International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.8, No.11 (2015), pp.255-264
http://dx.doi.org/10.14257/ijsip.2015.8.11.23

Fusion Detection Algorithm for Infrared Dim Target based on Temporal-Spatial Domain Accumulation and Difference

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Abstract

Aiming at the problem of the dim target real-time detection in Infrared search and track (IRST) systems, a fusion detection algorithm for infrared dim target based on temporal-spatial domain accumulation and difference is proposed. The proposed algorithm suppresses background and enhances targets by template filtering and difference processing in space domain, and the image sequences are processed by multi-frame energy accumulation and frame difference methods according to the target's moving characteristics in time domain. After the fusion segmentation of the temporal and spatial processing results with definite rule, the target can be detected by the relation of the possible target's position in adjoining frames according to target's moving continuity and regularity. Experimental results show that the proposed algorithm enormously increases the target's SNR after the temporal-spatial fusion enhancement, and it has high detection probability and high detecting speed. In the meantime, the algorithm is easy to realize in hardware and can be applied effectively in the real-time target detection of the IRST systems.

Keywords: *infrared dim target detection, temporal-spatial fusion, multi-frame energy accumulation, frame difference*

1. Introduction

At present, the low signal-to-noise ratio (SNR) infrared dim target detection is one of the core difficult problems of infrared search and track (IRST) systems, it always is the research hot spot and difficulty in this field [1-2]. As for IRST systems, the target is demand to possible earliest detect at a long distance (typically a few tens of kilometers or even hundreds of kilometers), since the influence of many factors such as complex battle environment, inhomogeneous atmospheric thermal radiation, internal noise of the detector, the target only about one or a few pixels in infrared images, the infrared radiation intensity is weak, so the SNR of the target is low, the target almost is submerged in clutter background, and sometimes even is lost, all these bring about great difficulties to dim target detection.

Single frame image is difficult used to detect a dim moving point target under the complex background, so the moving target detection is usually analyzed by images sequence [3]. According to whether there is a movement between the detector and the background, detection methods of the moving target are divided into the static background and moving background two cases, the main idea of these methods is general to enhance the target or suppress the background. For the case of the static background, the processing method is simpler, it can use frame difference or adaptive background cancellation method. For the case of moving background, the processing method is more complex, it firstly needs to the background moving compensation processing, and then uses frame difference or background cancellation method to detect the target. If the target

ISSN: 2005-4254 IJSIP

enhancement method is adopted, it also needs to multi-frame energy accumulation and noise suppression processing after the background moving compensation processing.

Image difference detection method has been widely applied in practice because of its simple algorithm and good real-time performance [4]. A joint temporal-spatial target extraction method of infrared images sequence is proposed by using the characteristics such as brightness and movement [5]. If the background image has been obtained, it can use spatial-temporal background differential for moving target detection [6]. With the development of the bilateral filtering technology [7], a preprocessing algorithm for IR point target detection is proposed based on adaptive neighborhood spatial-temporal bilateral filter [8].

The traditional information fusion is mainly considering the information of different space at the same time, this pure spatial fusion can be divided into five levels, namely the detection level, position level, attribute level, situation assessment and threaten estimation [9]. The pure spatial information fusion is not considering the characteristics of the target in temporal domain [9-10], so the description of the target features is not comprehensive.

In this paper, we present a fusion detection algorithm for IR dim target based on temporal-spatial domain accumulation and difference. The algorithm suppresses background and enhances targets by template filtering and difference processing in space domain, and the image sequences are processed by multi-frame energy accumulation and frame difference methods according to the target's moving characteristics in time domain. After the fusion segmentation of the temporal and spatial processing results with definite rule, the target can be detected by the relation of the possible target's position in adjoining frames according to target's moving continuity and regularity. The algorithm entirely considers the characteristics of the dim moving target in space and time domain, and it overcomes the limitations of using partial a frame image to detect the target, so as to improve the reliability of the target detection.

