Infrared moving dim point target detection based on spatial-temporal local contrast

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Abstract. Aiming at the detection of dim and small moving point targets in space-based infrared (IR) imaging systems, a detection method based on spatial-temporal local contrast (STLC) is presented. Firstly, use the spatial and temporal information to estimate the background gray value of each pixel, and obtain two prediction results respectively. Then, the spatial local contrast (SLC) and the temporal local contrast (TLC) are defined according to the original image and two estimated backgrounds. Next, the STLC is defined as the product of SLC and TLC. Finally, a threshold value is set in the STLC for target detection. Four groups of experiments are conducted, and the simulation results indicate that the proposed method has a great advantage in terms of background suppression factor (BSF) and gain of signal-to-noise (GSNR).

1. Introduction
IR detection of dim and small moving point targets plays an important role in many space-based applications such as early warning, space surveillance system and so on. Because of the long observation distance, the target always appears as a moving dark spot in the IR image. There are no distinguishable features that can be extracted, such as texture and shape. The only available information is the gray information and motion information of the target. Therefore, this issue has been a huge challenge for a long time.

To solve this problem, many approaches have been proposed during last decades. For example, Li et al. proposed a spatiotemporal saliency model to detect the moving IR dim target [1]. Lu et al. presented a detection method by a double sparse background dictionary which is learned online [2]. Zhang et al. and Zhou et al. proposed modified sparse representation methods to achieve IR small target detection [3, 4]. Ju et al. presented a method based on an efficient end-to-end network [5]. Wang et al. used a fully convolutional neural network and graph matching for low-altitude IR target detection [6]. Zhang et al. proposed a method by using zero-crossing saliency map to detect IR small targets, which achieves a good performance in clutters suppression [7]. In general, these novel approaches based on sparse representation or networks can obtain good performance in IR small target detection, but there are many problems in real applications because of the following two reasons: highly depend on the training data set and computational complex.

In recent years, the local contrast method was always employed for detecting IR dim small targets and obtained good performance [8-12]. In this paper, a simple STLC is defined using both the intra-frame and inter-frame information of the IR images. Four groups of experiments are conducted to verify the detection performance of our proposed algorithm.
2. Methods

Figure 1 shows the structure of our proposed algorithm. The algorithm mainly contains three steps: (1) calculating TLC according to temporal information, (2) calculating SLC according to spatial information and (3) calculating STLC due to TLC and SLC. The three steps will be respectively discussed in detail in this section.

![Diagram of the calculation process of STLC.](image-url)

**2.1. SLC**

Firstly, the intensity value of IR background is estimated using the intra-frame information to obtain the spatial predicted background (SB). A central patch $P_C$ of size $N \times N$ is defined around the central pixel. Eight neighboring patches $\{P_t^S\} t=1,2,\ldots,8$ of the same size are defined around the central patch, as shown in Fig. 2. The patch size $N$ should be larger than the target size. In space based IR images, the missile target is always smaller than 3 pixels $\times$ 3 pixels, thus $N$ is fixed at 3. The spatial predicted background of the pixel $(i, j)$ in $k$th frame is described as

$$SB(i, j, k) = \text{med}\{L_t^S\} t=1, 2, \ldots, 8$$

(1)

where $\text{med}\{\ast\}$ denotes the median operation, $L_t^S$ represents the average intensity of the neighboring patch $P_t^S$.

After obtaining the SB, the SLC is simply defined as:

$$SLC(i, j, k) = \frac{F(i, j, k)}{SB(i, j, k)} \times |F(i, j, k) - SB(i, j, k)|$$

(2)

where $|\ast|$ represents the absolute value symbol, $F(i, j, k)$ is the observed value of the pixel $(i, j)$ in $k$th frame.
2.2. TLC
Time difference method is widely employed to detect moving point target in many real applications. However, there is a major limitation of this method. If the target moves too slowly, it will be misjudged as a background and will be missed. On the contrary, if the target moves too fast, there will be two candidate targets in the difference image. To overcome the problem, we present a novel background prediction method using the inter-frame information. Let $TB(i, j, k)$ denote the temporal predicted background of the pixel $(i, j)$ in $k$th frame, defined as

$$TB(i, j, k) = \frac{1}{2(b+1)} \sum_{n=a}^{b} (F(i, j, k-n) + F(i, j, k+n))$$  \hspace{1cm} (3)$$

