Research on Infrared Point Target TBD Algorithm

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Abstract: Track-before-detect (TBD) is an effective method for infrared point target detection. Paper mainly introduced the three dimensional matched filtering, Hough transform, dynamic programming, multistage hypothesis testing, and five types of classic TBD particle filter algorithm and from the target category, environment noise, target motion, and track confirmation criteria as well as the advantages and disadvantages of algorithm six aspects has carried on the analysis and comparison of them, finally prospects the development trend of the infrared point target TBD algorithm.

1. Introduction

Traditional sense-before-track (DBT) technology firstly preprocesses to filter out background clutter and noise, and then carries out single-frame threshold detection. Although the idea is simple and the execution rate is high, if the threshold is lowered under the condition of low SNR, numerous false tracks will be generated subsequently. Therefore, how to improve the detection ability of weak targets is an urgent problem to be solved. In recent years, the track-before-detect (TBD) technology has become a research hotspot in the field of point target detection and tracking [1-3].

2. Common TBD Implementation Methods and Their Research Status Review

2.1 Hough Transform

In 1962, Paul Hough proposed a shape matching technique called Hough transformation. Later, Dr. D. G. Falconer adopted the Hough transform to solve the problem of extraction of point target trajectory and tracking and identification of state parameters that move in a straight line in a two-dimensional plane. W. E. Snyder et al. further popularized it and solved the problem of detection, tracking and recognition of each pixel target.

Hough transform requires no priori knowledge of any target, has a strong fault tolerance rate for noise interference, and is suitable for multi-target tracking occasions, which has been widely concerned by scholars at home and abroad [4].The traditional Hough transform image is mapped from a single point to multiple surfaces, which requires a large amount of storage space and computation. Sometimes the edges are not smooth and closed, and the phenomenon of "false peaks" and "missed detection" appears, which has a serious impact on practical applications. Wang xiaojuan et al. [5] determined the best threshold value by non-uniform quantization of the gradients in the horizontal and vertical directions of the image edge, and detected filters in the positive, negative and horizontal directions to solve the problem of false images in the cross-edge detection of infrared images under strong noise. An boween etc. [6] posts the Ostu threshold segmentation for Haitian edge information and the combination of Hough transform to detect the target, to random sampling of the background of the feature points, although to a certain extent, reduce number of target point and noise point synchronization, to ensure the real-time algorithm, but is still likely to feature points to the phenomenon of repeated sampling, lower the efficiency of algorithm. Wu mengyi et al. [7] selected the appropriate boundary curve equation to detect and segment the target according to the

shape characteristics and layout of the target. The experimental results show that the method is accurate but some edges are missing.

2.2 3D Matched Filter

In 1983, Reed et al. applied the matching filter theory in 3d sequence images and proposed the 3d matching filter. In 1990, Reed put forward a simplified method of 3d matching filtering method: Recursive-moving-target-Indication (RMTI) algorithm [8], which reduced computation quantity, saved storage space and had a good SNR gain. Subsequently, Porat et al. [9] also made a detailed explanation of 3d matching filtering, and proposed an algorithm based on frequency domain direction filter based on Reed, which was used to detect ground moving targets, greatly reducing the algorithm complexity in time domain.

Velocity and direction are the key points of 3d matched filter. If the priori information of the filter does not match with the actual target, the algorithm performance will decline seriously. To solve the above problems, a filter was set up in the two-dimensional frequency domain in reference [10]to compress the azimuth velocity parameters of the target, reducing the storage space. Matt Ward [11] implemented the speed selector, reducing the pressure of traversing the search. Hou wang et al. used the block strategy to divide the velocity domain and calculate the target motion velocity [12], which solved the difficulty of the basic RMTI algorithm in real-time detection and greatly reduced the calculation amount. The above method can only detect the moving target with uniform speed and straight line, but is not applicable to the nonlinear moving target.

2.3 Dynamic Programming

In 1985, Barniv in the United States introduced the idea of dynamic planning into TBD technology for the first time. In 1987, based on bayesian theory, Barniv used probability density function to optimize the construction of value function and analyzed the detection performance of the algorithm in detail. The experiment shows that the method has the effect of energy diffusion when the energy accumulates to the target. Arnold applied the algorithm to non-undulating targets in 1993 and improved it. Several years later, Tonissen et al. applied the algorithm to the fluctuation model under the assumed gaussian condition, and analyzed its detection and tracking performance [13]. These two types of methods for constructing value functions have become the main research direction of dp-tbd. Qiang yong et al. [14] proposed a unified recursive formula of value function based on the above two algorithms. Guo yunfei et al. [15] proposed a new value function construction method based on the amplitude correlation information of adjacent frames, rather than the amplitude itself. This algorithm relies on the continuous and steady fluctuation of the target amplitude between adjacent frames, and is only applicable to the target with uniform linear motion or weak maneuvering.

From 2013 to 2017, Grossi et al. conducted a large number of studies on the complexity of dp-tbd algorithm [16-17].Zhang peinan et al.[18] used neural network (NN) based on Hebb rule to perform cluster analysis on the original measurement data in the pre-processing stage, and used dp-tbd method to conduct amplitude accumulation after scaling amplitude according to classification. Compared with the algorithm in literature [16-17], NN's clustering analysis process takes a lot of time, so it is necessary to focus on how to reduce the running time of the algorithm.