The paper is organized as follows. In Section 2, we describe the infrared scene model. The spatial template filtering difference processing method is given in Section 3. The temporal multi-frame energy accumulation and difference processing method is given in Section 4. In Section 5, we propose temporal-spatial fusion detection algorithm. One experiment is given in Section 6 and conclusions are drawn in Section 7.

2. Infrared Scene Model

The infrared scene image sequence $f(x, y, k)$ including dim target may be described as follows:

$$f(x, y, k) = f_T(x, y, k) + f_B(x, y, k) + n(x, y, k) \tag{1}$$

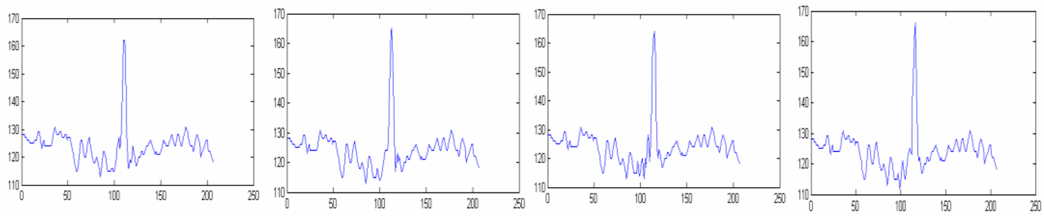
where $f_T(x, y, k)$ denotes the target image, $f_B(x, y, k)$ denotes the background image, $n(x, y, k)$ denotes the noise image, k is the frame number of image sequence. $f_B(x, y, k)$ is a two-dimensional random process with slow varying and non stationary, mean value of local gray scale may be a larger bigger changes in the background image, but it usually has longer correlation length in the image grayscale spatial distribution, and occupies the low-frequency part of spatial frequency domain in the scene image $f_T(x, y, k)$. In addition, $f_B(x, y, k)$ also contains the high frequency components in spatial frequency domain, they are mainly distributed in the edges of each homogeneous region in the background. $n(x, y, k)$ denotes the sum of all kinds of noise in the sensors and the circuits, the noises are a random distribution in spatial domain and uncorrelated to the background pixels.

IR point target is isolated from the background, which shows the singularity that the target is brighter than the background in gray scale distribution. Considering the optical diffusion effect, point target is generally expressed by the optical point spread function (PSF) as follows:

$$f_T(x, y, k) = \tau \cdot \exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\delta_x}\right)^2 + \left(\frac{y}{\delta_y}\right)^2\right]\right\} \tag{2}$$

where τ is the amplitude of the target radiation intensity, δ_x and δ_y is the spread width of the target in x、y direction respectively. The brightness and size of $f_T(x, y, k)$ have only smaller changes between adjacent frames, sometimes even the target point pixel only moves a pixel in a few frames. Since the influence of the optical diffusion, the point target is shown as isolated bright spot in each frame image.

If the target is modeled as a moving point source, the tempral features of the target can be modeled as an expansion or contraction deformation of one-dimensional varying curve, the model contains some unknown parameters, these paremeters depend on the velocity, gray scale and arrival time of the target, and the gray scale of the background. Figure 1 shows the temporal gray scale variation curves of the target pixels in IR images sequence, it can be seen that the gray scale of the pixel will appear a pulse when a moving target through a pixel. The pulse width is inverse proportional to the velocity of the target, and the pulse intensity is the gray scale of the target. The pulse difference of the target is very small between adjacent frames, so the multi-frame accumulation method of the later discussion is feasible.



