Overview of infrared dim and small target detection methods

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Keywords: Infrared Small Target, Detection algorithm, Filtering algorithm

Abstract: In the modern technology warfare, infrared weak target detection technology occupies a very important position. In civil use, the infrared weak target detection technology has also been widely applied and developed. The application and research status of infrared weak targets are briefly analyzed. The characteristics of infrared weak targets are introduced. The principles and steps of some classic improved methods for infrared small target detection methods in recent years are summarized. Finally, the differences of several classical algorithms such as Gauss filtering, mean filtering, median filtering, morphology and adaptive Wiener filtering are compared. This paper lays a foundation for the learning of infrared small target detection algorithm and is helpful to the research of improved algorithm for infrared small target detection.

1. Introduction

The infrared target detection technology has a significant advantage over radar systems in modern high-tech warfare[1] , capable of finding targets from a long distance in complex backgrounds such as cloud clutter or sea waves[2]. The infrared target detection technology uses the difference of infrared radiation between the background clutter and the weak target to filter the clutter as much as possible to identify the real target[3-5]. In practical applications, infrared weak target detection and tracking technology can be used in the military field of prevention and precision counterattack systems, environmental pollution and other aspects of life[6-9].Although the infrared weak target detection technology is of great significance for people's future development, since the small target imaging area is small and there is no fixed shape structure, the pixel size is lower than 80 pixels, and the background is complicated, the detection technique of the infrared weak target is Important research areas to be broken[10-12].

The infrared weak target detection algorithm can be divided into two categories: the pre-tracking detection algorithm (DBT) and the track before detector (TBD)[13]. The main difference between the two is the way the image is processed. DBT mainly deals with single-frame images, while TBD focuses on the processing of sequence images. The DBT searches for the target by preprocessing, and then divides the image by the threshold value to obtain the suspected target[14]. Finally, the real target is confirmed according to the target motion characteristics in the sequence image. TBD firstly tracks small targets in sequence images, obtains many suspected trajectories of the target, and then achieves target detection by determining the trajectory[15-17].

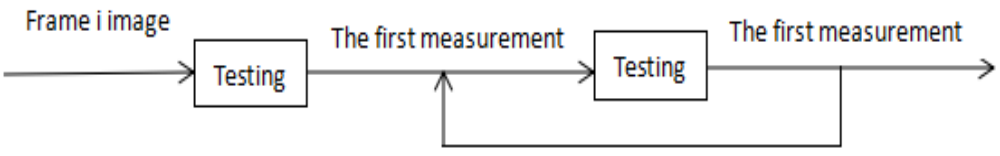

Fig.1 Basic Framework of DBT Technology

  DOI: 10.25236/mmmce.2019.142

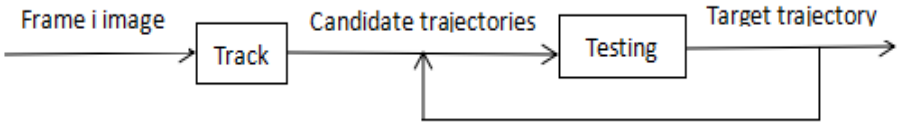

Fig.2 Basic Framework of TBD Technology

In summary, infrared small target detection technology is the focus of detection technology in recent years[18-20], and its role in military and civil areas can not be ignored. However, the real-time and robust detection of weak targets in complex backgrounds, reliability is a difficult point to be solved. This paper is also a method for summarizing the weak targets in recent years. This paper is also a method to summarize the weak targets in recent years. By comparing the methods, it helps to get some new ideas for improvement.

1.1. Research Status of Infrared Weak Small Target Detection Technology

In the late 1940s, Germany first studied the detection of small infrared targets. The first thing that emerged was the infrared projection material[21]. In the late 1980s, The infrared small target detection technology has attracted the world's countries to compete for research[22].Until the end of the 1990s, the infrared small target detection technology was widely used, making the theory a reality[23]. At present, foreign detection technologies for weak targets are becoming more and more mature. However, China's research on small target detection technology is relatively late. The most famous research institutions in China include National University of Defense Technology, and the 211th Research Institute of the Weapon Industry Group[24-26]. Among them, the research focuses on the infrared early warning system, the detection of ground and low-altitude targets by the airborne front-down system, and infrared guidance.

1.2. Characteristics and models of infrared small targets

The characteristics of infrared weak targets in the imaging system can be simply summarized as "weak" and "small". According to the definition of infrared dim targets by the Society of Photo-Optical Instrumentation Engineers (SPIE),for an image of size 256 × 256, the target with an imaging size smaller than 0.12% of the total number of pixels is a weak target[27-29].

