SENSOR SIGNAL PROCESSING FOR DEFENSE- SSPD CONFERENCE 2017

Multiple Mode Multi-Target Tracking in high noise environment using Radar measurements

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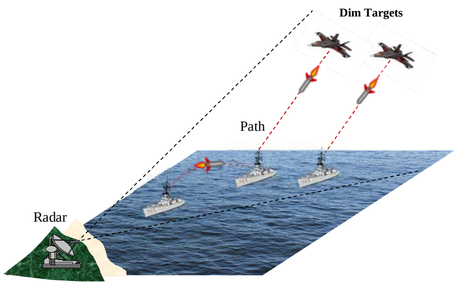
1. Introduction: Context, Problem , Motivation and the goal

Context and problem:



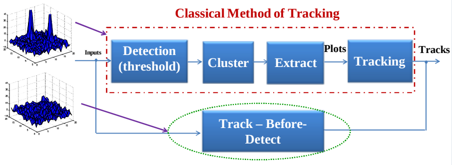
Multi-Target tracking in low SNR

❑Recent developments of stealthy military aircraft, warship and cruise missiles have emphasized the need to detect and track low SNR targets. This concept known as Track-Before-Detect approach.

❑In radar technology, track-before-detect (TBD) is a concept according to which a signal is tracked before declaring it a target.

Motivation:

Track-Before-Detect algorithms incorporate unthresolded measurements to track one or several targets under low SNR using particle filter.



Classical data and signal processing stages and TBD

Research goals

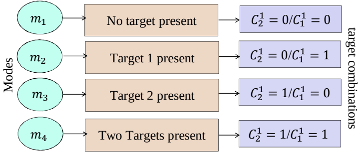
❑Using a multiple target Track-Before-Detect method for tracking varying number of target by estimating the target states under all possible existence combinations (modes).

❑Implementation of the multi-mode multi-target track before detect (MM-MT-TBD) algorithm recursively using particle filtering to track two moving targets according a coordinate turn motion model as an example for radar measurements.

2. Multitarget state Model and Matrix Transition

Multi-target state model:

We consider the radar problem of tracking $\mathcal{L}$ targets.



Target existence combination for two targets $\mathcal{M} = 4$

The dynamic multi-target state model for each mode can then be written as:

$$s_k^{[i]} = F^{[i]} s_{k-1}^{[i]} + v_k^{[i]}, \; i = 1, \dots \mathcal{M}$$

where $s_k^{[i]} = \begin{bmatrix} s_{k,1}^T & s_{k,2}^T & \dots & s_{k,\mathcal{L}}^T \end{bmatrix}^T$ and

$s_{k,\ell} = [x_{k,\ell} \quad \dot{x}_{k,\ell} \quad y_{k,\ell} \quad \dot{y}_{k,\ell} \quad I_{k,\ell}]^T, \; \ell = 1, \dots . \mathcal{L}$

$F^{[i]}$ and $v_k^{[i]}$ is transition matrix and process noise of each model.

Matrix transition:

Target existence variable is modeled as a random process with a two state first order Markov chain. The transition matrixcan be written as:

$$\Gamma_\ell = \begin{bmatrix} 1 - P_{b,\ell} & P_{b,\ell} \\ P_{d,\ell} & 1 - P_{d,\ell} \end{bmatrix}$$

The general mode of the transition matrix is given by:

$$\Pi = \Gamma_1 \otimes \Gamma_2 \dots \otimes \Gamma_\ell$$

3. Measurements Model and Likelihood Function

Measurement Model:

Each measurement frame is assumed to consist of $(N_r \times N_{\dot{r}} \times N_\theta)$ bins. The measurement equation is given by:

$$z_k^{(a,b,c)} = \begin{cases} \sum_{\ell=1}^{\mathcal{L}_i} C_\ell^i h_k^{(a,b,c)}\left(s_{k,\ell}^{[i]}\right) + \omega_k^{(a,b,c)}, & \text{for } i = 2, \dots, M \\ \omega_k^{(a,b,c)}, & \text{for } \quad i = 1 \end{cases}$$

where

$$h_k^{(a,b,c)}\left(s_{k,\ell}^{[i]}\right) =$$
$$A_k exp\left(-\left(\frac{a\Delta_r - r_{k,\ell}}{2\sigma_r}\right)^2 - \left(\frac{b\Delta_{\dot{r}} - \dot{r}_{k,\ell}}{2\sigma_{\dot{r}}}\right)^2 - \left(\frac{c\Delta_\theta - \theta_{k,\ell}}{2\sigma_\theta}\right)^2\right)$$

$r_{k,\ell}$, $\dot{r}_{k,\ell}$ and $\theta_{k,\ell}$ are the range, range-rate and azimuthal angle respectively of the ℓth target. Δ_r,$\Delta_{\dot{r}}$ and Δ_θ are their bin resolutions respectively.