The parameter $a$ is negatively correlated with the target velocity, i.e., if the target moves fast, the parameter $a$ should be small. We need to make a tradeoff in setting parameter $b$, a large $b$ means that more image data will be used in calculations and the noise impact will be reduced. However, a large $b$ also means that we need more storage and computation resources. In this paper, we set $a=3$ and $b=2$ via a set of experimental tests.

After obtaining the TB, the TLC is simply defined as:

$$TLC(i, j, k) = \frac{F(i, j, k)}{TB(i, j, k)} \times |F(i, j, k) - TB(i, j, k)|$$  \hspace{1cm} (4)$$

2.3. STLC
After obtaining SLC and TLC, the STLC is simply defined as their product:

$$STLC(i, j, k) = SLC(i, j, k) \times TLC(i, j, k)$$  \hspace{1cm} (5)$$

Fig. 3 shows examples of calculation results for SLC, TLC and STLC. Fig. 3(a) is the original image with cloud background, a simulated target is superimposed on the original image and marked with a red rectangle. Figure 3(b), (c) and (d) are the three-dimensional display of the calculation results of SLC, TLC and STLC, which clearly show that the newly defined STLC can greatly enhance the target while suppressing the background.

Finally, we can set a threshold in the STLC and achieve target detection.
3. Experiments

3.1. Data description
We choose four groups of IR image sequences as our experimental background images, which are described in detail in reference [13]. One simulated target which is marked with a red rectangle is superposed in each sequence, as shown in Fig. 4(a)-Fig. 7(a). Four experiments are conducted to check the target detection ability of the proposed algorithm.

3.2. Evaluation standard
To prove the advantage of our detection method, max-median (MM), time difference (TD), accumulated center-surround difference (ACSD) [14] and STLCF [15] are chosen as our four comparison algorithms. For quantitative evaluation, the BSF and GSNR are employed as two objective evaluation criteria, which are defined as

\[ BSF = \frac{\sigma_{IN}}{\sigma_{OUT}} \]  \hspace{1cm} (6)

\[ GSNR = \frac{SNR_{OUT}}{SNR_{IN}} \]  \hspace{1cm} (7)

where \( \sigma_{IN} \), \( \sigma_{OUT} \), \( SNR_{IN} \) and \( SNR_{OUT} \) denote the standard deviation and SNR of the input and output images respectively.

3.3. Experimental Results
The experimental results of target detection in four data sets are shown in Fig. 4 - Fig. 7 respectively.
For an intuitive comparison of the five detection methods, maximum value of the residual image is normalized to 1. The experimental results show that for homogeneous background such as Fig. 6(a), the background is well suppressed and the target is greatly enhanced by the five methods. But for the heterogeneous backgrounds such as Fig. 4(a) and Fig. 5(a), there are many false alarms when using the single frame based methods. When the background clutter is more intense like Fig. 7(a), target detection becomes very difficult for these two single frame based methods, and the performances of TD and STLCF have also dropped a lot. However, our proposed algorithm can accurately achieve background suppression and target enhancement in all situations.

Figure 4. Experimental results in data set 1.

