

# Research of infrared background suppression method based on anisotropic bilateral filtering

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**Abstract.** Infrared complex background suppression is an important part of infrared dim target detection, directly affects the target detection probability and false alarm rate of subsequent algorithms. Bilateral filter as a nonlinear smoothing method which considers not only the distance between pixels, but also the gray value similarity between adjacent pixels has a certain edge-preserving effect. However it did not take full account of the characteristics of the edge direction and reserves lots of edge residual. In this paper, an anisotropic bilateral filter which adapts the filter parameters by using the local characteristics of the image and ensures the filter direction along the edge is designed. It will separate the target from background more precisely. The experimental results show the effectiveness of the proposed method.

**Key words.** Dim target detection, Bilateral filter, Adaptive filter, Background suppression, Anisotropic filter.

## 1. Introduction

Infrared target detection is an important research content for infrared alarm system. When the distance of target-oriented imaging is rather far, the imaging dimension of object in the detector is rather small, which is very easily submerged in the complicated background so as to make its detection and trace become pretty difficult. Infrared background suppression utilizes the association between the space domain and time domain of image and uses the proper prediction model to estimate the background to strengthen the object and improve the detection performance for the object of infrared alarm system.

The traditional methods for infrared background suppression are space-domain

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background suppression method and time-domain background suppression method, in which the space-domain background suppression method is based on the spatial neighborhood association of image, which is very easy to keep a large amount of background in image border and other regions where the association is weak, including anisotropic diffusion[1], wavelet transform[2], mathematical morphology[3], self-adaptive local statistical information[4] and multiresolution segmentation[5–10], etc; although the background suppression effect of time-domain background suppression method represented by time-domain section[11] and minimum mean-square error of time-space domain is superior to the space-domain method's, the algorithm performance is subject to the stability of satellite platform, that is, when the imager motion of satellite platform is rather large, the association of interframe image decreases, so it is difficult to apply time-domain background suppression method

Bilateral filter is a nonlinear filtering method considering the neighboring degree of image space and similarity of gray level, which has better border suppression performance while compared to the traditional border suppression method. Li Fan[13] applies bilateral filter into background suppression for infrared image, so that favorable effect has got, that is, the gain of signal to noise ration is more than 2, while Cao Ying[14] self-adaptively selects bilateral filter neighborhood with the fuzzy classification method to have decreased the complexity of algorithm. However, the directivity of image border has not been considered in the traditional bilateral filter method at all, while the anisotropic bilateral filter background suppression method proposed in the Paper makes the filtering direction parallel to border direction and self-adaptively adjusts the dimension of filter through the local statistical information of image. The simulation experiment has verified the effectiveness of anisotropic bilateral filter background suppression method, that is, the gain of signal to clutter ratio after background suppression can reach to 4.

## 2. Anisotropic bilateral filter

### 2.1. Bilateral filter

Bilateral filter can earliest be traced back to Aurich's and Weule's[15] nonlinear gauss filter research and also it has once appeared in Simth's and Brady's[16] SUSAN FRAME, but finally it has been officially proposed by Tomasi and Manduchi[17]. Its definition can be roughly expressed by formula (1) as:

$$I^{filter}(x, y) = \sum_{(x_i, y_i)} I(x_i, y_i) * W_{ij}(I). \quad (1)$$

Where  $I(x, y)$  is the filtered image input,  $I^{filter}(x, y)$  is the filter output,  $(x_i, y_i)$  is the pixel coordinate and  $W_{ij}(I)$  is the filtered weight of bilateral filter, confirmed by the neighborhood relationship of distance among pixels and the similarity of gray

value of pixel mutually.

$$W_{ij}(I) = \frac{1}{W_p} \sum_{(x_i, y_i)} f_{\sigma_s}(\|I(x_i, y_i) - I(x, y)\|) \times g_{\sigma_r}(\|(x_i, y_i) - (x, y)\|). \quad (2)$$

$W_p$  is the normalized weight and both  $f_{\sigma_s}$  and  $g_{\sigma_r}$  are gauss kernel function.

## 2.2. Anisotropic bilateral filter

Although bilateral filter can well keep the border of image, the directivity information of image border has not been considered in traditional bilateral filter at all and the worst situation is that when the filter direction is vertical to the border direction, there will be bigger border background residual, while the anisotropic rapid gauss filter proposed by Geusebroek[18] has the border direction projected to gauss filter direction so as to make the filter direction parallel to border direction.

