Zhi-yong SONG, Xing-lin SHEN, Qiang FU, 2019. A novel algorithm to counter cross-eye jamming based on a multi-target model. *Frontiers of Information Technology & Electronic Engineering*, 20(7):988-1001.
https://doi.org/10.1631/FITEE.1800394

A novel algorithm to counter cross-eye jamming based on a multi-target model

Key words: Particle identity labels; Probability hypothesis density; Cross-eye jamming; Anti-jamming; Random finite set; Monopulse radar

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Motivation

1. Cross-eye jamming is essentially a form of coherent jamming, does not require the jammer be located apart from the platform, and can produce a large angle deviation away from the target.

2. The existing countermeasures for cross-eye jamming heavily depend on the radar system configuration and hardware conditions, thus limiting their popularization and application. These limitations are good reasons to explore an anti-jamming algorithm that can use an advanced signal and data processing algorithm based on the existing system resources without incurring additional hardware overhead.

Main idea

1. Establish the multi-target model for typical cross-eye jamming scenario based on a random finite set framework.

2. Develop multi-target tracking using probability hypothesis density filters by combining the characteristic differences between the target and jamming with the release process of jamming.

3. Use the estimated number of targets in the beam to detect the release of cross-eye jamming, and use the correlation and transmission between labels and the estimated states to distinguish the true target and the false jamming.

Method

1. Model for target and cross-eye jamming

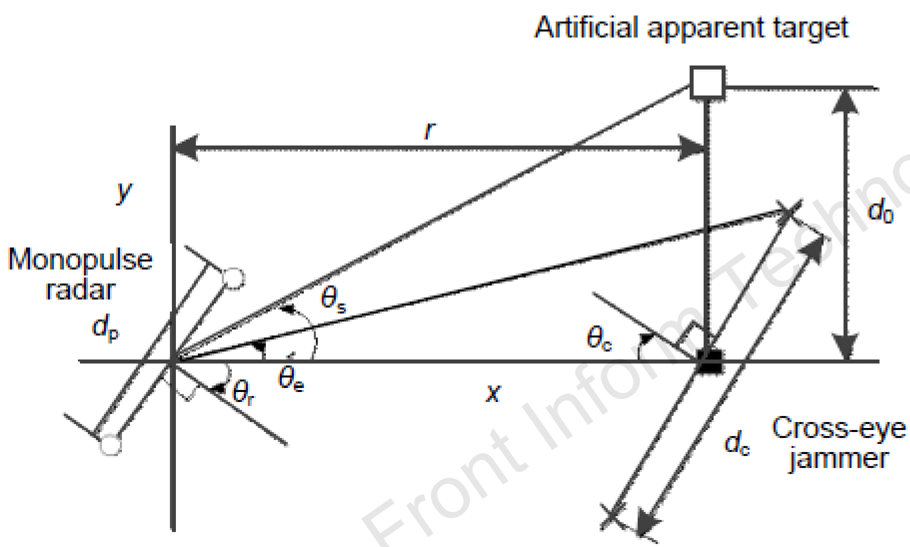

Fig. 1 Geometric depiction of cross-eye jamming and its effect on detection by the monopulse radar
d_0 denotes the distance between the apparent target and platform center

Target observation:

$$W = \begin{cases} \varnothing, & \text{no target exists,} \\ \{w_1\}, & \text{one target exists,} \end{cases}$$

Jamming observation:

$$\tilde{W} = \begin{cases} \varnothing, & \text{no jamming exists,} \\ \{\tilde{w}_1\}, & \text{one jamming exists,} \end{cases}$$

False alarm observation:

$$C = \begin{cases} \varnothing, & \text{no false alarm exists,} \\ \{c_1\}, & \text{one false alarm exists,} \\ \{c_1, c_2\}, & \text{two false alarms exist,} \\ \vdots & \vdots \\ \{c_i\}_{i=1}^{n}, & n \text{ false alarms exist.} \end{cases}$$