(a) Frame 1 (b) Frame 2 (c) Frame 3 (d) Frame 4

Figure 1. The Gray Scale Variation Curves of the Target in IR Images Sequence

3. Spatial Processing

The gray scale of a certain point of the background can be estimated by the pixels in the related adjacent area, from above mention analysis, we can see that the background has greater spatial correlation than the target in each frame image. In this paper, the bigger size template H_1 is used for image filtering, it will be good estimation to the background image, and the small size smoothing template H_2 is used to suppress part background noises for image filtering, the difference between H_1 filtering and H_2 filtering is the results of spatial difference. The filtering templates used in this paper are as follows:

$$H_1 = \begin{bmatrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 2 & -1 & -1 & -1 \\ -1 & -1 & 2 & 15 & 2 & -1 & -1 \\ -1 & -1 & -1 & 2 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix} \quad H_2 = 0.1\begin{bmatrix} 1 & 2 & 1 \\ 2 & 2 & 2 \\ 1 & 2 & 1 \end{bmatrix} \tag{3}$$

Assume the original image is I_H, the result image is as follows:

$$I_{spatial} = \left| I_H - I_{H_2} + I_{H_1} \right| \tag{4}$$

where $I_{spatial}$ denotes the processing result of spatial difference, I_{H_1} denotes the processing result of large scale template H_1 filtering, I_{H_2} denotes the processing result of small scale template H_2 filtering.

The target is enhanced and some isolated noise points also exist after the filtering template H_1, The target signal is suppressed after the filtering template H_2, the background information is mainly obtained. Spatial difference processing suppresses the correlation of the background in spatial domain, and the target is enhanced.

4. Temporal Processing

From the above analysis, the background movement between adjacent frames is very small for IR images sequence, so it is relatively negligible and regarded as stationary with that of the dim moving target, and the difference of dim target is also very small between adjacent frames. Therefore, we adopt the method of combining two frames accumulation with three frames difference in temporal domain in this paper.

For the actual IR images sequence, an enough high frame rate will ensure that there is little variation for the movement and the difference of the target and the background between adjacent frames, such hardware condition is of immense benefit to suppress the Gaussian white noise of IR images sequence. Multi-frame energy accumulation is an effective method to improve the image SNR and suppress the noise interference [11]. Usually the stationary part (such as the background) of the original images sequence does not change in the frame average image obtained, but the noise will be weakened because of multi-frame accumulation. Furthermore, because the velocity of the dim moving target is generally much lower than the frame rate, so multi-frame energy accumulation can enhance the energy of dim point target images sequence object, thus achieve the aim of improving the image SNR. The first L frame images are energy accumulated and averaged to obtain the average image, the SNR of the *i*-th frame image may be increased by $\sqrt{L}$ times, with the increase of adjacent frames number for energy accumulation, the SNR of obtained images will continue to improve.

There are two main categories of traditional image difference method. The first category is that making image difference between each frame of images sequence and a stationary reference frame, this condition is hard to satisfy for IRST. Another category is that firstly making difference between adjacent frames, then binaryzation is work on the difference image to extract the movement information of the target. However, this method also has many disadvantages, one is that a portion of the target is only detected, the overlapping part of adjacent two frames is not detected, and another one is that the detected target is much larger than the real. Here, an improved three frames difference method [12] is applied to overcome the disadvantages of traditional difference method.

The algorithm process is shown in Figure 2.

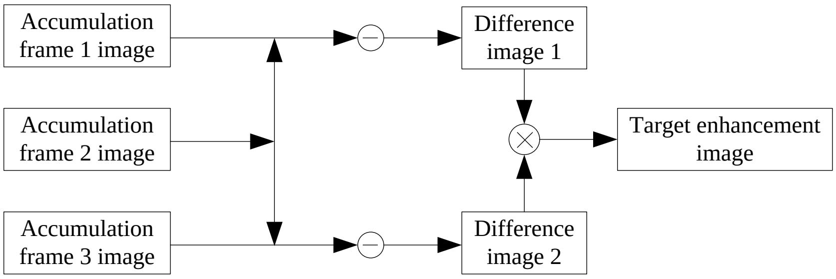


Figure 2. Process of Three Frames Difference Method

The main idea of three frames difference method is the difference processing between frame 1 and frame 2, the difference processing between frame 2 and frame 3, and so on. Assume the original images have M frames, after the two steps processing, the number of image frames reduces two frames, so the image frames of subsequent processing is M-2 frames. Because the IR detector now can take dozens of image frames per second, so two frames reduction has not a great influence on the overall results for multi-frame images processing. After the temporal difference processing, on the one hand the clutter background can be greatly reduced, on the other hand, part of the correlation can also be removed, and the processed image is closer to the moving target image under white noise background, so as to increase the probability of target detection.

