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Infrared moving point target detection based on spatial–temporal local contrast filter

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HIGHLIGHTS

- A novel spatial local contrast (SLC) is defined.
- A novel temporal local contrast (TLC) is defined.
- A simple but powerful spatial–temporal local contrast filter (STLCF) is proposed.
- STLCF has great superiority in detecting infrared moving point target.

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ABSTRACT

Infrared moving point target detection is a challenging task. In this paper, we define a novel spatial local contrast (SLC) and a novel temporal local contrast (TLC) to enhance the target's contrast. Based on the defined spatial local contrast and temporal local contrast, we propose a simple but powerful spatial–temporal local contrast filter (STLCF) to detect moving point target from infrared image sequences. In order to verify the performance of spatial–temporal local contrast filter on detecting moving point target, different detection methods are used to detect the target from several infrared image sequences for comparison. The experimental results show that the proposed spatial–temporal local contrast filter has great superiority in moving point target detection.

1. Introduction

Infrared point target detection is a very important application in military, surveillance and astronautics [1–3]. When the imagery distance is far, the target in the image always appears as a dim small speckle embedded in a heavy cluttered background. Under these conditions, there have no available feature information like shapes, scales, colors and textures but the unknown intensity and motion velocity to use for target detection. Therefore, moving point target detection is a challenging task, especially detection from complicated backgrounds. To solve this problem, researchers have developed many robust methods [4,5]. Generally, the target detection methods can be approximately divided into two classes: the method based on single frame image and that based on image frames sequence.

Most of the methods based on single frame image are always using spatial filter techniques. One of classical method is two dimensional least mean square (TDLMS) filter proposed by Hadhoud [6], which predicts the pixel intensity using the weighted intensity of nearby pixels, and the performance of TDLMS adaptive filters on small target detection is estimated in [7]. Based on TDLMS filter, some modified filters are proposed, such as two-dimensional block diagonal least mean square (BDLMS) method [8], 2D adaptive lattice algorithm (2D AL) [9], TDLMS filter based on neighborhood analysis [10], mask-weighted TDLMS method [11], Edge directional 2D LMS filter [12] and Bilateral 2D LMS filter [13]. In addition, some other methods are also proposed. Max-mean and Max-median filters was proposed [14], which can preserve the edges of clouds and structural backgrounds to help detect small target, but the methods cannot get good effectiveness on detecting small target from infrared sequences when the contrast of target and background is low. Qi et al. [15] presented a robust directional saliency based method (DSBM) for infrared small target detection inspired by visual effect of human eyes

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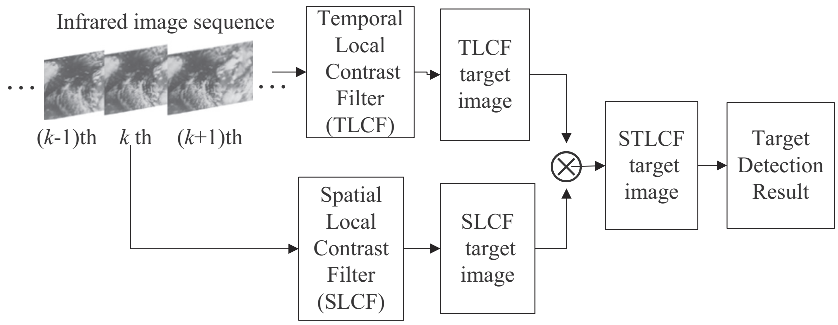

Fig. 1. The flow diagram of STLCF for detecting moving point target.

between a small target and backgrounds, and Han et al. [16] also proposed a detection method based on human visual system. Some detection method based on information entropy are also proposed, such as the adaptive Butterworth high-pass filter (BHPF) based on the weighted information entropy of the image [17] and the method based on fast local reverse entropy operator [18], which are robust to restrain the clutter. However, most of spatial filter methods are based on the assumption that the target has a larger intensity than the background. Then the assumption is not always reasonable, since many other objects may have higher gray levels than the targets.