Method

2. Joint detection and tracking of the multiple targets integrated with the identity label

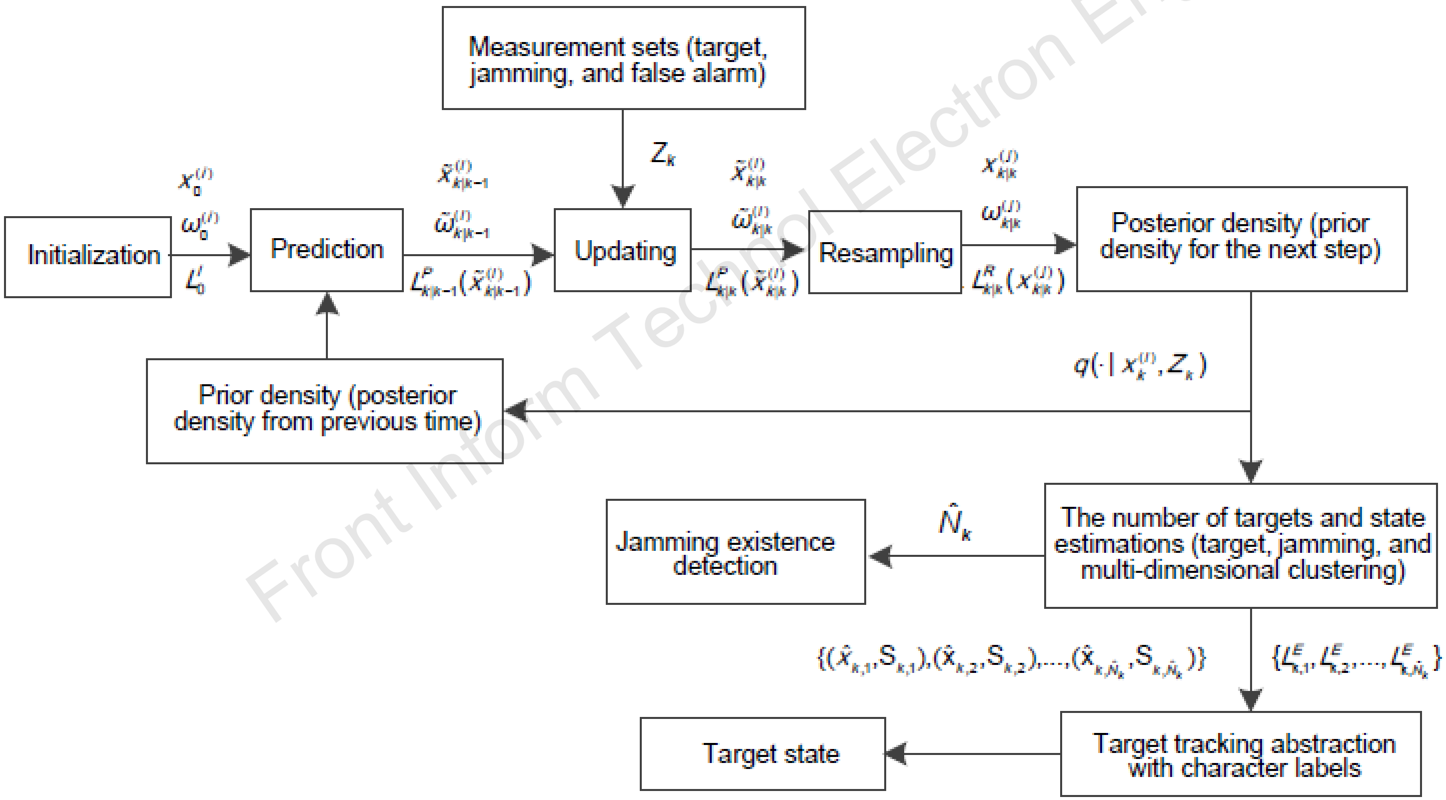

Fig. 3 Flow process depicting the steps involved in joint detection and tracking of the multiple targets integrated with identity label

Method

3. Experimental setup

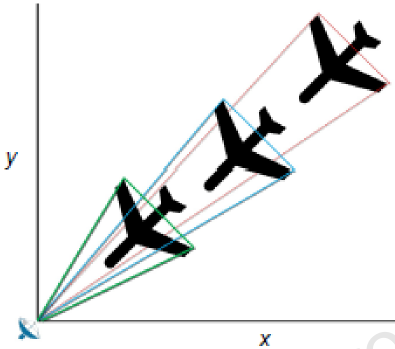

Fig. 4 A sketch depicting the target and jamming mapped in a two-dimensional (2D) plane