5. Temporal-Spatial Fusion Processing

Spatial processing and temporal processing are regarded as two independence process, The algorithm suppresses background and enhances targets by template filtering and difference processing in space domain, and the processed images mainly contain the target's moving characteristics of adjacent frames by two frames accumulation and three frames difference in time domain. Fusion detection entirely considers the characteristics of the dim moving target in space and time domain, it overcomes the limitations of using partial a frame image to detecting the target, so as to improve the SNR of dim moving point target and reduce the false alarm rate (FAR). The process of temporal-spatial fusion detection algorithm is shown as Figure 3.

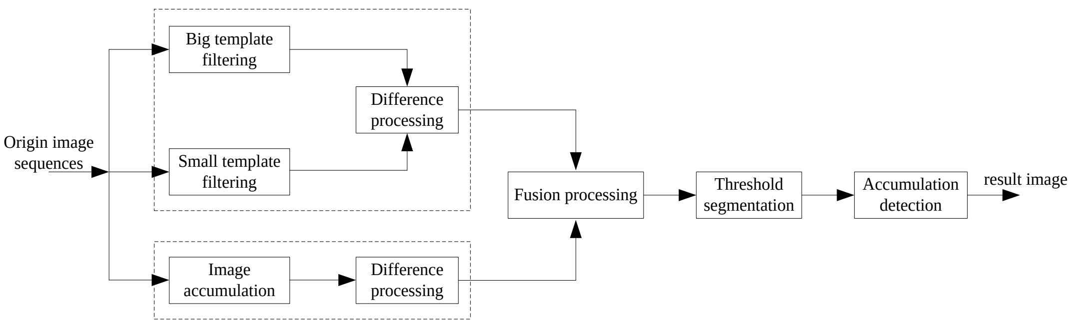


Figure 3. Process of Temporal-Spatial Fusion Detection Algorithm

Assume the images after spatial and temporal processing are $I_{spatial}(x, y, i)$ and $I_{temporal}(x, y, i)$ respectively, the fusion detection algorithm mainly consists of three steps as follows:

Step 1: $I'_{spatial}(x, y, i)$ and $I'_{temporal}(x, y, i)$ are obtained by the contrast enhancement processing for $I_{spatial}(x, y, i)$ and $I_{temporal}(x, y, i)$ respectively.

$$I'(x,y,i) = \begin{cases} 1 & I(x,y,i) > \mu + k\sigma \\ 0.5 + \dfrac{I(x,y,i) - \mu}{2k\sigma} & \mu - k\sigma < I(x,y,i) < \mu + k\sigma \\ 0 & I(x,y,i) < \mu - k\sigma \end{cases} \tag{5}$$

where μ is the mean value of $I(x, y, i)$, σ is the standard deviation of $I(x, y, i)$, k is an adjustment factor, k =3~10.