The methods based on frame sequences have been frequently applied to moving target detection, which can make use of temporal information and spatial information simultaneously. This kind of methods always contain two types: multi-step processing and three-dimensional (3D) spatial–temporal processing. The former often consist of some spatial processing in each single frame followed by some temporal processing, while the latter treat multiple frames in a image sequence as a whole, and detect the small target in the 3D spatial–temporal space. The classical 3-D match filter based on a mix process [19] has an excellent detection performance for point targets with known constant velocity in white noise-dominated scenario. A three-dimensional double directional filter is used to detect target in infrared cluttered background [20], and a directional matched filter proposed by Tartakovesky and Brown [21] is also an effective adaptive spatial–temporal technique for clutter suppression. In Ref. [22], authors extended the traditional anisotropic diffusion model into a spatial–temporal processing model, and proposed a 3-D spatial–temporal anisotropic diffusion clutter suppression method for moving point target detection. A spatial and temporal infrared target detection method using spatial bilateral filter and temporal cross product (BF–TCP) in infrared images is proposed [23], which takes advantage of the effectiveness of the bilateral filter on preserving edge details of the background. In Ref. [24], a bidirectional local binary pattern coding is proposed to suppress clutter and for detecting moving point target, then a spatial temporal local increment coding (STLIC) is also proposed [25]. The detection method based on temporal profile are also proposed [26] for detecting small moving infrared target. Most of these methods always depend on the assumptions that some information is consistent between frames or is known in advance, such as velocity of targets. However, it is hardly be obtained in real applications.

Recently, the local contrast operator as one of the most efficient tool is applied to detect infrared small target and obtains good results [27,28]. For a small or point target, local contrast operator can enhance the target effectively. Therefore in this paper, we define a novel spatial local contrast (SLC) and a temporal local contrast (TLC) to enhance the target's contrast, and by combining the spatial and temporal local contrast information present a spatial–temporal local contrast filter (STLCF) to obtain better target detection performance.

The remainder of this paper is organized as follows. Section 2 describes spatial–temporal local contrast filter used for detect small target in detail. In Section 3, we verify the merits of STLCF by detecting point target from infrared image sequences. Section 4 draws the final conclusions.

2. Theory and method

Generally speaking, the region where the target is located is different from its neighborhood, despite sometimes the discrimination between the target and the area of the neighborhood is not obvious. It means that the target is different in a spatial local region. Furthermore, for a moving point target, the target's position is different in the different frames, but the background is similar. Namely, the target is also different in temporal local range. Therefore, we define a new spatial local contrast (SLC) and a new temporal local contrast (TLC) to enhance the target contrast firstly, and then propose a spatial–temporal local contrast filter by combine the SLC and TLC information to improve the target detection performance.

The flow diagram of spatial–temporal local contrast filter (STLCF) used to detect infrared point target is shown as Fig. 1. The whole process includes the following steps: (1) calculating the temporal local contrast (TLC) and spatial local contrast (SLC); (2) calculating spatial–temporal local contrast according to the results of TLC filtering and SLC filtering; and (3) based on the STLCF map, detecting the target by setting a threshold.

2.1. Temporal local contrast

Let $\ldots, I_{k-1}, I_k, I_{k+1}, \ldots$ be a infrared image sequences, the size of each frame is $R \times C$, and $f(i,j,k)$ represents the intensity of (i,j) $(1 \leqslant i \leqslant R,\ 1 \leqslant j \leqslant C)$ pixel at the kth frame. Let $C_t(i,j,k)$ denote the temporal local contrast at (i,j,k) pixel, and we define it as

$$C_t(i,j,k) = |f(i,j,k) - m_t(i,j,k)| \quad (1)$$

where $|*|$ denotes absolute value symbol, which makes the C_t is non-negative. $m_t(i,j,k)$ is the mean intensity of the pixels at the temporal local range, and it is defined as

$$m_t(i,j,k) = \frac{1}{N_k}\sum_{n=1}^{N_k/2}[f(i,j,k-n) + f(i,j,k+n)] \quad (2)$$

where N_k is a even and denotes the number of the frames which is used for calculating temporal local contrast. It is noted that the pixel at the kth frame is excluded when calculating $m_t(i,j,k)$.

