Infrared Small Target Detection Based on Multi-scale Block Discrete Cosine Transform

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Abstract: Due to the variable target size and complex detection environment, small target detection for infrared images may be challenging for individual target analysis, making it easier to overlook alarm or false alarm issues. This study proposes an infrared small target detection technique based on multi-scale chunking discrete cosine transform, combining different characteristics of infrared images in the spatial and frequency domains. First, to improve the correlation between pixels, the multi-scale image-chunking model is applied in the spatial domain to chunk the image at various scales. Next, the chunked image goes through varying degrees of chunked discrete cosine transform reduction to eliminate background information by filtering the low frequency coefficients. Then the small target images is reconstructed to obtain after different scales of frequency filtering. Lastly, multi-scale fusion is carried out to produce the final small target detection outcomes.

Keywords: Image Patching; Discrete Cosine Transform; Image Reconstruction; Object Detection

1. Introduction

Infrared image processing in the infrared search, maritime, fire rescue and people's daily life in the security warning, vehicle monitoring and other fields have a wide range of applications, This is because infrared images are created by using an object's own thermal radiation, which gives them a longer detection range than visible light imaging but also makes them more resistant to light and weather-related changes in their properties. For these reasons, infrared imaging is important for long-distance, nighttime target detection and tracking. As a result, long-range and nighttime target recognition and tracking benefit greatly from the use of infrared imaging. However, in long-distance infrared imaging, the target to be localized and tracked accounts for only a few to a dozen pixels in the whole infrared image acquired, lacking the specific shape of the target or its texture characteristics. Additionally, due to the uncertainty of the imaging environment, the imaging background of the small target detection of the interference is relatively strong, therefore, the study of infrared small target detection technology under the complex background has always been a major difficulty, and one of the research hotspots in the infrared image processing[1].

At present, many scholars at home and abroad are committed to infrared small target detection technology research, according to the infrared image in the space domain and frequency domain different characteristics of the proposed many classic infrared small target detection algorithms, for example: based on the morphology of the space domain of the top-hat filtering algorithm[1-3], local contrast analysis[4,5] and so on, based on the frequency domain detection algorithms are common wavelet transforms[6], spectral residual algorithms[7]; In addition to this, in recent years, scholars have proposed to transform the infrared small target detection problem into a low-rank sparse recovery problem, and at the same time, in order to improve the target detection rate to reduce the false alarm rate, in 2013, Gao et al. proposed to apply the infrared image patch-model to a single infrared small target detection[8], to carry out the local image chunking and construction of the original infrared image, in order to enhance the correlation between the pixels in the background of the infrared image, and then use the principal component analysis to get the initial infrared small target detection map, and finally use the threshold segmentation and refinement to get the final detection results, although the algorithm improves the efficiency of small target detection and reduces the false alarm rate to a certain extent, but the algorithm complexity is high, and there are some limitations in practical applications[9]. Due to the uncertainty of the actual size of the acquired small targets, the selection of the template size in the image spatial domain analysis, the number of layers in the wavelet transform decomposition in the frequency domain, and the selection of reconstruction coefficients will directly affect the target detection effect, and if it is based on the analysis of a single field or scale, it is easy to cause false alarms or omissions in the case of complex backgrounds, for the deficiencies in traditional algorithms, many scholars have proposed that multiple algorithms can be combined and applied to infrared small target detection. For the shortcomings of traditional algorithms, many scholars have proposed that multiple algorithms can be combined and applied to infrared small target detection[9][10][11], or multi-scale analysis in the airspace to improve the detection rate of the algorithm[12-14].

Inspired by the above algorithms, this paper combines the Infrared Patch Image Model and Discrete cosine transform to propose an infrared small target detection algorithm based on multi-scale block discrete cosine transformation to process infrared small target images. The algorithm takes into account the different characteristics of infrared small target images in airspace and frequency domains, which can effectively detect infrared small targets in complex backgrounds and reduce the false alarm rate.