Step 2: according to the processing results of step 1, the new images sequence $I''(x, y, i)$ are obtained by temporal-spatial fusion with definite rule, the fusion rule in this paper is as follows:

$$I''(x,y,i) = \left[I'_{spatial}(x,y,i) \cdot I'_{temporal}(x,y,i)\right]^{1/2} \tag{6}$$

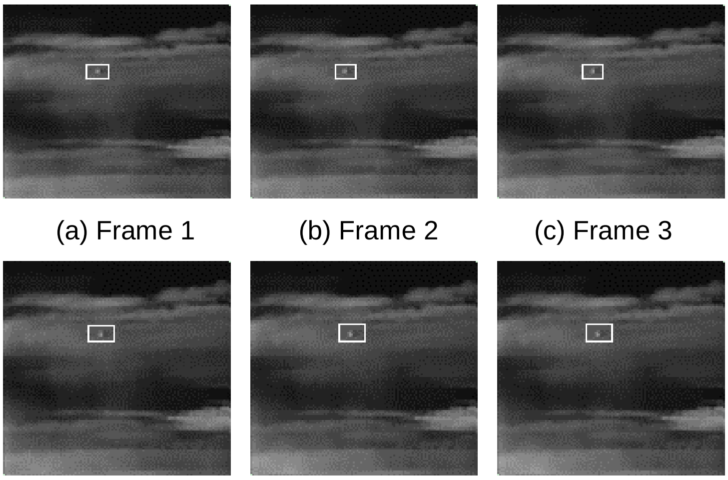
Step 3: the binaryzation images sequence $I'''(x, y, i)$ are obtained by image segmentation for the images sequence $I''(x, y, i)$, so the bright points of the images are candidate target points, the binaryzation formula is as follows:

$$I'''(x,y,i) = \begin{cases} 1, & I''(x,y,i) \ge T \\ 0, & I''(x,y,i) < T \end{cases} \tag{7}$$

where T is the threshold.

6. Experiment and Analysis

The experiment selects IR moving dim target images sequence under cloud background to proving the algorithm. The size of the image is 256×256 pixels, because of the optical diffusion effect, the target is shaped about 1~3 pixels and has a linear motion velocity of 0~2 pixels/ frame, the image SNR is about 2. The original 6 frame images are shown in Figure 4.

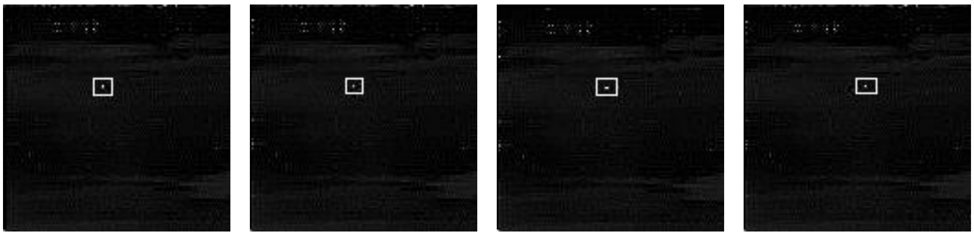


(a) Frame 1 (b) Frame 2 (c) Frame 3

(d) Frame 4 (e) Frame 5 (f) Frame 6

Figure 4. Original 6 Frame Images

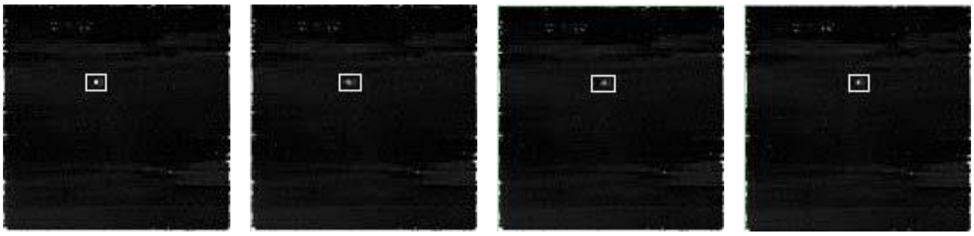
The original images are filtered by the template H_1 and the template H_2 respectively, then the filtered images are processed by spatial difference, the results of spatial difference processing are shown in Figure 5. It can be seen that the noises of background image are weakened, the target is also weakened, but the image SNR is increased. Moreover, the target of some image is not too obvious after spatial difference processing, so which requires making further processing on the target detection by subsequent temporal difference.