From Eq. (1) we can find that, the temporal local contrast is obtained by the difference between the intensity of (i,j) pixel at the kth frame and the mean intensity of its neighbor N_k frames. Due to the position of moving target is different in the different frames, C_t map will make the target's contrast enhance, it can be seen clearly by comparing Fig. 2(B) and (C).

2.2. Spatial local contrast (SLC)

As mentioned above, the region where the target located is always different from its neighborhood. Therefore, we define the spatial local contrast as

$$C_s(i,j,k) = |f(i,j,k) - m_s(i,j,k)| \tag{3}$$

where $m_s(i,j,k)$ is the mean intensity of spatial local image patch $p(i,j,k)$ at kth frame except pixel (i,j,k), and it is defined as

$$m_s(i,j,k) = \frac{s(i,j,k)}{w^2 - 1} \tag{4}$$

where $s(i,j,k)$ is the sum intensity of spatial local image patch $p(i,j,k)$ frame except pixel (i,j,k), and the size of the patch $p(i,j,k)$ is $w \times w$. The target's contrast will be enhanced in C_s map, it can be seen clearly by comparing Fig. 2(B) and (D).

2.3. Spatial–temporal local contrast filter (STLCF)

The spatial–temporal local contrast filter is defined as

$$I_{st}(i,j,k) = I_t(i,j,k) \times I_s(i,j,k) \tag{5}$$

where

$$I_t(i,j,k) = \frac{C_t(i,j,k)}{\max_{i,j}\{C_t\}} \tag{6}$$

$$I_s(i,j,k) = \frac{C_s(i,j,k)}{\max_{i,j}\{C_s\}} \tag{7}$$

Fig. 2 gives an example of the effectiveness of TLC, SLC and STLC filter on enhancing target's contrast. Fig. 2(A) and (B) are the original infrared image and the corresponding 3D map, respectively. The target in Fig. 2(A) is marked with red border. Fig. 2(C)–(E) are the corresponding results of TLC, SLC and STLC. By comparing Fig. 2(C)–(E) with Fig. 2(B), we can find that using TLC and SLC filter can improve the contrast of target, then using STLC filter can improve more obviously than using TLC and SLC filter. After getting the spatial–temporal local contrast map I_{st}, the target can be detected by setting a threshold T.

3. Experimental results

It is known that the reliability of detection target mainly depends on the results of spatial–temporal local contrast filtering,

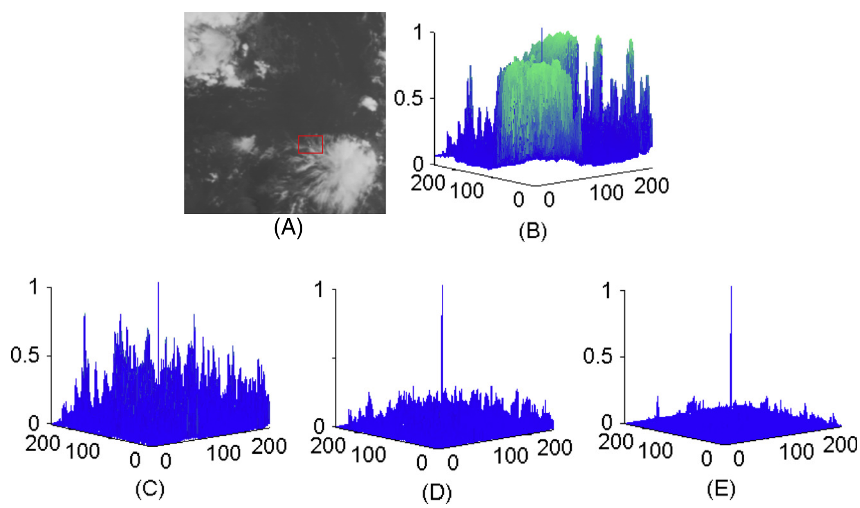

Fig. 2. An example of calculating TLC, SLC and STLC. (A) Original infrared image, (B) the 3D map of the original infrared image, (C) result of TLC, (D) result of SLC, and (D) result of STLC.

