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Survey on dim small target detection in clutter background: wavelet, inter-frame and filter based algorithms

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Abstract

Dim small target is an active and important research area in image processing and pattern recognition. Various algorithms have been proposed to detect and track dim small target. This paper reviews some algorithms for dim small target detection, including the wavelet based algorithms, inter-frame difference based algorithms and filter based algorithms. Also, the further development of the technologies has been briefly analyzed.

Keywords: Dim small target; target detection; clutter background; survey

1. Dim small target models

The size of dim small target is very small, and the signal intensity is very weak as well. The intensity distribution of a dim small target in an image could be well modeled by the following 2D Gaussian function [1, 14]:

$$S(x,y)=exp\{-[(x/\sigma_x)^2+(y/\sigma_y)^2]/2\}. \quad (1)$$

$S(x,y)$ is the target intensity. (x, y) represents the spatial coordinates of the target. σ_x, σ_y are horizontal and vertical extent variances, respectively.

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The observation of a random image embedded with dim small target could be modeled as [1, 14]

$$f(x,y,k)=S(x,y,k)+f_b(x,y,k)+n(x,y,k),\ k=0,1,2,\ldots, \quad (2)$$

where，f denotes an image embedded with dim small target, S represents the signal intensity of the target, f_b is the clutter background，n is the noise of image. This model is named as the SPN (Signal Plus Noise) model.

An image only consists of the target and noise [1, 14] could be obtained after subtracting the clutter background from the original image as follows.

$$f_T(x,y,k)=f(x,y,k)-f_b(x,y,k)=S(x,y,k)+n(x,y,k). \quad (3)$$

This mathematical model indicates that, ideally, the target could be correctly detected if the image background could be estimated accurately and the noise in the image could be excluded. However, in real cases, the background and noise of image are difficult to be estimated if the background is clutter and the target is dim. So, many background estimation algorithms are proposed to suppress the influence of complex background and noise, and to achieve the target enhancement and detection [1, 14-23] based on the given SPN model.

2. Some researches on dim small target detection

Effective algorithm of dim small target detection should have good performance for target recognition in single frame image and thus decrease the difficulty of target tracking in the image sequences. Therefore, research on the target detection is very important. To effectively detect the dim small target, many algorithms [1, 14-23] have been proposed, including the wavelet based algorithms, inter-frame difference based algorithms, filter based algorithms and so on.

2.1 Wavelet based algorithms

Wavelet is one of the important mathematical tools [24] in image processing, which has been widely applied in target detection [7, 23-27]. Wavelet possesses many advantages, including: (1) the ability of being able to completely reconstruct; (2) decomposing an image following the structure information to highlight the ROI (region of interest); (3) having fast computation method; (4) providing the directional sensitivity complying with human vision; (5) Being a multi-resolution analysis method, which could be used to analyze image features in different scales.

Dim small target detection based on wavelet [7, 23-27] mainly takes the advantages of the multi-scale analysis method of wavelet to discriminate the background and ROI. Image information generated by wavelet in different scales supplies the feature information that could distinguish the target and clutter background, which means that the features of the target and background at different wavelet scales are different. Based on this idea, many methods of dim small target detection in clutter background using wavelet are proposed [7, 23-27]. However, images with low SNR may affect the performance of the wavelet based algorithms.

2.2 Inter-frame difference based algorithms

Inter-frame difference [28] analyzes the moving property of target in image sequence using the absolute value of the gray value difference of two frames, which could determine the possibly moving targets. If the absolute value of the difference is less than a threshold T, there is no target; otherwise, there is target. Inter-frame difference based algorithms could be categorized into different methods following different threshold selecting ways. The simplest and easiest way is setting thresholds for each frame.

However, this way is mainly effective for images with good contrast between the foreground and background. Furthermore, it may be sensitive to the changing of the sensor or illumination. To improve the performance of inter-frame difference based algorithm, some improved inter-frame difference based algorithms are proposed, such as the hypothesis testing based algorithms [29], high order statistic based algorithms [30], self-adaptive background subtraction based algorithms [31] and so on.

Inter-frame difference algorithms based on hypothesis testing determine the possible targets and noises through developing statistic models and hypothesis testing. These algorithms detect not only the targets, but also the cavities left by the motion which are false alarms. The next problem is how to eliminate the false alarms and keep the real moving objects, which increases the difficulty of the post-processing of the algorithms.

Inter-frame difference based on high order statistic gives a rough detection and motion estimation to obtain the high order statistic of the inter-frame difference through random signal detection using the local model, but the problem of the cavity is still remained.

Inter-frame difference based on self-adapting background subtraction firstly obtains the estimated background through the averaging of consecutive images, then self-adaptively updating the estimated background by using the motion properties of the multi-frames, which could be used to detect the possible targets through subtract the estimated background from images. As these algorithms obtain the background through self-adaptively estimating the background, it is named self-adaptive background subtraction. Although the performance of the self-adaptive background subtraction is prior to that of the background subtraction based on Kalman filtering, over-lapping problem may exist in the result. Also, because of the contrast between the detected moving target and the background is small, the post-processing is still not easy.

The analysis above indicates that, inter-frame difference based algorithms may produce possible false alarms, which affects the performance of these algorithms. However, combining the superiorities of these algorithms with other methods may improve the performance of these algorithms.

2.3 Filter based algorithms

In many cases, because the target regions are dim and the sizes are small, dim small target could be recognized as the noise region which is different from the clutter background. In this situation, image background could be estimated through mage filters, and then the targets could be detected through subtracting the estimated background following equation (3). But, because there are many noises in clutter background image, the crucial part of filter based algorithms is to design a filter that could both well filter target regions and suppress noises.

The traditional mean filter and median filter perform well in some cases. But, they are sensitive to the clutter background. Maxi-mean filter [21] and max-median filter [21] designed by Deshpande based on the gray distribution characteristic of target region could suppress clutter background and detect the real target region, but they suffer the disadvantage of sensitive to the changing of parameters. To suppress the effect caused by the parameters to the filter based algorithms, Soni [15] analyses the none-parameter filter method in details. These algorithms do not very sensitive to the parameters, which could be effectively used for dim small target detection. But, very clutter background will still affect the performance of these algorithms. Various filters for dim small target detection [4, 8, 15-17, 20] have been designed based on the gray distribution difference between the target region and background regions. But, the performance of these filters is still limited in the image with very small target region or un-clear difference between the noise and target regions.

3. Conclusion and future directions

Based on the survey of some dim small target detection algorithms, most of them are based on one or several mathematical tools and have certain limitations. The key task of the dim small target detection in clutter background is detecting the real target region from the clutter background fast and efficiently. However, most of the algorithms have defects in efficiency or fastness. So, two important problems should be solved. (1) To effectively detect dim small target, the algorithms should well distinguish the noise and clutter background. (2) To fast detect dim small target, the algorithm should be simple. All of these will increase the difficulty of the dim small target detection and tracking. In conclusion, the future directions of dim small target detection are using reasonable mathematical theory, being easily implemented in hardware and having high computation efficiency, so that the algorithm would be both effective and fast.

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