The mathematical expression for anisotropic gauss filter is shown as follows:

$$g_{\theta}(u, v; \sigma_u, \sigma_v, \theta) = \frac{1}{\sqrt{2\pi}\sigma_u} \exp\left(-\frac{1}{2} \frac{u^2}{\sigma_u^2}\right) * \frac{1}{\sqrt{2\pi}\sigma_v} \exp\left(-\frac{1}{2} \frac{v^2}{\sigma_v^2}\right), \quad (3)$$

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix}, \quad (4)$$

$u$  and  $v$  respectively are the border direction of image and perpendicular direction of border and  $\theta$  is the direction angle of image border.

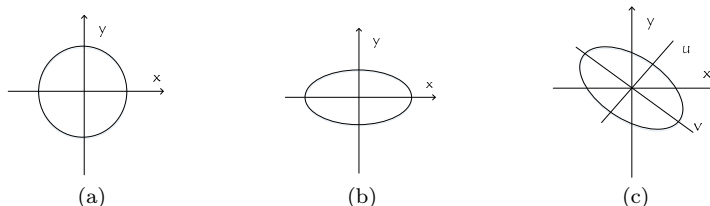


Fig. 1. (a) isotropic gauss kernel (b) anisotropic gauss kernel (c) rotation of anisotropic gauss

To keep smaller border information after background suppression, anisotropic gauss kernel function  $g_{\sigma_r}$  is adopted in the Paper and anisotropic bilateral filter has been improved to make the filter direction and border direction of filter stay the same.

The efficient sobel operator can be adopted for direction angle of image border in formula (4) to carry out gradient estimation,

$$E_x = x\_mask * I, \quad (5)$$

$$E_y = y\_mask * I, \quad (6)$$

$$x\_mask = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}, \quad (7)$$

$$y\_mask = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \quad (8)$$

$$\theta_{\perp} = \arctg[\text{abs}(\frac{E_x}{E_y})], \quad (9)$$

\* in the formula means convolution and  $\theta_{\perp}$  is the normal direction of image border,  $\theta = \theta_{\perp} + 90^{\circ}$ .

### 2.3. Dimension of filter

In anisotropic bilateral filter, the influence of filter with different dimension on the filtering effect is still huge. Emin Kugu[19] measures the influence of filter with different dimension on remote sensing image processing of bilateral filter with MSE (Mean Square Error), Entropy, SSIM (Structural Similarity Based Image Quality Assessment) and Second Derivative, while with the maximization rule of signal to noise ratio, Honghong Peng and Raghuvver Rao[20] have derived that the optimal filter dimension is:  $\sigma_r = 1.5\sigma_i$  and  $\sigma_s = 2.5\sigma_i$ , in which  $\sigma_i$  is the noise standard deviation of image.

Wang Huaiye[21] has fully analyzed anisotropic gauss filter  $\sigma_u$  and  $\sigma_v$  and the setting problem of filter dimension, in which for gentle region where local region variance of image is smaller, the scale of  $\sigma_u$  and  $\sigma_v$  should be close to 1 as much as possible, while for the region where the local region variance of image is bigger, the filter is degraded into the linear filter along the tangential direction of image border and the scale of  $\sigma_u$  and  $\sigma_v$  is close to 0.

Scale factor on  $\sigma_u$  and  $\sigma_v$  direction:

$$R = \frac{k}{k + \sigma}, \quad (10)$$

$\sigma$  is the standard deviation of image region and the optimal  $k$  value is 20.

### 2.4. Mask dimension

To improve the background suppression effect of bilateral filter, Bae[22] has introduced a self-adaptive adjustment method based on mask dimension of border filter. First, this method accumulates the gray change on the horizontal, vertical and diagonal direction of targeted pixel neighborhood and the proper mask dimension is selected in accordance with the size of gray change. The specific selection method

for mask dimension is shown in formula (11):

$$M = \begin{cases} N + 2 & E(i, j) > \alpha \times E_{\max} \\ N + 1 & E(i, j) > \beta \times E_{\max} \\ N & \text{Others} \end{cases} \quad (11)$$

The mask dimension is  $(2M + 1) \times (2M + 1)$ , in which  $E(i, j)$  in the formula means the border filter output in pixel  $(i, j)$  and  $E_{\max}$  is the maximum value of border filter output. It is suggested to adopt the parameter setting like  $N = 1$ ,  $\alpha = 0.75$  and  $\beta = 0.5$  in literature [20].

