An Infrared small target detection method based on local contrast measure and gradient property

Xiang Li¹, Guili Xu* and Quan Wu¹

¹College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, 210016, China

*Corresponding author’s e-mail: guilixu@nuaa.edu.cn

Abstract. Infrared small target detection plays an important role in infrared search and tracking applications. In order to solve the problem of detection has high false alarm rates and low probabilities with complex backgrounds. An infrared small target detection method based on local contrast measure and gradient property (LCG) is proposed in this paper. Initially, the contrast map of the input image is calculated using the modified local contrast measure which is employed to enhance target and suppress background. Then, according to the property of distribution regularly around the target, the gradient map is calculated from the input image to further suppress clutters. Next, the feature map is achieved by integrating the local contrast map and gradient map in a pixel-wise multiplication manner. Finally, an adaptive threshold is used to extract the target region. Experimental results on two real sequences demonstrate that the proposed method has a good performance in background suppression and target enhancement. Besides, the proposed method has satisfying robustness under complex backgrounds.

1. Introduction

Infrared small target detection is widely utilizing in infrared search and tracking (IRST) system. On the one hand, owing to the distance between the target and the detector is too long, the target normally has a small size without obvious shape information and useful texture feature in the raw infrared image and is easily submerged in the complex background[1]. On the other hand, some interferences in infrared image, such as high brightness backgrounds, complex background edges and pixel-sized noises with high brightness, are easy to be falsely detected as targets[2]. Hence the small infrared target detection is an extremely challenging task.

In recent year, many methods are proposed to detect infrared small targets effectively. Most traditional methods detect small traget by designing appropriate filters to enhance target foreground or suppress background interference, such as Top-hat filter method[3], bilateral filter method[4], MaxMean filter/MaxMedian filter method[5] and 3-D matched filter method[6]. These methods have good detection efficiency, but they are easy to detect clutter as target. In addition to methods based on filter, some methods using the spatio-temporal information of targets were proposed to detect small target. But the detection results of these methods depend on whether the hypothesis of target motion continuity is correct. For example, Gao et.al uses Gaussian mixture model and Markov random field model to simulate small targets in complex background, and then uses the variational Bayesian method to separate the target from the background[7]. However, it is difficult to ensure the detection accuracy when the prior knowledge of the target is inadequate. Recently, some methods transform the problem of small target detection into an optimization problem of recovering low-rank and sparse matrices, such as IPI[8],
TV-PCP[9], PSTNN[10], have good detection performance but they are difficult to realize real-time processing. Researchers Inspired by the contrast mechanism of human vision system (HVS) and apply it to infrared small target detection in recent year. Kim et al.[11] applied the Laplacian of Gaussian (LoG) filter to improve image contrast in the field of infrared small target detection. However, LoG filter is sensitive to not only real small target but also background edges, which creates a high false alarm rate. Chen et al.[12] utilized the ratio of the center block and the neighborhood blocks as the local contract measure (LCM). LCM is more effective than the conventional method, but detection efficiency will be reduced when the image have complex background and clutter. In order to achieve higher efficiency, Han et al.[13] proposed improved LCM (ILCM) method. which divided the preprocessed image into sub-blocks. Then, Han et al.[14] proposed a method named relative LCM (RLCM) to solve the problem of different size of small targets in complex background. Zhang[15] proposed LIG method based on intensity information and gradient property of small target. LIG have a good performance in enhancing the targets and suppressing backgrounds and clutters, but it easily mistake some isolated pixels that have the similar gray value of targets for targets.

In this paper, a detection method for infrared small target based on local contrast measure and gradient property (LCG) is proposed to pursue a good performance in detection rate and false alarm rate with intricate background. First, a modified local contrast measure is used to obtain the contrast map of input infrared image. Using contrast mechanism to replace the intensity of pixels can enhance the target and suppress background to obtain the contrast map with higher signal-to-noise rate. Then, the gradient map of input infrared image is obtained by using gradient property of small target. Next, the feature map is achieved by integrating the local contrast map and gradient map in a pixel-wise multiplication manner. Finally, we obtain the targets via an adaptive threshold from the feature map.