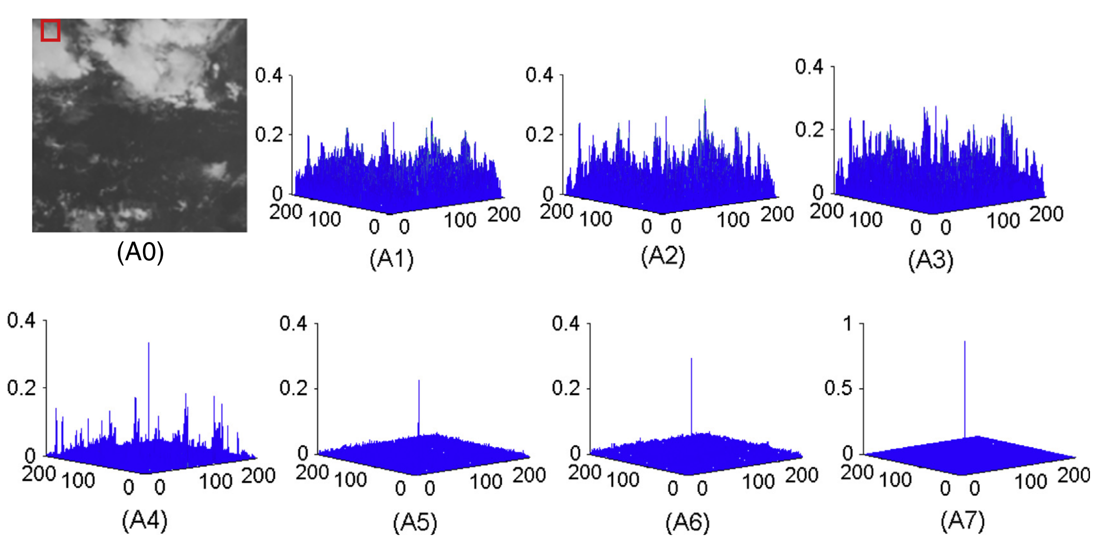

Fig. 3. Detection results of image (A0) using different methods. (A0) Original infrared image, (A1) detection result of MaxMean method, (A2) detection result of MaxMedian method, (A3) detection result of BHPF method, (A4) detection result of BF–TCP method, (A5) detection result of STLIC method, (A6) detection results of TCF method, and (A7) detection result of STLCF method.