### 3. Experiment

#### 3.1. Evaluation criterion for performance

To measure the background suppression effect, for the evaluation of algorithm performance, we adopt indexes like signal to clutter ratio (SCR), gain of signal to clutter ratio (GSCR) and background suppression operator (BSF) to evaluate and the definition for each evaluation index is as follows:

$$SCR = \frac{e_{target} - e_{background}}{c_{clutter}}, \quad (12)$$

$$GSCR = \frac{SCR_{out}}{SCR_{in}}, \quad (13)$$

$$BSF = \frac{c_{in}}{c_{out}}, \quad (14)$$

Where  $e_{target}$  is the peak of targeted region,  $e_{background}$  is the mean of background region,  $c_{clutter}$  is the standard deviation of background region,  $SCR_{out}$  is the SCR after background suppression,  $SCR_{in}$  is SCR of original image,  $c_{in}$  is the standard deviation of background region of original image and  $c_{out}$  is the standard deviation of background region after background suppression.

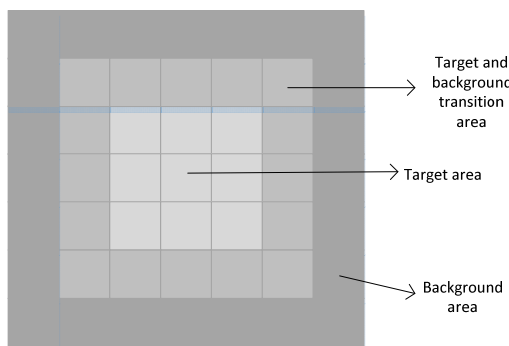


Fig. 2. Pixels used for statistics estimation for a target

According to the definition for weak target, the dimension of the targeted region is set as 3\*3 in the Paper and the background energy is estimated with 7\*7 region. Considering the influence of diffusion of targeted energy on background suppression, set 5\*5 region as the transition region between target and background, as shown in the above figure.

### 3.2. Experimental analysis

In order to verify the validity of the background suppression algorithm proposed in this paper, the small dim target of simulation design is added into infrared scene1, 2, 3 and 4 captured actually to obtain experimental input. At the same time, advancement of filtering algorithm proposed in this paper is verified with comparison of background suppression effects of anisotropic bilateral filtering, isotropic bilateral filter, R-NLM[23] and the improved 2DLMS[24].

In the experiment, the standard deviation of all pixel neighborhoods in the image is calculated with the method of setting the background in Fig.2, and the mean of the K minimum standard deviations is taken as the final image noise standard deviation  $\sigma_i$ .  $\sigma_s = 2.5\sigma_i, \sigma_u = 1.5\sigma_i, \sigma_v = R \times \sigma_i$ . The detailed calculation process of the anisotropic bilateral filtering mask proposed in this paper is as follows.

In Fig. 3, the central pixel of the cloud border in infrared scene 2 is taken as the target pixel, such as the center in the left amplification area.  $\sigma_i$  calculated in infrared scene 2 is about 0.25 and the standard deviation of the target pixel neighborhood is about 30, with  $R= 0.3892, M= 3$  and border direction angle of  $135^\circ$  estimated by sobel operator. The dynamic range of the input image in bilateral filter is  $[0,1]$ , so the pixel gray value of the target neighborhood shown in the image is normalized to  $[0,1]$ .



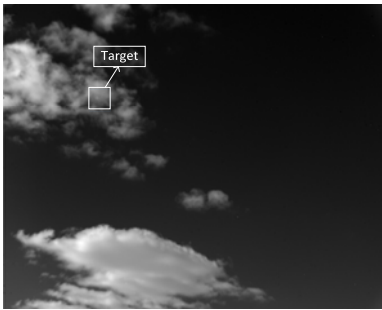
Fig. 3. The process of pixel weights calculation

Compared to Fig. 4 (b), Fig. 5 (b) and Fig. 4 (E), Fig. 5 (E), filtering directions are always along the horizontal and vertical image by using isotropic bilateral filtering background suppression algorithm. There is strong residual background in the border of image after background suppression, and the filtering scale and direction of filter can be adjusted self-adaptively according to local statistics and direction information in the image by using anisotropic bilateral filtering background suppression algorithm. There are few residual borders after filtering, and these false

alarms resulted from the strong border residues can be eliminated with the subsequent multi-frame recognition.