This paper is organized as follows. In section 2, we provide a detailed description of our method for infrared small target detection. Section 3 presents the results of experiments to demonstrate the effectiveness of our method. Finally, the conclusions and future works are provided in Section 4.

2. Proposed method

2.1. Analysis of small target characteristic

By analyzing the gray distribution of infrared images, as shown in Figure 1, it can be found that the local background area in an infrared image is uniform and stable. In addition, the gray value of small target in the infrared image has the radiation characteristics. Generally, infrared small target could be modeled by a two-dimensional gaussian function[16]:

$$I(x, y) = \gamma e^{-\frac{1}{2} \left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)}$$

(1)

where $\gamma$ is the maximum value of the target pixels, $\sigma_x$ and $\sigma_y$ denote horizontal and vertical standard deviation parameters, respectively.

An small target is usually brighter than its surrounding background in an infrared image[17]. Therefore, we can use the local contrast measure to enhance target and suppress background, which is valuable for detecting small targets.

Zhang[15] assumed that the gradient vectors of the target point to its center, which is shown in a red bounding box in Figure 2. In addition, the gradient directions of the strong edges, such as the edges of clouds, are generally consistent, which is shown in a blue bounding box in Figure 2. Therefore, we can use this gradient property to detect small targets. According to the above analysis, the local contrast measure and gradient property are valuable for infrared small target detection.
2.2. Calculation of the contrast map $C$

Due to contrast mechanism can effectively improve the detection capabilities, such as detection rate, false alarm rate and speed, it has been introduced to infrared small target detection. In this paper, we design an modified local contrast measure to achieve effective detection.

A sliding window moves on the infrared image from up to down and left to right pixel by pixel. As shown in Figure 3(b), the red box indicates the initial position of the sliding window, the blue box indicates the position of the sliding window after moving it to the right by one step, and the orange box indicates the position of the sliding window after moving it to the down by one step. Then the sliding window is divided into $3 \times 3$ cells. Note that the central cell denoted by “0” is a region where the target could appear and other cells denoted by “1” to “8”, which is shown in Figure 3(a). The gray mean value of the $i$th cell is denoted by $m_i (i=1,2,...,8)$, that is,

$$m_i = \frac{1}{N_i} \sum_{j=1}^{N_i} I_j$$  \hspace{1cm} (2)

where $N_i$ is the number of the pixels in the $i$th cell, and the $I_j$ is the gray level of the $j$th pixel in the $i$th cell. Therefore, the contrast between central cell and the $i$th surrounding cell is defined by

$$C_i = \left( \frac{L_m}{m_i} \right)^2 \ln \left( \frac{L_m}{m_i} \right) \cdot L_m$$  \hspace{1cm} (3)

where $L_m$ represents the peak value of the central cell, it can be calculated by

$$L_m = \max_{j=1,2,...,N_m} I_j^0$$  \hspace{1cm} (4)

where $N_m$ is the number of the pixels in the central cell, and the $I_j^0$ represents the $j$th pixel in the central cell. Generally, target is brighter than its surrounding pixels in infrared image. So the contrast map $C$ can be obtained by
The computation process of contrast map \( C \) is given in Algorithm 1. From the definition above, we can discover that the modified local contrast measure can enhance the target and suppress backgrounds.

1. If the current location is the region where the target appears, \( L_a \) is the maximum gray value of the target. It is easy to find that \( L_a > m_i \) since the gray value of target is larger than the means of surrounding cell. The contrast of the pixel belongs to the target is given by

\[
C = \min \left[ \left( \frac{L_a}{m_i} \right)^2 \cdot \ln \left( \frac{L_a}{m_i} \right) \cdot L_a \right] > L_a.
\]

2. If the current location is the background, \( L_a \) is the maximum gray value of the background. Due to the background is usually uniform and continuous in an infrared image patch, we can easily get \( L_a \approx m_i \). The contrast of the pixel belong to the background is given by

\[
C = \min \left[ \left( \frac{L_a}{m_i} \right)^2 \cdot \ln \left( \frac{L_a}{m_i} \right) \cdot L_a \right] \approx 0.
\]