The set of complete measurements collected up time k is denoted as :

$$Z_k = [z_1^T \quad z_2^T \quad \cdots \quad z_k^T]^T$$

Likelihood Function:

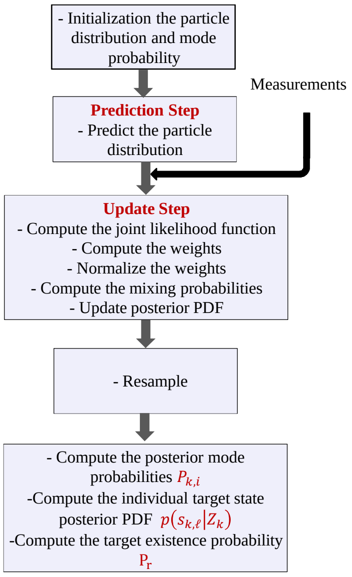
The joint likelihood function can be written as

$$p_{j,i}\left(z_k \middle| s_k^{[i]}\right) =$$
$$\begin{cases} \prod_{a=1}^{N_r} \prod_{b=1}^{N_{\dot{r}}} \coprod_{c=1}^{N_\theta} \mathcal{N}\left(z_k^{(a,b,c)}; \mu_k^{(a,b,c)}\left(s_k^{[i]}\right), \sigma^2\right), & m_k = 2, \dots, \mathcal{M} \\ \prod_{i=1}^{N_x} \prod_{j=1}^{N_y} \mathcal{N}\left(z_k^{(a,b,c)}; 0, \sigma^2\right), & m_k = 1 \end{cases}$$

Where $\mu_k^{(a,b,c)} = \sum_{\ell=1}^{\mathcal{L}} C_\ell^{\mathrm{i}} h_k^{(a,b,c)}\left(s_k^{[i]}\right)$ is the cumulative contribution to bin (a, b, c) from all the targets in mode i.

4. MM-MT-TBDF-PF

The particle filter implementation of the MM-MT-TBD algorithm are summarized in this steps:



- Initialization the particle distribution and mode probability

Measurements

Prediction Step
- Predict the particle distribution

Update Step
- Compute the joint likelihood function
- Compute the weights
- Normalize the weights
- Compute the mixing probabilities
- Update posterior PDF

- Resample

- Compute the posterior mode probabilities $P_{k,i}$
-Compute the individual target state posterior PDF $p\left(s_{k,\ell} \middle| Z_k\right)$
-Compute the target existence probability $\mathrm{P_r}$

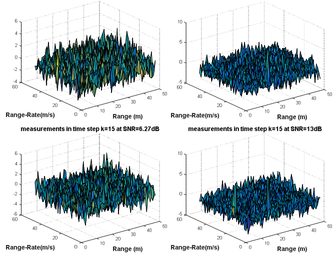
MM-MT-TBDF-PF steps for two targets ($\mathcal{M} = 4$)

5. Simulation and Results

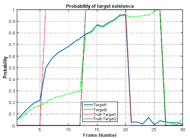
The measurements are generated from radar located at (0,0) at 6.27dB peak SNR .Table 1 shows the target combinations.

Time Step (k)	C_ℓ^i	**Mode ($m_k = i$)**
1-5	None	1
6-12	T1	2
13-20	T1+T2	4
21-26	T2	3
27-30	None	1

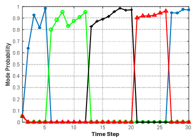
Table1: Target combination at different time step (k)



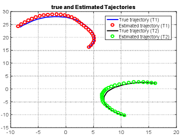
Measurement data at different time steps (k=9,15) at 6.27 dB and 13 dB peak SNR



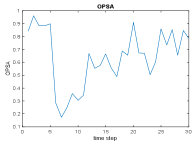
Target Existence Probability for two targets at 6.27 dB peak SNR



Mode Probability for two Targets at 6.27 dB



Tue and estimated target trajectories for 2 targets at 6.27 dB



Tracking Error at 6.27 dB

Conclusion & Perspectives

❑In this paper, we derived a track-before-detect algorithm to track a varying number of targets under low signal-to-noise-ratio conditions that can be implemented particle filter.

❑The MM-MT-PF-TBD estimate the target states under all possible target existence combinations or modes.

❑This algorithm can keep track of targets entering or leaving a monitoring region.

Perspectives:

❑This paper can be extended for geolocation and tracking of ground moving targets based on radar imagery and satellite imagery (GPS) for defense applications.

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