Fig.4 (c), Fig.5 (c) and Fig. 4 (d), Fig. 5 (d) are the outputs of 2DLMS and R-NLM filtering background suppression. Compared to anisotropic bilateral filtering, 2DLMS algorithm which adjusts the filtering scale self-adaptively by predicting variance information of pixel neighborhood and R-NLM algorithm which uses gray value similarity of time domain are able to suppress the border. However, above algorithms weaken the target energy to a certain extent at the time of background suppression.

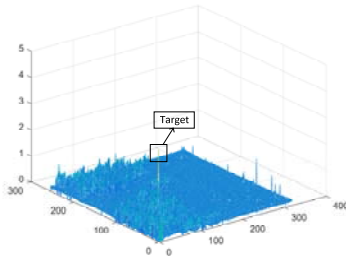
Local statistics of target area of anisotropic bilateral filtering, isotropic bilateral filtering, improved 2DLMS filtering and NL-means filtering output in four scene are shown in Tab.1. Signal-to-clutter ratio gain of the image and background suppression operator after infrared background suppression by anisotropic bilateral filtering, improved 2DLMS filtering and NL-means filtering are higher than those of isotropic bilateral filtering, and there is not significant difference among the background suppression operators of target areas output by three filtering algorithms. However, since the target energies retained by the improved 2DLMS filtering and NL-means filtering are weaker than that retained by anisotropic bilateral filtering algorithm, signal-to-clutter ratio gains after background suppression by two filtering algorithms is lower than that of anisotropic bilateral filtering.