3. If the current location is the background edge, such as the edges of clouds or building, \( L_a \) is the maximum gray value of the background edge. Since background edges usually distribute along a particular direction, and the brightness of each side of edge has continuity in a small local region. So the brightness of central cell will lower than that of the surrounding cell with higher brightness. Therefore, there exists \( m_i \) make \( L_a < m_i \). The contrast of the pixel belongs to the background edge is given by

\[
C = \min \left[ \left( \frac{L_a}{m_i} \right)^2 \cdot \ln \left( \frac{L_a}{m_i} \right) \cdot L_a \right] < 0.
\]

From the discussions above, we can get the conclusion that after modified local contrast measure calculation, true small targets will be enhanced, and background and edges will be suppressed. The contrast map \( C \) with high signal-to-clutter (SCR) can be obtained to detect small target.

**Related work:** calculation of the gradient map \( G \)

An infrared small target detection method named LIG[15] intorduced gradient property to further improve detection accuracy. In this paper, we utilize the method that calculate the local gradient value to improve the proposed method. LIG method divided an image patch into four parts along the radial direction. Then a polar coordinate system is established by setting the center of the patch as the origin. The gradients vector which point to the small target center can be expressed as follow:

\[
\phi_v = \{ g_{v_i} (m,\alpha,\gamma,\theta) \}^2 + \pi < \alpha < \frac{\pi}{2}, \pi, (\gamma,\theta) \in \psi_v
\]

where \( \phi_v \) is the set of the gradients satisfying the constraint in the region \( \psi_v \), which represents the \( i \) th part in the patch. \( g_{v_i} (m,\alpha,\gamma,\theta) \) is the gradient element in the set \( \phi_v \). \( m \) and \( \alpha \) represent the magnitude and direction of \( g_{v_i} \), respectively. \( (\gamma,\theta) \) represent a point in the polar coordinate system.

Then, calculate the mean square of gradient amplitudes of the each part in an image patch by

\[
G_i = \frac{1}{N_j} \sum_{j} g_{v_i}^2
\]

where \( N_j \) is the number of \( g_{v_i} \) in the set \( \phi_v \). Hence, the maximum value and minimum value of \( G_i \) can be obtained by

\[
G_{max} = \max_{i=1,4} G_i, \quad G_{min} = \min_{i=1,4} G_i
\]

Since the gradient directions of small target in infrared image are evently distrbuted in all directions and background clutters are generally local orientated. The gradient map of input image can be calculated by
\[
G = \begin{cases} 
\frac{\sum_{i=1}^{N_0} G_i}{L_m} & \text{if } \frac{G_{\text{sum}}}{G_{\text{max}}} > k_1 \\
0 & \text{otherwise}
\end{cases}
\]  

(12)

where \(G\) is local gradient value of an image patch, and \(k_1\) is the parameter to suppress the background and noise.

2.3. Small target detection method based on local contrast measure and gradient property

Figure 4 illustrates the overview of our method. According to Algorithm 1 and equation (12), the contrast map \(C\) and gradient map \(G\) can be obtained, respectively. The detection process is shown in Algorithm 2, where \(F_{ij}, C_{ij}\) and \(G_{ij}\) are the pixel value of the feature map, \(C\) map and \(G\) map; \(W\) and \(H\) are the width and height of the maps; \(k_2\) is a const value, \(\sigma\) and \(\mu\) are the mean and the standard deviation of the feature map, respectively. And \(T\) is the adaptive threshold.

Figure.4 The overview of the proposed method.

3. Experimental results and analysis

In this section, we firstly introduce the evaluation metrics for comparison in this paper. Then we use two real image sequences to test the proposed method. All the experiments were conducted on a computer with 8-GB memory and 2.50-GHz Intel i5 processor, and the code was implemented in MATLAB R2016a.
3.1. Evaluation metrics
The common metrics of evaluating the infrared small target detection performance are the signal-to-clutter (SCR), the SCR gain \(G_{\text{SCR}}\) and the background suppression factor (BSF) which are defined as\[8\]:

\[
\text{SCR} = \frac{\mu_t - \mu_b}{\sigma_b}, \quad G_{\text{SCR}} = \frac{\text{SCR}_{\text{out}}}{\text{SCR}_{\text{in}}} , \quad \text{BSF} = \frac{C_{\text{in}}}{C_{\text{out}}}
\]  