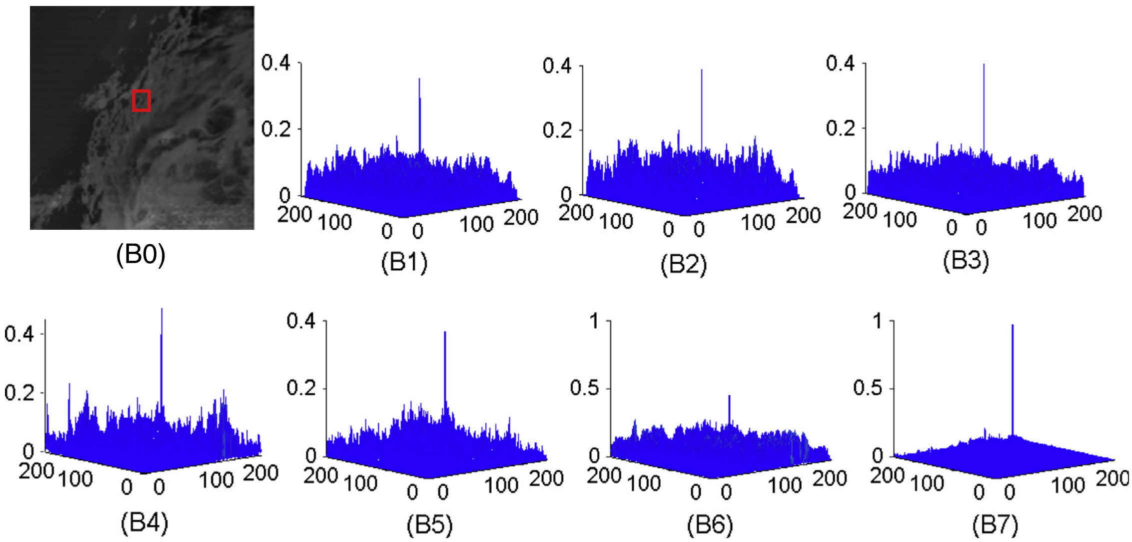

Fig. 4. Detection results of image (B0) using different methods. (B0) Original infrared image, (B1) detection result of MaxMean method, (B2) detection result of MaxMedian method, (B3) detection result of BHPF method, (B4) detection result of BF–TCP method, (B5) detection result of STLIC method, (B6) detection result of TCF method, and (B7) detection result of STLCF method.

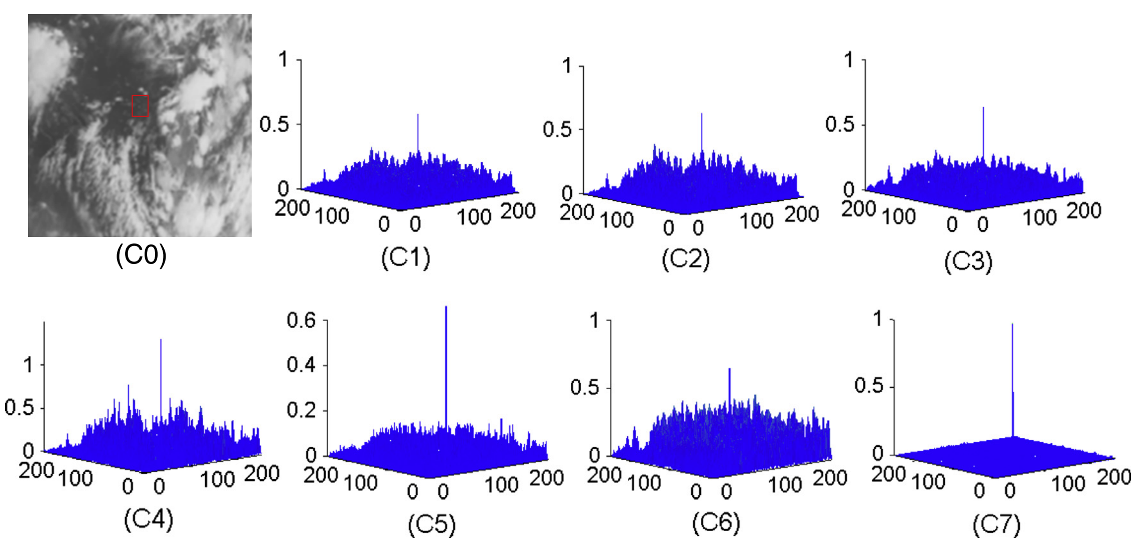

Fig. 5. Detection results of image (C0) using different methods. (C0) Original infrared image, (C1) detection result of MaxMean method, (C2) detection result of MaxMedian method, (C3) detection result of BHPF method, (C4) detection result of BF–TCP method, (C5) detection result of STLIC method, (C6) detection result of TCF method, and (C7) detection result of STLCF method.

so the performance of STLCF method on detecting target can be verified by testing the merits of I_{st} obtained by using spatial–temporal local contrast filter. In the following test, the experimental data are obtained through simulations. Firstly, acquiring background image from actual infrared image frame sequences; then simulating moving point target as point-like using one or several pixels, and adding its energy to background images to get the experimental images. For simplicity, it is assumed that only one target exists in each image frame sequence. In order to verify the robustness of the proposed method, we will test four infrared image frame sequences, and the size of each frame image in each sequence is 256×256 pixels. For comparison, we use different methods to detect the target from each frame sequence, and one of frame will be selected from the each detection result sequence for showing in figures.