Table 1 Parameters used in the simulation

Parameter type	Parameter	Value
Target	Initial range R	5 km
	Initial velocity V	1200 m/s
	Fly direction	Toward a target
	Amplitude scaling a_s	0.02
	Phase shift ϕ_s	30°
Jamming	Time of releasing	11^{th} step
	Baseline length	20 m
	Amplitude ratio a	0.95
	Phase difference ϕ	175°
	Range difference relative to the target	10 m
	Velocity difference relative to the target	6 m/s
Radar	Beam width	5°
	Line of sight direction	Toward a target
Other	Measuring period	6 ms
	Initial signal-to-noise ratio	0 dB
	Equivalent jamming-to-signal ratio	34 dB
	Total simulation time	1 s

Major results

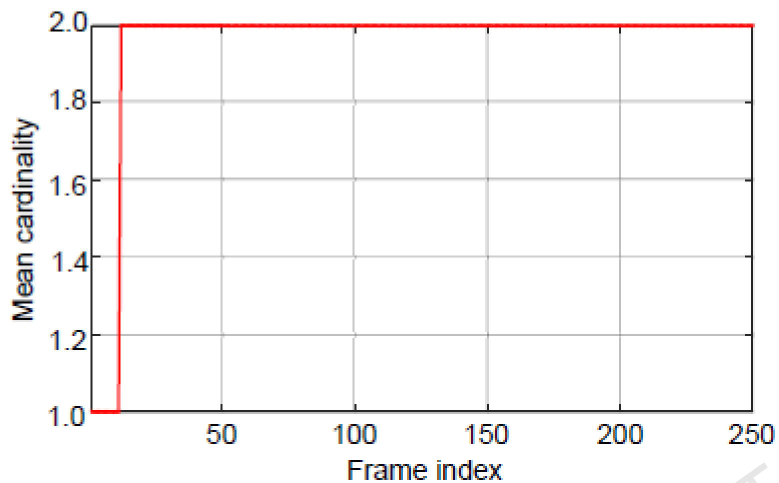

Fig. 7 Average of the estimation results for the number of targets at each moment

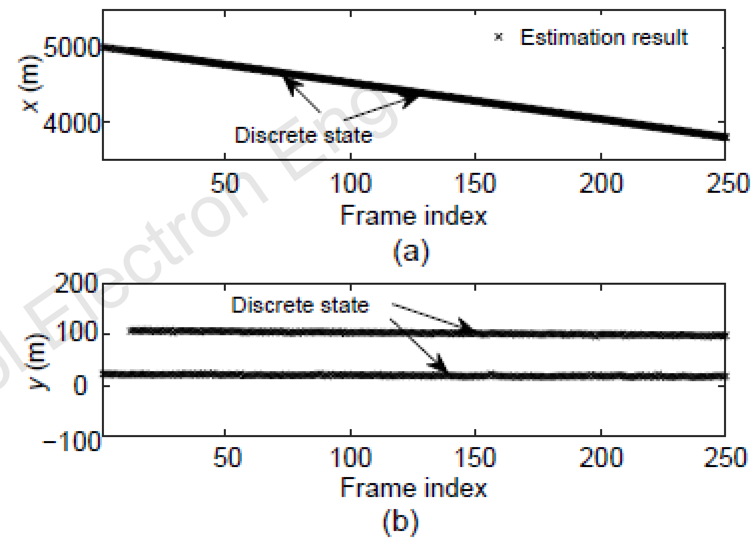

Fig. 8 State estimation for the traditional PHD filter in the x (a) and y (b) axes

The average detection delay is only one frame period, which means that real-time detection of jamming is highly effective.

The association between the target state and the target identity is not obtained. Therefore, the filtering results are some isolated state values, there is no stable track corresponding to the target attribute, and it is not clear whether the state is the target or jamming.