Fig.3 Infrared images

At present, when studying the detection algorithm of infrared weak target, it is mainly based on its characteristics of roughly circular, no anisotropy and main direction, and similar to the two-dimensional Gaussian function[30]. Fig. 3 is actual infrared images, and the upper right corner is the result of magnifying the weak target area in the image for clear display. Figures 4 is respectively a three-dimensional intensity map of a weak target in two images[31-32]. The model can be represented by a two-dimensional Gaussian function[33], as shown in equation (1).

$$s(x,y)=\gamma \exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\sigma x}\right)^2+\left(\frac{y}{\sigma y}\right)^2\right]\right\} \quad (1)$$

Where x and y represent the horizontal and vertical coordinates, respectively; γ is the gray scale of the target; σ_x and σ_y are the horizontal and vertical scales, respectively parameter.

2. Infrared weak target detection method

The classical algorithms for infrared weak targets mainly include median filtering, morphological filtering, Gaussian filtering, etc. Many detection methods are based on the improvement of classical methods[34-37]. The detection methods of infrared weak targets in this paper are mainly based on classical algorithms. The summary of the improved method is mainly to summarize the method principle, main steps and feature advantages.

2.1. Comprehensive filtering algorithm

The integrated filtering algorithm combines three classical algorithms. Firstly, the target point is regarded as the gray singular point in the image. The high-pass filtering method is used to filter the common pixel points, accurately obtain the target point in the image, and then the median filtering method is used to filter out high frequency noise and interference in the image. Median filtering can achieve better suppression of interference pulses and random point noise under the premise of better maintaining image edge definition. In addition to the target, the background image after suppression may still contain a small amount of noise and a slight background leakage. In order to more accurately detect the target from the residual image, the image is segmented. After the background suppression is completed, most of the pixels are in the low gray region, and the target and some noise are in the high luminance region. At this time, the global threshold segmentation method is used to detect the small target.

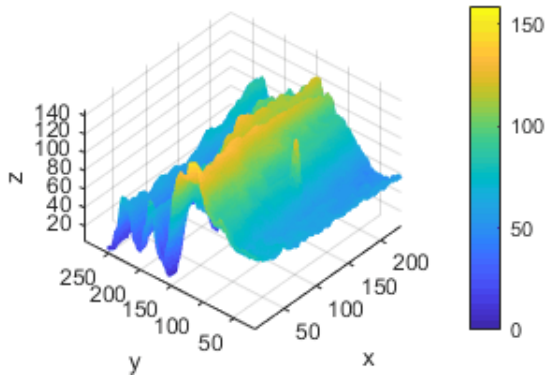

Fig.4 3D Map of Weak and Small Targets (The x, y, and z in each 3D image represent the pixel values in these three directions.)

2.2. Airspace-time domain joint algorithm

The airspace-time domain joint algorithm can better perform background suppression and noise elimination, and accurately and effectively detect weak targets of infrared motion. The spatial-temporal joint algorithm firstly proposes an algorithm for adaptively determining the size of structural elements. Morphology is used to estimate the background of the detected images, which ensures the versatility and flexibility of the top hat transform algorithm for images with different sizes. After the image is suppressed by the background, the average iterative threshold segmentation method is used to gradually refine the gray level of the image to determine a more accurate segmentation threshold T, and then the image is effectively segmented. According to the "motion form" feature of the target, find the pixel set that satisfies the feature, eliminate the remaining noise, and reduce the false alarm rate. Finally, an algorithm based on neighborhood multi-frame image phase and decision is proposed to realize the infrared weak moving target. Sequence detection.

2.3. Two-dimensional normal cloud model algorithm

The two-dimensional normal cloud is composed of two independent one-dimensional normal

cloud model functions. The distribution point of the target pixel is regarded as a cloud drop, and the cloud formed by the entire pixel distribution area reflects the characteristics of the target in the image, and then the normal cloud model is generated by the function generator according to the target discriminant condition function. Finally, the objective function of each cloud layer is constructed under the infrared image weak target detection error function, and the infrared image weak target detection error function is minimized by the objective function of each cloud layer to optimize the data. The algorithm suppresses the background of the infrared image weak target well, effectively detects the target and eliminates the background complexity interference. In practice, it can be widely used in security surveillance, defense military and industrial automation detection.

