbol{\mu}_t^f, \mathbf{C}_t^f, \mathbf{C}_t$

- 1: Hyperparameter θ is learned via Eq. (11)
 - 2: Compute the predicted state $\tilde{\mathbf{S}}_t$ via Eq. (13) and the predicted covariance $\tilde{\mathbf{P}}_t$ via Eq. (14)
 - 3: Compute the associated measurement \mathbf{Z}_t according to inequality (15) and Eqs. (16)–(20)
 - 4: Compute mean $\hat{\boldsymbol{\mu}}_t^f$ and covariance $\hat{\mathbf{C}}_t^f$ of the estimated state via Eqs. (21) and (22), respectively
 - 5: Compute cross-covariance \mathbf{C}_t via Eq. (23)
 - 6: Compute mean $\boldsymbol{\mu}_t^f$ and covariance \mathbf{C}_t^f of the training set by Eqs. (26) and (27), respectively
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$$V_{x_{t-1}} = (x_{t-1} - x_{t-2}) / T_d$$

$$\tilde{\mathbf{S}}_t = \mathbf{F}\mathbf{S}_{t-1},$$

$$\tilde{\mathbf{P}}_t = \mathbf{F}\mathbf{P}_{t-1}\mathbf{F}^T + \mathbf{Q},$$

$$\mathbf{Z}_t = \sum_{i=0}^m \beta_{ij} \mathbf{Z}_{ij}$$

$$\hat{\boldsymbol{\mu}}_t^f = \tilde{\boldsymbol{x}}_t + \mathbf{K}_t (\mathbf{x}_t - \tilde{\boldsymbol{x}}_t), \quad \boldsymbol{\mu}_t^f = \boldsymbol{\mu}_{t-1}^f + \tilde{\mathbf{K}}_t (\mathbf{x}_t - \tilde{\boldsymbol{\mu}}_t^f),$$

$$\hat{\mathbf{C}}_t^f = \tilde{\mathbf{C}}_t^f - \mathbf{K}_t \tilde{\mathbf{C}}_t^f, \quad \mathbf{C}_t^f = \mathbf{C}_{t-1}^f - \tilde{\mathbf{K}}_t \mathbf{J}_t \mathbf{C}_{t-1}^f,$$

$$\mathbf{C}_t = \mathbf{C}_{t-1}^f \mathbf{J}_t^T (\tilde{\mathbf{C}}_t^f)^{-1} \hat{\mathbf{C}}_t^f, \quad \tilde{\mathbf{K}}_t = \mathbf{L}_t \mathbf{K}_t = \mathbf{C}_{t-1}^f \mathbf{J}_t^T (\tilde{\mathbf{C}}_t^f + \sigma_n^2 \mathbf{I})^{-1},$$

Method

Major results

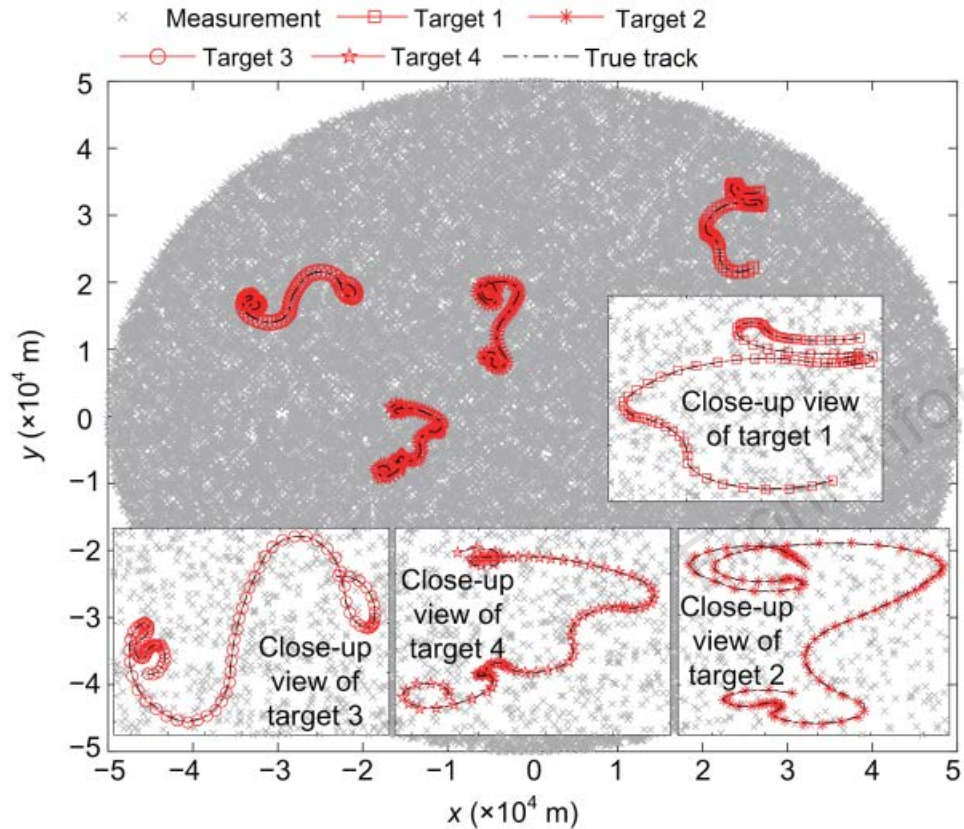


Fig. 1 True target tracks and position estimates

Table 1 Mean root mean square error

Method	x (m)	y (m)	V_x (m/s)	V_y (m/s)
IMM	4622.23	3893.82	242.07	217.04
GPMT	7518.37	7234.40	238.78	243.84
Ours	297.48	297.44	215.36	227.07

Table 2 Processing time

Method	Time (s)
IMM	0.0219
GPMT	0.1829
Ours	0.1816

Conclusions

1. This paper proposes a hybrid-driven approach for tracking multiple highly maneuvering targets, leveraging the advantages of both data-driven and model-based algorithms.
2. The time-varying constant velocity model is integrated into the Gaussian process (GP) of online learning to improve the performance of GP prediction.
3. This integration is further combined with a generalized probabilistic data association algorithm to realize multi-target tracking.
4. The proposed hybrid-driven method outperforms existing techniques such as IMM and GPMT under challenging scenarios involving highly maneuvering targets in cluttered environments.



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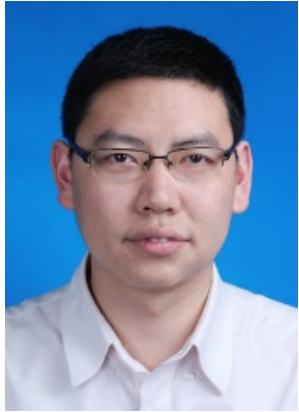
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