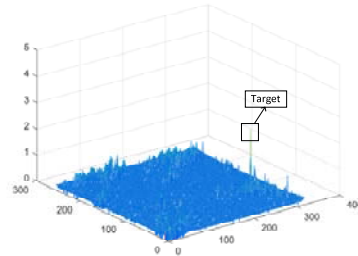
(a1) original infrared sequence 1



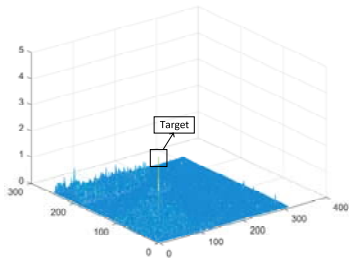
(a2) original infrared sequence 2



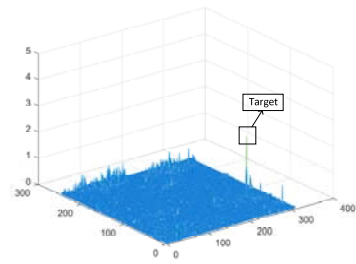
(b1) isotropic bilateral filter output



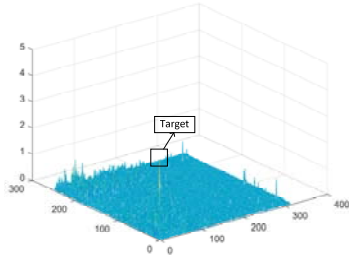
(b2) isotropic bilateral filter output



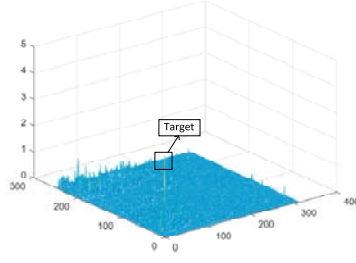
(c1) proposed 2DLMS filter output



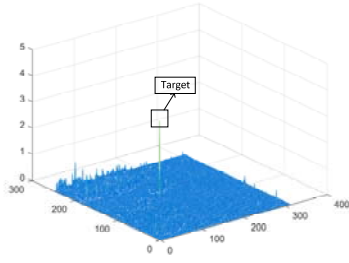
(c2) proposed 2DLMS filter output



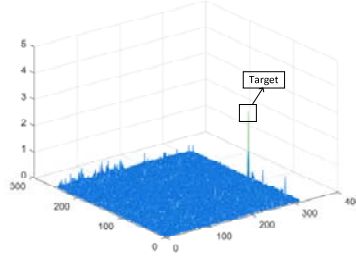
(d1) NL-means filter output



(d2) NL-means filter output



(e1) anisotropic bilateral filter output



(e2) anisotropic bilateral filter output

Fig. 4. Filter result of IR sequence1 and IR sequence2



(a1) original infrared sequence 3



(a2) original infrared sequence 4



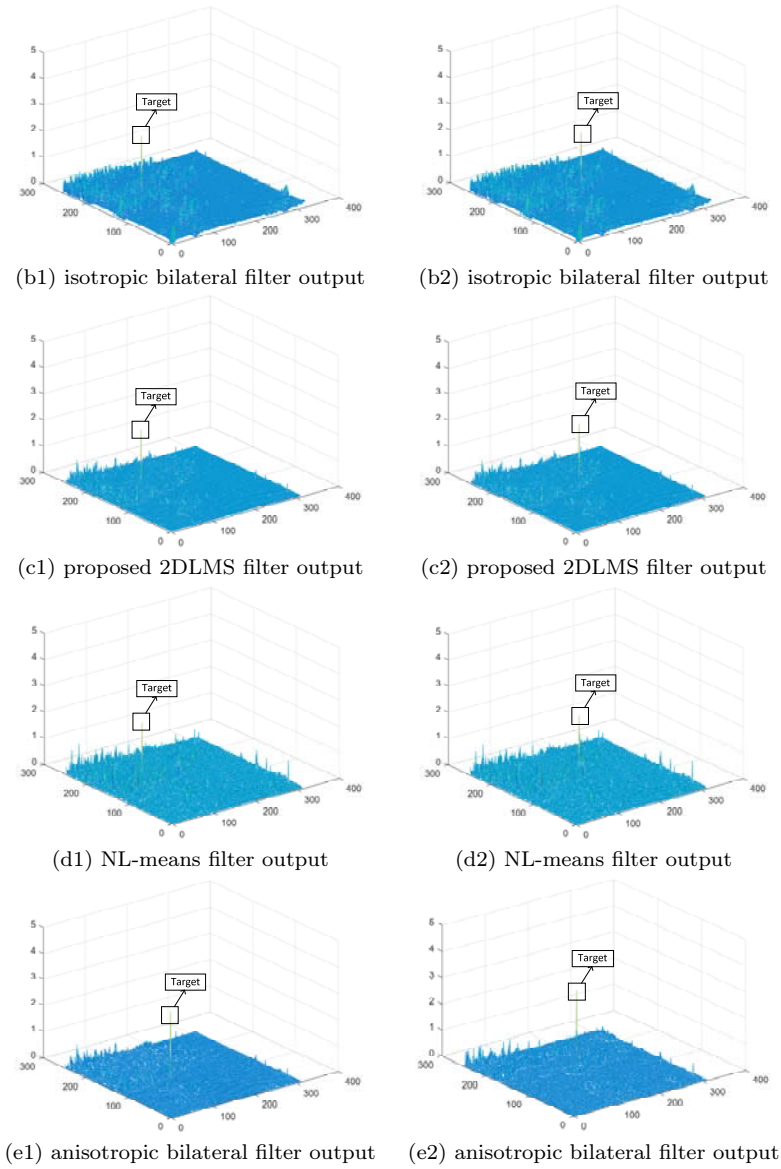


Fig. 5. Filter result of IR sequence3 and IR sequence4

Table 1. Performance comparison of different methods

Sequence	<i>SCR</i> <sub>in</sub>	<i>GSCRBF</i>	<i>BSFBF</i>	<i>GSCR</i> <i>2DLMS</i>	<i>BSF</i> <sub>2</sub> <i>DLMS</i>	<i>GSCRNL</i> <i>-means</i>	<i>BSFNL</i> <i>-means</i>	<i>GSCRAni-</i> <i>BF</i>	<i>BSFAni</i> <i>-BF</i>
Sequence 1	4.58	1.47	2.13	3.54	4.55	3.79	4.31	4.18	4.41
Sequence 2	4.07	1.14	2.11	3.71	4.49	3.45	4.42	4.02	4.39
Sequence 3	4.33	1.31	1.98	3.41	4.82	3.52	4.59	4.22	4.68
Sequence 4	3.91	1.39	2.04	3.69	4.93	3.75	4.61	4.16	4.53

## 4. Conclusion

The background suppression algorithm for anisotropic bilateral filter designed on the basis of local statistical information of remote sensing image and directivity characteristic of cloud border in the Paper can self-adaptively adjust the filter dimension and filter direction. The simulation experiment result shows that this method can better suppress background border while trying its best to keep the targeted energy and the gain of targeted local signal to clutter ratio after background suppression is more than 4.

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