(13)

where \(\mu_t\) is the average gray value of the target, \(\mu_b\) and \(\sigma_b\) are the average gray value and standard deviation of the gray values of surrounding area, respectively. Figure 5 shows the target area and the surrounding area. \(d\) is a parameter determining the size of neighboring area which equals to 20 pixels in our experiment. \(\text{SCR}_{\text{in}}\) and \(\text{SCR}_{\text{out}}\) denote the SCR of the input image and processed image, respectively. \(C_{\text{in}}\) and \(C_{\text{out}}\) are the standard deviations of the backgrounds in the input image and processed image. Generally speaking, the higher the SCR and BSF values of a small target image are, the easier the target can be detected.

The probability of detection \(P_d\) and the false-alarm rate \(P_f\) are also helpful to evaluate the detection performance of various small target detection methods. \(P_d\) and \(P_f\) are defined as following:

\[
P_d = \frac{\text{number of detected true detections}}{\text{number of real targets pixels}}
\]  

(14)

\[
P_f = \frac{\text{number of detected false targets}}{\text{number of total pixels in an image}}
\]  

(15)

![Figure 5](image.png)

3.2. Experimental results
To verify the validity of our method, we use two real sequences from the infrared image dataset named A dataset for infrared detection and tracking of dim-small aircraft targets under ground/air background\[18\] to test our method. Denoted by sequence 1 and sequence 2, two sequences with single target are gathered under different conditions. Backgrounds of sequence 1 are composed of sky, building and ground, while sequence 2 contains sky, mountain and buildings backgrounds. Each real image sequences contains 150 images with a resolution of \(256 \times 256\). The average SCR of two sequences are 3.84 and 3.01, respectively.

In order to further illustrate the performance of LCG method, we adopt six other methods for comparison. These methods are the Top-Hat filtering method, MaxMean method, MaxMedian method, ICM method, ILCM method, as well as LIG method. Figures 6-7 show the representative image of two sequences, the detection results of baseline methods and LCG method and their three dimensional surface. Experimental results of these methods with the \(G_{\text{SCR}}\) and \(\text{BSF}\) are shown in Table 1. The highest value of each evaluation indicator in each row is marked in red, while the second highest value is marked in blue.

From Figures 6-7, we can obviously see that the LCG method has better detection performance than other methods. In addition, we can also find that the LCG method have a good performance in target enhancement and background suppression. From Table 1, we can see that the LCG method achieves the highest \(G_{\text{SCR}}\) value and \(\text{BSF}\) value in sequence 1. In sequence 2, the LCG method achieves the highest
value and second highest BSF value, while BSF of the LIG method is slightly higher. So we can conclude that the LCG method obtain better results than other methods.

The receiver operating characteristic (ROC) curves are given in Figure 8 to demonstrate the robustness of the LCG method. The LCG methods mainly has higher $d_P$ than the other methods under identical $p_T$. It proves that the LCG method has good performance in small target detection.

Figure 6 Target enhancement results obtained by different methods using sequence 1.
Figure 7: Target enhancement results obtained by different methods using sequence 2.

Table 1: $\overline{SCR}$ and $\overline{BSF}$ comparisons of infrared sequences

| Sequences | Metrics | TopHat | MaxMean | MaxMedian | LCM | ILCM | LIG | Our method (LCG) |
|-----------|---------|--------|---------|-----------|-----|------|-----|-----------------|
| Sequence 1 | $\overline{SCR}$ | 1.138 | 1.508 | 0.891 | 2.145 | 1.972 | 1.545 | 2.542 |
|           | $\overline{BSF}$   | 0.899 | 0.755 | 0.757 | 0.719 | 0.803 | 7.758 | 11.085 |
| Sequence 2 | $\overline{SCR}$ | 1.243 | 1.248 | 1.020 | 1.976 | 1.834 | 2.237 | 2.909 |
|           | $\overline{BSF}$   | 0.930 | 0.775 | 0.777 | 0.821 | 0.824 | 12.896 | 11.567 |

Figure 8: The ROC curves of eight methods for two real image sequences. (a) Real Sequence 1. (b) Real Sequence 2.

