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Improved plot fusion method for dynamic programming based track before detect algorithm

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ABSTRACT

The detection of randomly distributed extended multi-targets under various circumstances is of special interest. An improved plot fusion method is proposed in this work. The proposed plot fusion method is based on a multi-contour tracking and region growing algorithm. The proposed method is applied to the DP-TBD algorithm for extended targets in the K-distributed sea clutter. Models and shortcomings of existing methods are presented. The principle of the DP-TBD algorithm for extended targets and implementation of the improved plot fusion method are explained in detail. In the simulation, the methods are applied to almost all situations, close trajectories, crossing trajectories, small targets, weak targets and targets in a high clutter region. Comparison with existing methods demonstrates that the proposed method is practical and superior to the existing methods.

1. Introduction

The detection of multiple manoeuvring and low SNR targets by sea surveillance radars is always a challenging problem due to low signal-to-noise ratio (SNR) and a complicated environment for observation. Various algorithms are proposed for this problem by processing video data directly [1–6]. With the increased resolution of modern radars, targets can be found in several resolution cells rather than in one single resolution cell [2–5]. One extended target is considered in [6]. Track before detect algorithms that are based on non-extended targets are unsuitable in these scenarios. Therefore, the question is how to detect multiple extended targets with video data. A promising track before detect filter for tracking multiple extended targets from phased array observations is proposed in [7]. A novel phased array track before detect filter is proposed in [8] for the same problem, the method employs random finite set formalism in order to detect and track multiple targets in K distributed noise.

In the surveillance area, the quantity of resolution cells increases significantly with increased resolution. One frame of video data must be processed within a radar scanning cycle [1]. Therefore, the complexity and calculation methods are significant. Compared with existing methods in [9–13], an efficient plot fusion method based on a tracking contour algorithm [14] for potential extended targets is proposed in [1]. Unlike the methods in [9–13,15,16], not all of the cells in the frame are involved with removing noise and detecting targets; calculation is saved for this reason. The method can be combined with a dynamic programming based track before the detect algorithm to detect weak extended targets. However, there are still three shortcomings. First, size and RCS (radar cross section) of targets are different. Therefore, the tremendous difference between acquisitions of targets makes it difficult to detect all of the potential extended targets with a single contour. Second, the targets are randomly distributed in the surveillance area. Measurement ambiguity between closely distributed targets would cause targets to be easily missed with a single contour. Third, the surveillance area is highly complicated. The presence of non-intentional interference (sea clutter, thermal clutter and ground clutter) and echoes from the background (mountains, shores, buildings, islands and motor vehicles) [17,18], create enormous potential for false alarms. The average power of non-intentional interference varies in different areas. Sea conditions are varied in the whole surveillance area. With a single threshold in [1] it is hard to obtain all the contours of potential extended targets in an area of high seas. Therefore, a novel and efficient plot fusion method is of great importance for the track before detect algorithm based on dynamic programming.

The improved plot fusion method uses multi-contour tracking and region growing algorithm. In the proposed method, multiple detection thresholds are used for multi-contours to eliminate the effects of various sea conditions in the surveillance area. The targets under various sea conditions are detected with multiple thresholds. DP-TBD with the improved plot fusion method is

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processed with simulated data to demonstrate performance of the proposed method. The compound K-distribution sea clutter model in [19–21] and the model of target shapes in [22] are applied. The three problems above, i.e., various targets, closely distributed targets, high sea conditions are considered in simulated video data. The results show that better results are obtained with the proposed method.

The remainder of the work is organized as follows. In chapter 2, the models for multiple extended targets tracking are presented. In chapter 3, the DP-TBD algorithm and the improved plot fusion method are illustrated in detail. Simulation results are shown in chapter 4. Finally, the study's conclusions are presented in chapter 5.

2. Models and notations

2.1. Target model

Assume that the extended targets are randomly distributed in the x–y plane. We use M_k to denote the number of targets at k stage. The shape of targets can be modelled by an ellipse. At each stage, our goal is to estimate the joint kinematic feature state vector of each target, which is denoted by $St_k^m = \{x_k^m, vx_k^m, y_k^m, vy_k^m, l_m', s_m'\}$, $1 \leqslant m \leqslant M_k$, $1 \leqslant k \leqslant K$. The sets $\{x_m^k, y_m^k\}$ and $\{vx_m^k, vy_m^k\}$ denote the position and velocity of the mth extended target. $\{l_m^{k'}, s_m^{k'}\}$ denotes the major axis and minor axis of the extended target. According to the support function based shape model in [22], the area occupied by an extended target in the x–y plane can be calculated by Eq. (1).

$$\frac{\left((x-x_k^m)\cos\alpha_k^m+(y-y_k^m)\sin\alpha_k^m\right)^2}{(l_m')^2} + \frac{\left((y-y_k^m)\cos\alpha_k^m+(x-x_k^m)\sin\alpha_k^m\right)^2}{(s_m')^2} < 1, \tag{1}$$

where α_k^m represents the course of the target. The expression of α_k^m is given in Eq. (2). The area occupied by one target is usually much larger than one resolution cell. The resolution cells with locations that satisfy Eq. (1) are regarded as the occupied cells of a target.