2. Algorithm Description

2.1 Algorithm Architecture

The proposed infrared small target detection algorithm based on multi-scale chunking discrete cosine transform is shown in Figure 1, which processes the image in the spatial and frequency domains, respectively. In the spatial domain, we use the infrared patch-image model to carry out multi-scale chunking in order to enhance the correlation between background pixels, and at the end of the algorithm we use the airspace dot-multiplication algorithm to suppress the background information. In the frequency domain, the low-frequency coefficients in the discrete cosine transform coefficients are set to zero in order to suppress the background information. the correlation operation is performed by combining the different performances of the background and the small target in the spatial and frequency domains to obtain the final small target detection image.

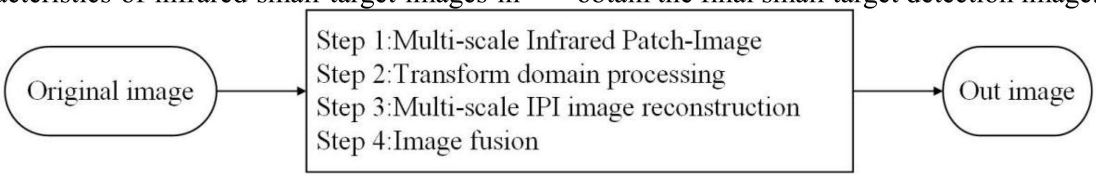


Figure 1. The Algorithm Process in This Article

2.2 Multi-scale Infrared Patch-Image model

Multi-scale Infrared Patch-Image(IPI) model contains two parts: image chunking and image reconstruction[8], Multi-scale IPI image chunking model is shown in Figure 2, in this paper, we use three sliding windows of S1 × S1, S2 × S2 , S3 × S3, respectively, in steps of S1/2, S2/2, S3/2 from left to right, The original image is chunked in a top-down pattern, and the pixels within the sliding window are column-vectorized and sorted and recombined according to the sequential sliding order, finally obtaining a large matrix, which enhances the correlation between the background pixels, as well as the sparsity of the target.

Multi-scale IPI image reconstruction is shown in Figure 3, the reconstruction of the image chunking model in this paper deals with the image after the frequency domain filtering, the image reconstruction is the inverse process of the image chunking, and it is enough to take the median of the pixels of the overlapping region.

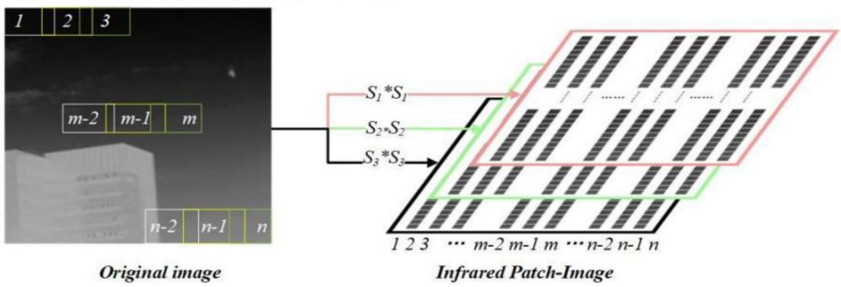


Figure 2. Multi-Scale Infrared Patch-Image

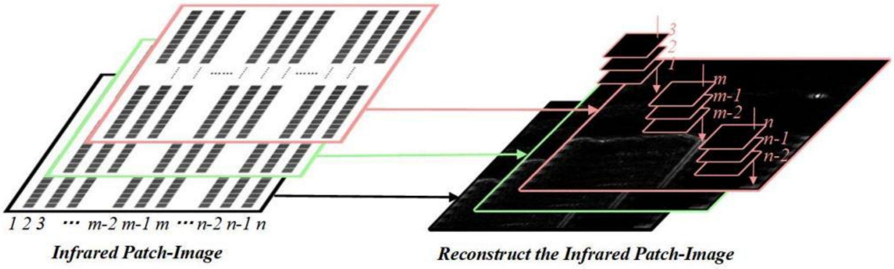


Figure 3. Multi-Scale Infrared Patch-Image Image Reconstruction

2.3 Discrete Cosine Transform

Observing the infrared image, it is not difficult to find that the background occupies most of the area in the image, and there is correlation between the pixels, so the background belongs to the low-frequency information in the frequency domain analysis, while the small target usually occupies only a few to a dozen pixel points in the image, and compared with the surrounding pixels, its pixel value is higher, belongs to the mutation area, and has the sparseness, so the small target should belong to the high-frequency information in the frequency domain analysis.