4. Conclusion
This paper proposed an effective method for small infrared target detection based on local contrast measure and gradient property (LCG). The key idea is to implement the modified local contrast measure and gradient property obtain the feature map from input image for suppressing the backgrounds and enhancing the targets. The proposed method can improve the SCR and BSF values of the image. In this way, the proposed method can achieve high probabilities detection and low false alarm rates. The robustness of the proposed method is validated by ROC curves of two real infrared image sequences. In the future, we will further improve the flexibility of our method in target cases with variable size in further investigation.

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References
[1] Gao C, Meng D, Yang Y. (2013) Infrared Patch-Image Model for Small Target Detection in a Single Image. J. IEEE Transactions on Image Processing, 22:4996-5009.
[2] Han J, Ma Y, Zhou B. (2014) A Robust Infrared Small Target Detection Algorithm Based on Human Visual System. J. IEEE Geoscience & Remote Sensing Letters, 11:2168-2172.

[3] Bai X, Zhou F. (2010) Analysis of new top-hat transformation and the application for infrared dim small target detection. J. Pattern Recognition, 43:2145-2156.

[4] Bae T W, Lee S H, Sohng K I. (2010) Small target detection using the Bilateral Filter based on Target Similarity Index. J. Ice Electronics Express, 7:589-595.

[5] Deshpande S D, Er M H, Ronda V. (1999) Max-mean and max-median filters for detection of small targets. J. Proceedings of SPIE - The International Society for Optical Engineering, 3809.

[6] Reed I S, Gagliardi R M, Stotts L B. (2002) Optical moving target detection with 3-D matched filtering. J. IEEE Transactions on Aerospace & Electronic Systems, 24:327-336.

[7] Gao C, Wang L. (2018) Infrared small-dim target detection based on Markov random field guided noise modeling. J. Pattern Recognition the Journal of the Pattern Recognition Society, 76:463-475.

[8] Gao C, Meng D, Yang Y. (2013) Infrared Patch-Image Model for Small Target Detection in a Single Image. J. IEEE Transactions on Image Processing, 22:4996-5009.

[9] Wang X, Peng Z, Kong D. (2017) Infrared dim target detection based on total variation regularization and principal component pursuit. J. Image and Vision Computing, 63:1-9.

[10] Zhang L, Peng Z. (2019) Infrared Small Target Detection Based on Partial Sum of the Tensor Nuclear Norm. J. Remote Sensing, 11:1-34.

[11] Kim S, Yang Y, Lee J. (2009) Small Target Detection Utilizing Robust Methods of the Human Visual System for IRST. J. Journal of Infrared Millimeter & Terahertz Waves, 30:994-1011.

[12] Chen C L P, Li H, Wei Y. (2013) A Local Contrast Method for Small Infrared Target Detection. J. IEEE Transactions on Geoscience & Remote Sensing, 52:574-581.

[13] Han J, Ma Y. (2014) A Robust Infrared Small Target Detection Algorithm Based on Human Visual System. J. IEEE geoscience and remote sensing letters, 11:2168-2172.

[14] Han J, Liang K, Zhou B. (2018) Infrared Small Target Detection Utilizing the Multiscale Relative Local Contrast Measure. J. IEEE Geoscience and Remote Sensing Letters, 15:612-616.

[15] Zhang H, Zhang L. (2018) Infrared small target detection based on local intensity and gradient properties. J. Infrared Physics & Technology, 89:88-96.

[16] Chan D S K, Langan D A, Staver D A. (1990) Spatial-processing techniques for the detection of small targets in IR clutter. J. Proc Spie, 1305:53-62.

[17] Wang X, Lv G, Xu L. (2012) Infrared dim target detection based on visual attention. J. Infrared Physics & Technology, 55:513-521.

[18] Hui Bingwei, Song Zhiyong and Fan Hongqi. A dataset for infrared detection and tracking of dim-small aircraft targets under ground / air background. DB. Science Data Bank, 2019. (2019-10-28). DOI: 10.11922/sciencedb.902.