Figs. 3(A0), 4(B0), 5(C0) and 6(D0)[1] are four frame images selected from the four infrared image sequences, the targets are marked with red border. In test, Max-mean and Max-median methods [14], BHPF [17], BF–TCP [23], STLIC [25], TCF [28] and the proposed STLCF method are used to detect the targets.

The detection results of Figs. 3(A0), 4(B0), 5(C0) and 6(D0) using the seven methods are shown in Figs. 3–6, respectively. From the detection results of the four image sequences, we can find that the proposed STLCF method can suppress clutter more effectively than other methods. Namely, STLCF can obtain greater reliability on detecting target than other methods.

In order to compare the performance of above methods objectively, two metrics, signal-to-clutter ratio gain (SCRG) and the background suppression factor (BSF) [29], are evaluated:

$$\mathrm{SCRG} = \frac{(S/C)_{\mathrm{out}}}{(S/C)_{\mathrm{in}}} \tag{8}$$

$$\mathrm{BSF} = \frac{C_{\mathrm{in}}}{C_{\mathrm{out}}} \tag{9}$$

[1] For interpretation of color in Figs. 4–6, the reader is referred to the web version of this article.

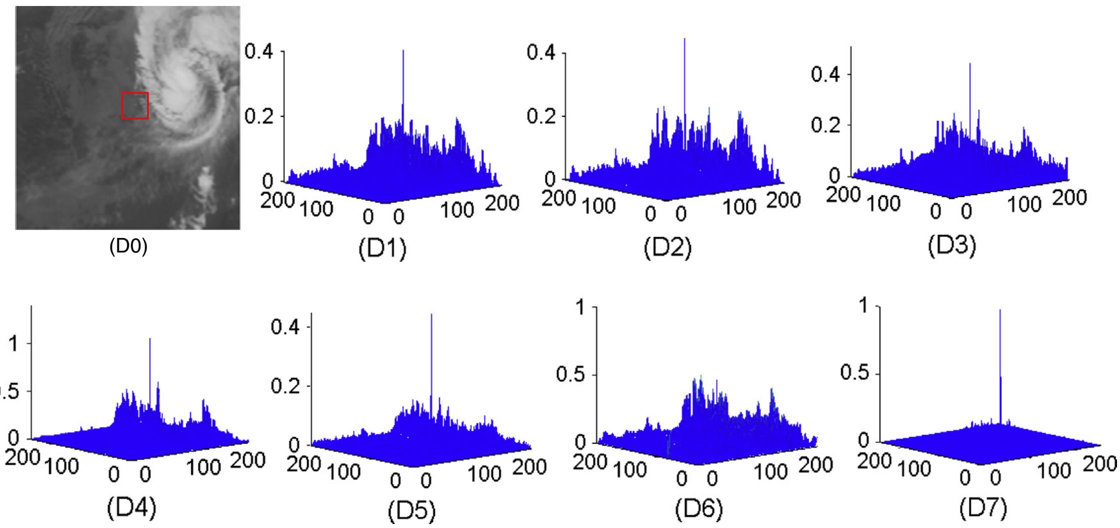

Fig. 6. Detection results of image (D0) using different methods. (D0) Original infrared image, (D1) detection result of MaxMean method, (D2) detection result of MaxMedian method, (D3) detection result of BHPF method, (D4) detection result of BF–TCP method, (D5) detection result of STLIC method, (D6) detection result of TCF method, and (D7) detection result of STLCF method.

Table 1
Comparison of target detection performance of different methods.