(a) Frame 1 (b) Frame 2 (c) Frame 3 (d) Frame 4

Figure 5. Spatial Difference Processing Results

The target has been enhanced after temporal accumulation, but the noise also has been increased, both the gray scale of the target and background are enhanced, resulting in the SNR of the image decreased, which requires subsequent three frames difference processing. The results of temporal difference processing are shown in Figure 6.



(a) Frame 1 (b) Frame 2 (c) Frame 3 (d) Frame 4

Figure 6. Temporal Difference Processing Results

From Figure 6, we can see that the target has been enhanced by difference processing, but the noises of the background and bright points already exist in the image. 4 frame images of spatial and temporal difference processing respectively are used to image fusion, and then the target flight trajectory is obtained by threshold segmentation and superposition processing for fusion images. The results of the IR sequence fusion detection are shown in Figure 7.

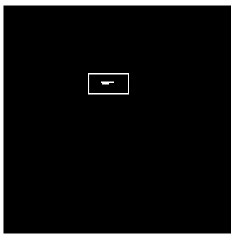
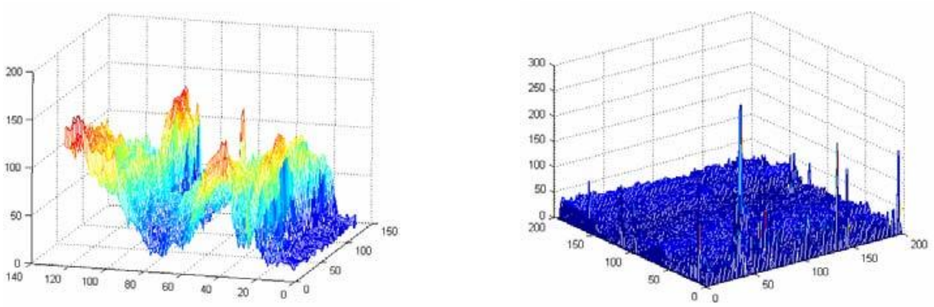


Figure 7. Fusion Detection Image

The gray scale distribution of a certain frame image is shown in Figure 8. As can be seen from Figure 8, the influence of the background to the target is larger before fusion, if the image is direct segmented, there will be many false targets. The target is already evident after spatial differential fusion processing, and the target can be detected by threshold segmentation.



(a) Gray Scale Distribution Before Fusion (b) Gray Scale Distribution After Fusion

Figure 8. Gray Scale Distribution of a Certain Image

7. Conclusion

The experiment results show that the algorithm can obtain good result toward low SNR IR images sequence under complex background, the algorithm have high detection probability and low false alarm probability. In the meantime, the algorithm is easy to realize in hardware and can be applied effectively in the real-time target detection of the IRST systems. The following conclusions can be drawn. Firstly, the algorithm considers the isolated spot characteristics of dim moving target in a single frame image and the motion characteristics of the target in adjacent frames, IR images sequence are processed to effectively detect the target by temporal-spatial fusion and segmentation. Secondly, temporal-spatial fusion filtering method can effectively detect low SNR moving target under complex background, but it can be seen that there will be false detection situation for a single frame image from the detection results, so it needs to handle this problem from the motion characteristics of multi-frame images. Thirdly, there may be some clutter pixels in images sequence, their temporal gray scale are very similar to the target's in the process of image processing, so it's on the cards that these clutter pixels may produce false alarm. It must be emphasized that this algorithm is effective under the condition of the background remaining constant or changing very slowly. If the background changes very quickly, this algorithm is not suitable for the dim moving target detection. In the next step of research, how to detect the dim moving target under the rapidly variation background is to be considered.

Acknowledgments

This work was supported by the Nature Scientific Fundamental Research Program funded by Shaanxi Provincial Education Department (No. 2012JM8020). We want to thank the helpful comments and suggestions from the anonymous reviewers.

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