Major results (Cont’d)

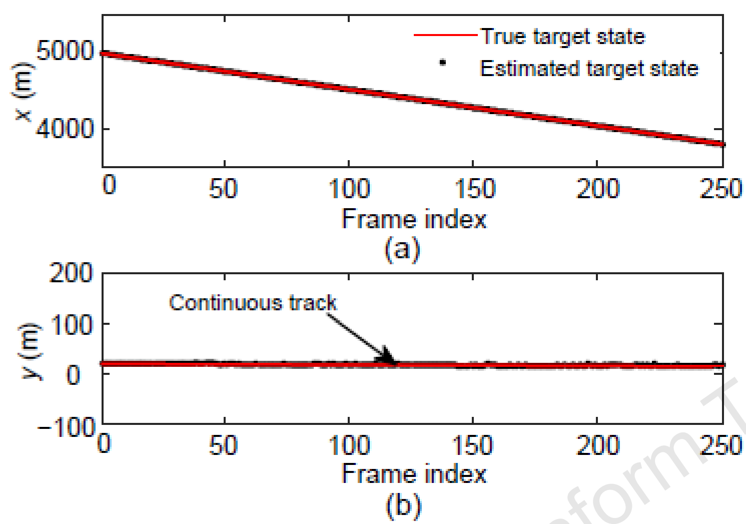

Fig. 9 State estimation obtained using the proposed algorithm in the x (a) and y (b) axes

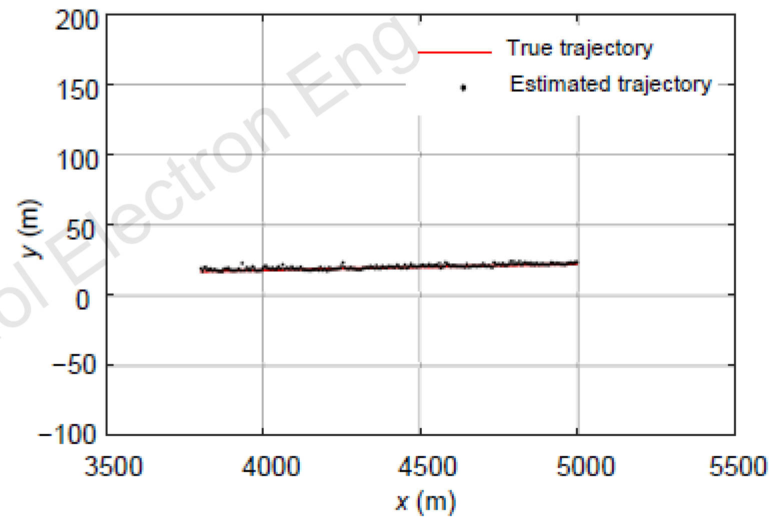

Fig. 10 Two-dimensional estimated state results for the proposed algorithm

After adopting the label PHD, continuous tracking of the true target state can be released by associating the estimated state with the identity label.

The state estimation for the target obtained by the proposed algorithm is always close to the true target location under cross-eye jamming.

Major results (Cont'd)