Methods		(A0)	(B0)	(C0)	(D0)
MaxMean	SCRG	1.9750	2.2046	3.0030	3.8596
	BSF	6.5928	4.1212	5.0020	8.1219
MaxMedian	SCRG	2.4668	2.2954	3.1010	4.5199
	BSF	7.7353	3.9318	4.7351	8.6468
BHPF	SCRG	2.3447	2.7174	3.6068	4.6389
	BSF	7.0526	4.5370	5.5017	8.8528
BF–TCP	SCRG	14.0905	3.0787	3.9357	6.9488
	BSF	37.0998	4.1841	2.9503	5.5697
STLIC	SCRG	15.9353	4.3431	7.6848	10.0693
	BSF	56.5475	7.8050	11.3601	19.1926
TCF	SCRG	16.5045	1.8111	2.1058	2.8418
	BSF	47.1027	2.5682	3.1220	5.0829
STLCF	SCRG	411.7082	37.1617	89.5347	113.6226
	BSF	410.0937	25.2117	89.5347	98.0273

where S is the signal amplitude and C is the clutter standard deviation, and C_{in} and C_{out} are the clutter standard deviation of the input image and the output image, respectively.

Table 1 gives the evaluated values of SCRG and BSF corresponding to the target detection results shown in Figs. 3–6. From the objective comparison results of Table 1, we can find that the proposed STLCF method can get much greater SCRG and BSF than the other methods. In other words, on point-like target detection, the proposed STLCF method has obvious superiority over other methods under the same circumstance.

4. Conclusion

This paper proposes a new simple but powerful spatial–temporal local contrast filter for detecting moving point target. Firstly, a novel temporal local contrast and a novel spatial local contrast are proposed, and based on them, a spatial–temporal local contrast filter (STLCF) is presented. The process of using STLCF method to detect moving point target is demonstrated, and the performance is verified by detecting target from different image sequences. The experiment results indicate that STLCF method has great superiority in detecting infrared moving point target.

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References

[1] L. Liu, N. Sang, R. Huang, Background subtraction using shape and colour information, Electron. Lett. 46 (1) (2010) 41–42.
[2] C. Gao, N. Sang, R. Huang, Biologically inspired scene context for object detection using a single instance, PLoS ONE 9 (5) (2014) e98447.
[3] C. Yang, J. Ma, S. Qi, J. Tian, S. Zheng, X. Tian, Directional support value of Gaussian based infrared small object detection, Appl. Opt. 54 (9) (2015) 2255–2265.
[4] H. Zhu, T. Zhang, L. Deng, Indirect target detection method in FLIR image sequences, Infrared Phys. Technol. 60 (2013) 15–23.
[5] C. Gao, D. Meng, Y. Yang, Y. Wang, X. Zhou, A. Hauptmann, Patch-image model for small target detection in a single image, IEEE Trans. Image Process. 22 (12) (2013) 4996–5009.
[6] M.M. Hadhoud, D.W. Thomas, The two-dimensional adaptive LMS (TDLMS) algorithm, IEEE Trans. Circ. Syst. 35 (5) (1988) 485–494.
[7] T. Soni, J.R. Zeidler, W.H. Ku, Performance evaluation of 2D adaptive prediction filters for detection of small objects in image data, IEEE Trans. Image Process. 2 (3) (1993) 327–340.
[8] M.R. Azimi-Sadjadi, H. Pan, Two-dimensional block diagonal LMS adaptive filtering, IEEE Trans. Signal Process. 42 (9) (1994) 2420–2429.
[9] P.A. Ffrench, J.R. Zeidler, W.H. Ku, Enhanced detectability of small objects in correlated clutter using an improved 2D adaptive lattice algorithm, IEEE Trans. Image Process. 6 (3) (1997) 383–397.
[10] Y. Cao, R. Liu, J. Yang, Small target detection using two-dimensional least mean square (TDLMS) filter based on neighborhood analysis, Int. J. Infrared Millimeter Waves 29 (2) (2008) 188–200.
[11] T.W. Bae, Y.C. Kim, S.H. Ahn, K.I. Sohng, An efficient two-dimensional least mean square (TDLMS) based on block statistics for small target detection, J. Infrared Millimeter Terahertz Waves 30 (10) (2009) 1092–1101.
[12] T.W. Bae, F. Zhang, I.S. Kweon, Edge directional 2D LMS filter for infrared small target detection, Infrared Phys. Technol. 55 (1) (2012) 137–145.
[13] Y. Zhao, H. Pan, C. Du, Y. Peng, Y. Zheng, Bilateral two-dimensional least mean square filter for infrared small target detection, Infrared Phys. Technol. 65 (2014) 17–23.
[14] S. Deshpande, M. Er, V. Ronda, P. Chan, Max-mean and max-median filters for detection of small-targets, Proc. SPIE 3809 (1999) 74–83.
[15] S. Qi, J. Ma, C. Tao, C. Yang, J. Tian, A robust directional saliency-based method for infrared small-target detection under various complex backgrounds, IEEE Geosci. Rem. Sens. Lett. 10 (2013) 495–499.