2.4 Multilevel Hypothesis Testing

In 1991, Blostein and Huang proposed a TBD algorithm called multi-order hypothesis test, and first introduced the structure of tree to represent the target trajectory.

The subsequent development of multi-order hypothesis test (MMHTT) based on the target motion state model[19], although it avoids the problem that the number of detection frames is larger than the number of algorithm execution frames, it may be affected by the lack of upper limit on the stop time of SPRT, especially in the case of specifying errors. Cui changwei et al. [20] proposed an inverse method, which took a certain pixel point as the target end point to reverse search and solved the problem of combinatorial explosion due to many initial points. Liu xiang et al. [21] introduced

multispectral information to suspicious target points in the traditional MHT algorithm, and conducted multispectral statistical judgment in the formed search tree.

2.5 Particle Filter

In 2001, Salmond et al. first proposed particle filtering algorithm at the international conference on control. The core idea is to extract N independent identically distributed sample $\{x_k^i\}_{i=1}^N$ (particle set) from the importance sampling density $p(x_k|z_{1:k})\ q(x_k|z_{1:k})$. By weighting the posterior probability density of the system state, the posterior probability density $p(x_k|z_{1:k})$ at time *k* is:

$$p(x_k|z_{1:k}) \approx \sum_{i=1}^{N} w_k^i \delta(x_k - x_k^i) \tag{1}$$

In the formula: w_k^i is the weight of the particle at time *k*, x_k^i is the particle state at time *k*, and $\delta(\cdot)$ is the Dirac delta function. As the number of particles approaches infinity, the system state that obeys arbitrary probability distribution can be approximated and the optimal solution of Bayesian estimation can be reached.

As a new filtering algorithm, particle filter performs well in non-gaussian nonlinear environment. Although re-sampling can effectively reduce degradation, after several iterations, high-weight particles will be selected for multiple times, thus losing particle diversity and resulting in sample (particle) shortage. Which greatly reduces the real-time performance of the algorithm. Chong Y et al. [22] proposed a particle filter tracking algorithm based on adaptive fusion of color features and edge features, which overcame the impact of environmental mutation on tracking stability but failed to effectively suppress particle degradation. Wang hongxiang et al. [23] adopted a simple two-layer feedforward convolutional network to extract high-level abstract features of the target through hierarchical filter convolution. Wang haimei et al. [24] proposed a PF algorithm based on target gray scale and motion characteristics, which greatly improved the accuracy and robustness of tracking.

2.6 TBD Algorithm Analysis and Comparison

The above five typical TBD algorithms represent the development process of TBD. Table 1 analyzes and compares them from six aspects: target category, noise environment, target motion, trajectory recognition criteria and advantages and disadvantages of the algorithm. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

It can be seen from the table that under the condition of gaussian noise, all these methods can detect the target moving in a uniform and straight line. Hough transform has a high robustness to random noise. Multistage hypothesis test USES trajectory features without fixed sampling length. 3d matched filter is the optimal linear filter for detecting known velocity targets. However, all the above algorithms can generate a large amount of computation and storage, and the processing is relatively complex. Compared with the other four algorithms, particle filter does not need to make any prior assumptions on the system and directly carries out discrete sampling estimation. When the number of particles is large enough, it can infinitely approximate the true probability density of the target state, which has more advantages in dealing with the state estimation of complex nonlinear and non-gaussian systems.

Table 1. Tbd Algorithm Analysis and Comparison

TBD algorithm	target category	noise environ-ment	target motion	track confirmation criterion	advantage	disadvantage
Hough transform	Single target/m-ultiple target	gaussian	Uniform motion in a straight line	Parametric spatial peak	Two-dimensional plane detection, small track search operation, strong fault tolerance for random noise	When the noise is strong and the inter-frame shift is large, the energy of the target decreases and the performance of the algorithm decreases.
3 d matching filter	Single target/m-ultiple target	gaussian	Uniform motion in a straight line (Speed known)	Filter output signal to noise ratio	At the same input signal to noise ratio, the output is the maximum.	Need to know the speed information, the application range is small, high requirements for hardware structure.
Dynamic programming	Single target/m-ultiple target	gaussian	Uniform straight line/weak maneuvering target	Value function	Hierarchical processing mode, small amount of calculation, convenient for hardware implementation.	In the case of low SNR, the space complexity is high, the real-time performance is poor, and the applicability of maneuver or extended target is weak
Multistage hypothesis test	Single target/m-ultiple target	gaussian	Uniform motion in a straight line	Truncate sequential hypothesis testing	The sampling length does not need to be set artificially	Too many candidate track trees cause the rear branch combination to explode.
Particle filter	Single target/m-ultiple target	gaussian/non-gaussian	Uniform straight line/ maneuvering target	Target probability or likelihood ratio test	Not limited by motion model and measurement model, it is more suitable for complex environment.	The problem of particle degradation and diversity loss is inevitable.

3. Conclusions and Prospects

As the research progresses, the boundary between detection and tracking becomes less and less obvious. Combined with the analysis in this paper, when the target is too weak to provide effective information in pre-detection, TBD algorithm adopts the tracking idea before detection, directly based on the trajectory estimation of target original data, so as to achieve the cumulative effect of small targets along the trajectory and improve the detection performance, which is an optimal choice. In addition, with the development of intelligent science and information technology, particle filtering will be the development direction of infrared point target tracking in the future due to its good performance in nonlinear non-gaussian systems with low SNR.

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