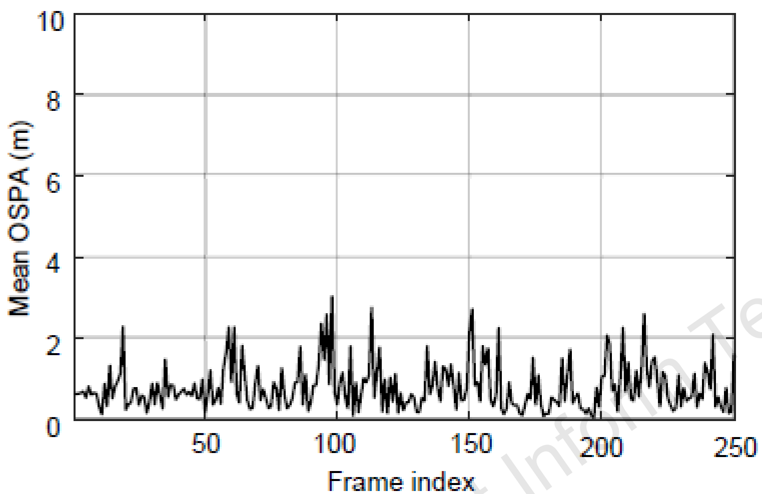

Fig. 11 OSPA error performance for target tracking

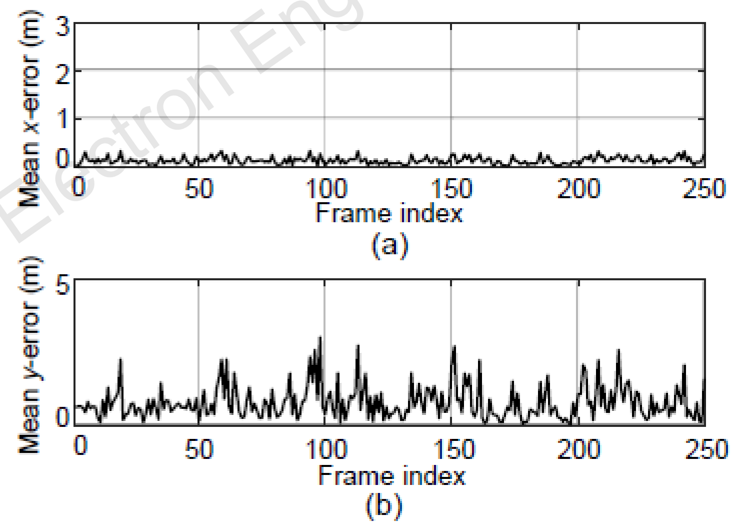

Fig. 12 Target estimation errors in the *x* (a) and *y* (b) axes

The average OSPA error for the target with the proposed algorithm is less than 3 m.

The estimation errors in the *x* and *y* axes are both less than 3 m in the Cartesian coordinate system.

Major results (Cont'd)

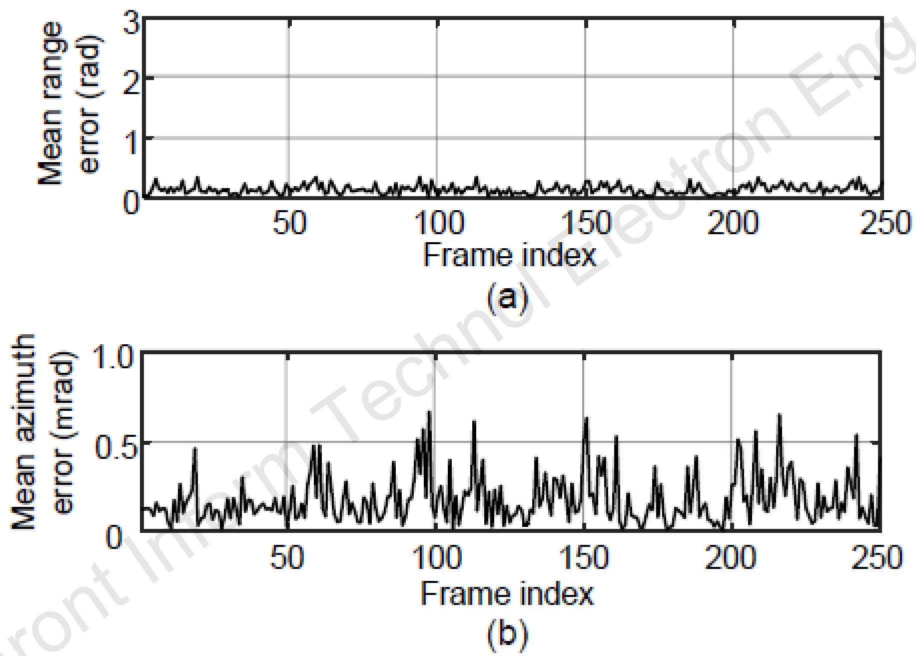

Fig. 13 Range (a) and angle (b) estimation errors

In the polar coordinate system, the angle estimation errors are very small, ensuring that the monopulse radar always points to the true target without being disturbed.

Conclusions

1. A novel antijamming method based on the PHD filter has been developed combining the characteristic differences between the target and jamming with jamming release processing information.

2. The proposed algorithm can detect the release of jamming with high probability and small delay, and can achieve an accurate state estimation and correct target recognition.

3. The tracking error for the true target has been found to be small, ensuring that the monopulse radar retains the correct bearing and table track for the true target.