$$\alpha_k^m = \arctan\left(\frac{vy_k^m}{vx_k^m}\right). \tag{2}$$

In the motion model of targets, the motion of a nearly constant velocity model can be regarded as a Gaussian distributed Markovian process, denoted by Eq. (3).

$$St_k^m | St_{k-1}^m \propto N(St_{k-1}^m \cdot F, Q), \tag{3}$$

where $N(\mu, \sum)$ denotes the Gaussian probability density with mean μ and covariance $\sum$. The state transition matrix F is represented in Eq. (4), where parameter T is the scanning cycle of radar.

$$F = \begin{bmatrix} F_s & \mathbf{0}_{2\times2} & \mathbf{0}_{2\times3} \\ \mathbf{0}_{2\times2} & F_s & \mathbf{0}_{2\times3} \\ \mathbf{0}_{3\times2} & \mathbf{0}_{3\times2} & E \end{bmatrix}, F_s = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}, E = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4}$$

It is assumed that the targets are Swerling type 1 targets and the magnitude of echoes y_t follow the Rayleigh distribution in (5)

$$f_t(y_t) = \frac{2y_t}{pt_m}\exp\left(-\frac{y_t^2}{pt_m}\right), y_t > 0. \tag{5}$$

The parameter pt_m in Eq. (5) denotes the average reflection strength of targets present in a single pulse.

2.2. Noise model

In this section, sea clutter and thermal noise are considered as measurement noise. The sea clutter distribution model of major theoretical and practical interest is a K-distributed clutter model in [19]. The PDF (probability distribution function) of the sea clutter in this model can be expressed by Eq. (6).

$$f_c(p_c) = \frac{2b}{\Gamma(v+1)}\left(\frac{bp_c}{2}\right)^{v+1} K_v(bp_c), \tag{6}$$

where the parameter p_c is the power of the sea clutter, parameter ν is the shape parameter and b is the scale parameter. $\Gamma(v)$ is the gamma function and $K_v(u)$ denotes the modified Bessel function of second order. Considering thermal noise, a compound form of the K distribution assumes that the intensity of clutter plus noise can be described by an exponential distribution [20]:

$$f(y_n|p_c, p_v) = \frac{1}{p_c+p_v}\exp\left(-\frac{y_n^2}{p_c+p_v}\right), \tag{7}$$

where parameter p_v represents the power of thermal noise.

2.3. Measurement model

The surveillance area is divided into $N_A \times N_R$ resolution cells, i.e., N_A bins in azimuth axis and N_R bins in range axis. According to Eq. (1), the range-azimuth resolution cell is occupied by an extended target under the condition that Eq. (8) holds, where an indicator function $I_k^m(\cdot)$ is used to indicate whether the cell is occupied [23].

$$I_k^m(r,a) = \begin{cases} 1, & \left\| N \cdot R \cdot \begin{bmatrix} x(r,a) - x_k^m \\ y(r,a) - y_k^m \end{bmatrix} \right\| \leqslant 1 \\ 0, & \left\| N \cdot R \cdot \begin{bmatrix} x(r,a) - x_k^m \\ y(r,a) - y_k^m \end{bmatrix} \right\| > 1 \end{cases}, \tag{8}$$

$$R = \begin{bmatrix} \cos\alpha_k^m & \sin\alpha_k^m \\ -\sin\alpha_k^m & \cos\alpha_k^m \end{bmatrix}, \tag{9}$$

$$N = \begin{bmatrix} \frac{2}{l_m'} & 0 \\ 0 & \frac{2}{s_m'} \end{bmatrix}. \tag{10}$$

Parameter $(x(r, a), y(r, a))$ in Eq. (8) denotes the location of the range-azimuth resolution cell (r, a) in the Cartesian coordinate system. The magnitude of each cell is denoted by $M(r,a)$, $1 \leqslant r \leqslant N_R$, $1 \leqslant a \leqslant N_A$ and its definition is given below.

$$M(r,a) = \begin{cases} M_n(r,a), & \text{Nothing exists in this cell except noise} \\ M_t(r,a)+M_n(r,a), & \text{A target of interest exists in this cell} \\ M_b(r,a)+M_n(r,a), & \text{Object of background exists in this cell} \end{cases}, \tag{11}$$

where $M_b(r, a)$ and $M_t(r, a)$ mean the magnitude of echoes returned from huge objects in the background and the return from targets, respectively. The magnitude of K-distributed noise in this cell is expressed by $M_n(r, a)$.

As is shown in Fig. 1, an extended target is illuminated by beams; the 3 dB azimuth beam width θ_0 is usually much larger than the width of one azimuth bin ($360°/N_A$). Due to the movement of the antenna beam while scanning, the illuminated area shifts. According to the theory in [21], the measurement of the cell on the line of sight can be obtained from Eq. (12).

$$z(r,a) = \frac{\sum_{k=-\frac{bw-1}{2}}^{\frac{bw-1}{2}} \omega(k\cdot\Delta A) M(r, a-k)}{\sum_{k=-\frac{bw-1}{2}}^{\frac{bw-1}{2}} \omega(k\cdot\Delta A)}, \tag{12}$$