2.4. Threshold segmentation algorithm

Threshold segmentation algorithm is an algorithm based on target and background area difference and modified gray entropy. Firstly, adaptive median filtering and mean filtering are used for image preprocessing to reduce noise interference. Then the modified gray entropy formula is given, and the final threshold selection formula is constructed by using the characteristics of the difference between the target and the background area[38]. Finally, the optimized search strategy is adopted on the histogram to further reduce the computational complexity of the algorithm. Because of the large difference between the target and the background area, the established threshold segmentation method is beneficial to the detection of smaller targets in the image, and the modified gray entropy formula effectively overcomes the undefined problem in the entropy calculation, which can directly reflect the uniformity of pixel distribution within the target and background classes, and the calculation speed is fast.

2.5. Local mean algorithm

Based on the local gray mean value, the algorithm for determining the size and position information of the infrared small target is based on making full use of the difference between the small target and its local background[39]. First, the necessary condition for judging that the pixel belongs to the small target is determined. The condition determines which pixels in the image may belong to the infrared small target. Secondly, the possible size values of the small target are given based on the pixels that may belong to the small target; then, the results obtained are optimized to eliminate false alarms; finally, the size and location of the small targets are determined based on the results obtained in the first three stages. For the infrared image of the complex cloud background, this algorithm can accurately give the position information of the target based on the selection of appropriate parameters, and can better estimate the small target size. However, this new algorithm still needs to be further improved in the detection speed.

2.6. Multi-filter fusion algorithm

Based on the multi-filter fusion algorithm[40] combined with the imaging characteristics and space-time characteristics of small infrared targets, a detection method proposed on the basis of previous research results has high detection accuracy in different scenarios. By analyzing the imaging characteristics and space-time characteristics of small infrared targets and background noise, Top-hat algorithm is combined with improved Robinson spatial filter with guard band to effectively suppress background and highlight targets. Adaptive threshold segmentation is used to extract candidate targets, and Unger smoothing filter and multi-objective correlation filter are used to eliminate noise and false targets.

3. Comparison of Some Classical Algorithms

Although infrared small target detection technology has made great progress, many methods are based on the improvement of classical algorithms. The classical infrared small target detection algorithms include Gaussian filtering, mean filtering, median filtering, morphology, Wiener filter, etc. These algorithms are all ways to remove background noise and enhance the brightness of the target area to obtain small targets. The detection algorithm that suppresses background noise is the

basis of the infrared small target detection method.

Table 1 Comparison of Some Classic Algorithms

Filter	Measuring noise	Advantage	Disadvantage
Gaussian filtering	Gaussian noise	Highlight key points	The effect of filtering out noise is not very good
Mean	Particle noise	Simple algorithm and fast calculation	Can't remove noise, only reduce noise
median	Salt and pepper noise	The effect of suppressing noise is very good, and the resolution of the picture is basically maintained.	The suppression of Gaussian noise is not very good
Morphological	No specific value	Good adaptability, good effect of filtering out noise	The structural element size is not easy to grasp
Adaptive Wiener	White Noise	Filter out noise is better	Large amount of calculation

It can be seen from Table 1 that these classic algorithms have their own advantages, but there are certain disadvantages. Gaussian filtering actually uses Gaussian functions to filter out noise, mainly for Gaussian noise, and can highlight key areas. The effect of filtering out noise is not very ideal. Mean filtering, as the name implies, is to assign the mean value of the selected region to the target pixel. It is suitable for particle noise. The calculation is simple and fast, but it can only reduce the noise and cannot be removed. The median filter uses the combination of alignment and the pixel values of the selected area are arranged from small to large, and then the intermediate value is given to the target pixel. This algorithm basically does not damage the sharpness of the image, and the noise suppression effect is good, but it is not suitable for Gaussian noise. Morphology is an algorithm that has developed well in recent years, but there are great limitations on the choice of structural elements, and the size of structural elements cannot be well grasped. Adaptive Wiener filtering is suitable for white noise filtering, and the filtering effect is good, but the amount of calculation is too large to achieve real-time problems.

4. Summary

Aiming at the small target detection method, this paper makes a general summary, and focuses on some improved methods of infrared small target detection in recent years. Finally, the differences between Gaussian filtering, mean filtering, median filtering, morphological filtering and adaptive Wiener filtering are compared, and their advantages and disadvantages are given. Although the detection technology of infrared small targets has made great progress in recent years, many of these methods are based on the improvement of classical algorithms, and do not solve the problems of reliability, versatility, real-time and robustness. The detection technology of infrared small targets has yet to be developed and explored.

Acknowledgments

This work has been supported by the National Natural Science Foundation of China (under grant number of 61563049).

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