[16] J. Han, Y. Ma, B. Zhou, F. Fan, K. Liang, Y. Fang, A robust infrared small target detection algorithm based on human visual system, IEEE Geosci. Rem. Sens. Lett. 11 (12) (2014) 2168–2172.
[17] L. Yang, J. Yang, K. Yang, Adaptive detection for infrared small target under sea–sky complex background, Electron. Lett. 40 (2004) 1083–1085.
[18] H. Deng, Y.T. Wei, M.W. Tong, Background suppression of small target image based on fast local reverse entropy operator, IET Comp. Vis. 7 (5) (2013) 05–413.
[19] I. Reed, R. Gagliardi, L. Stotts, Optical moving target detection with 3-D matched filtering, IEEE Tans. Aerosp. Electron. Syst. 24 (4) (1988) 327–336.
[20] M. Li, T. Zhang, W. Yang, X. Sun, Moving weak point target detection and estimation with three-dimensional double directional filter in IR cluttered background, Opt. Eng. 44 (2005). 107007-1C4.
[21] A.G. Tartakovsky, J. Brown, Adaptive spatial–temporal filtering methods for clutter removal and target tracking, IEEE Tans. Aerosp. Electron. Syst. 44 (4) (2008) 1522–1537.
[22] X. Sun, T. Zhang, L. Yan, M. Li, Clutter suppression method based on spatiotemporal anisotropic diffusion for moving point target detection in IR image sequence, J. Infrared Milli Terahz Waves 30 (2009) 496–512.
[23] T. Bae, Small target detection using bilateral filter and temporal cross product in infrared images, Infrared Phys. Technol. 54 (2011) 403–411.
[24] Z. Cheng, T. Zhang, L. Yan, X. Wang, Clutter suppression algorithm based on bidirectional local binary pattern for moving point target detection in infrared image sequences, Opt. Eng. 49 (10) (2010) 107005.
[25] L. Deng, H. Zhu, Moving point target detection based on clutter suppression using spatial temporal local increment coding, Electron. Lett. 51 (8) (2015) 625–626.
[26] D. Liu, J. Zhang, W. Dong, Temporal profile based small moving target detection algorithm in infrared image sequences, Int. J. Infrared Millimeter Waves 28 (5) (2007) 373–381.
[27] C.L.P. Chen, H. Li, Y. Wei, T. Xia, Y. Yan Tang, A local contrast method for small infrared target detection, IEEE Trans. Geosci. Rem. Sens. 52 (1) (2014) 574–581.
[28] S. Kim, S.-G. Sun, K.-T. Kim, Highly efficient supersonic small infrared target detection using temporal contrast filter, Electron. Lett. 50 (2014) 81–83.
[29] C.I. Hilliard, Selection of a clutter rejection algorithm for real-time target detection from an airborne platform, Proc. SPIE (2000) 74–84.