Figure 5. Experimental results in data set 2.
For a quantitative comparison of the five methods, we repeat each experiments for 20 times and record the average values of BSF and GSNR, which are shown in Table 1. Experimental results indicate that regardless of the complexity of the background, our method can achieve the best background suppression and target detection results.
Table 1. Quantitative comparison of the experimental results

| Image Data | Criteria | MM   | TD   | ACSD  | STLCF  | Our method |
|------------|----------|------|------|-------|--------|-------------|
| Data set 1 | BSF      | 130.97 | 153.27 | 184.27 | 155.06 | 877.12      |
|            | GSNR     | 16.03  | 16.44 | 22.68 | 16.41 | 105.99      |
| Data set 2 | BSF      | 116.06 | 115.72 | 128.01 | 113.38 | 484.74      |
|            | GSNR     | 7.54   | 8.74  | 10.36 | 8.72  | 40.86       |
| Data set 3 | BSF      | 69.76  | 44.45 | 135.41 | 48.13 | 345.73      |
|            | GSNR     | 5.53   | 3.15  | 10.98 | 3.35  | 28.04       |
| Data set 4 | BSF      | 772.14 | 1565.85 | 932.52 | 869.13 | 3250.16     |
|            | GSNR     | 5.27   | 12.64 | 7.76  | 10.67 | 56.41       |

4. Conclusions
This paper presented a new STLC algorithm for detecting moving IR dim point target. This method has three contributions. (1) Inspired by local contrast method, a novel spatial filter is designed to estimate the background image using the intra-frame information. (2) Combining the speed information of the target, we defined a new time difference method to obtain the temporal background using the inter-frame information. (3) The STLC is defined according to the original image and the two estimated backgrounds. Experiments indicate that our method has a great advantage in terms of background suppression and target detection.

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References
[1] Li, Y., Zhang, Y., Yu, J., et al. (2016) A novel spatio-temporal saliency approach for robust dim moving target detection from airborne infrared image sequences. Information Sciences, 369: 548-563.
[2] Lu, Y., Huang, S., Zhao, W. (2019) Sparse representation based infrared small target detection via an online-learned double sparse background dictionary. Infrared Physics & Technology, 99: 14-27.
[3] Zhang, T., Peng, Z., Wu, H., et al. (2021) Infrared small target detection via self-regularized weighted sparse model. Neurocomputing, 420: 124-148.
[4] Zhou, F., Wu, Y., Dai, Y. (2021) Infrared small target detection via incorporating spatial structural prior into intrinsic tensor sparsity regularization. Digital Signal Processing, 111: 102966.
[5] Ju, M., Luo, J., Liu, G., et al. (2021) ISTDet: An efficient end-to-end neural network for infrared small target detection. Infrared Physics & Technology, 114: 103659.
[6] Wang, H., Li, H., Zhou, H., et al. (2021) Low-altitude infrared small target detection based on fully convolutional regression network and graph matching. Infrared Physics & Technology, 115: 103738.
[7] Zhang, X., Ding, Q., Luo, H., et al. (2017) Infrared small target detection based on directional zero-crossing measure. Infrared Physics & Technology, 87: 113-123.
[8] Cui, Z., Yang, J., Li, J., et al. (2016) An infrared small target detection framework based on local contrast method. Measurement, 91: 405-413.
[9] Zhang, H., Zhang, L., Yuan, D., et al. (2018) Infrared small target detection based on local intensity and gradient properties. Infrared Physics & Technology, 89: 88-96.
[10] Cui, Z., Yang, J., Jiang, S., et al. (2018) An infrared-small-target detection method in compressed sensing domain based on local segment contrast measure. Infrared Physics & Technology, 93: 41-52.
[11] Chen, Y., Song, B., Wang, D., et al. (2018) An effective infrared small target detection method based on the human visual attention. Infrared Physics & Technology, 95: 128-135.
[12] Li, Q., Nie, J., Qu, S. (2021) A small target detection algorithm in infrared image by combining multi-response fusion and local contrast enhancement. Optik, 241: 166919.

[13] Zhao, B., Xiao, S., Lu, H., et al. (2018) Spatial-temporal local contrast for moving point target detection in space based infrared imaging system. Infrared Physics & Technology, 95: 53-60.

[14] Xie, K., Fu, K., Zhou, T., et al. (2014) Small target detection based on accumulated center-surround difference measure. Infrared Physical Technology, 67: 229-236.

[15] Deng, L., Zhu, H., Tao, C., et al. (2016) Infrared moving point target detection based on spatial–temporal local contrast filter. Infrared Physical Technology, 76: 168-173.