The discrete cosine transform in digital image processing is commonly used in the field of data and image compression, and its positive transform is defined as Eq. The inverse transform is defined as shown in Equatuion (1) and Equation (2)[15]:

$$F(u,v)=\frac{2}{\sqrt{mn}}\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}f(x,y)C(u)C(v)\cos\frac{(2x+1)u\pi}{2m}\cos\frac{(2y+1)v\pi}{2n} \tag{1}$$

$$f(x,y)=\frac{2}{\sqrt{mn}}\sum_{u=0}^{m-1}\sum_{v=0}^{n-1}C(u)C(u)F(u,v)\cos\frac{(2x+1)u\pi}{2m}\cos\frac{(2y+1)v\pi}{2n} \tag{2}$$

Where $f\ (x,y)$ is the input data, $F(u,v)$ is the discrete cosine transform coefficients of the transform domain, m,n are the dimensions of the input data, x,y are the dimensions of the data in the transform domain, and $C(u)$、$C(v)$ are defined as shown in

Equation (3)and Equation (4) [15]:

$$C(u)=\begin{cases}\frac{1}{\sqrt{m}} & u=0\\ \frac{\sqrt{2}}{\sqrt{m}} & 1\le u\le m-1\end{cases} \tag{3}$$

$$C(v)=\begin{cases}\frac{1}{\sqrt{n}} & v=0\\ \frac{\sqrt{2}}{\sqrt{n}} & 1\le v\le n-1\end{cases} \tag{4}$$

After the image is discrete cosine transformed, the main energy of the image will be concentrated in the upper left corner, which is the low-frequency information; away from the upper left corner of the image for the high-frequency information in the image, in the transformed domain to inhibit the low-frequency coefficients and then carry out the inverse discrete cosine transform can be obtained from the high-frequency information of the infrared image, to extract the high-frequency infrared small targets that need to be detected.

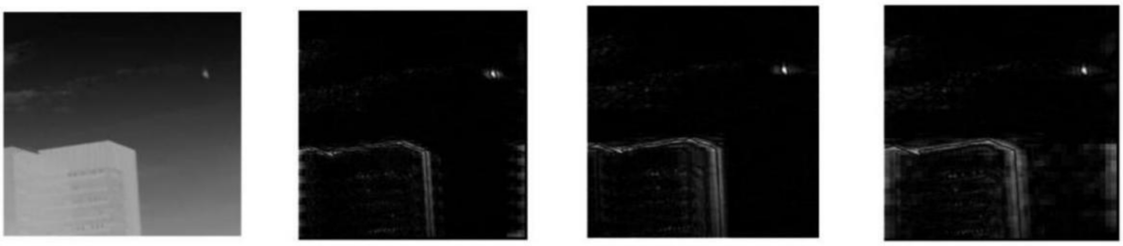
In this paper, the image after Multi-scale IPI chunking is further chunked into 8×8, 10×10 and 12×12 chunks respectively, and the discrete cosine transform is performed on each small chunk, and the coefficient in the upper-left corner of each image chunk are set to zero, and then inverse transformation as well as Multi-scale IPI reconstruction are performed to suppress part of the background region, and the reference results are shown in Figure 4.

After the original image has been processed by Multi-scale IPI and DCT, most of the information in the image has been filtered out, but there are still some edge background regions remaining, observing the resultant figure, it can be found that the infrared small target belongs to the brightest part of the image, with higher pixel value, while the background is darker, with lower pixel value, combining with the above features to further utilize the point multiplication operation to carry out point multi-scale fusion on the image.

2.4 Multi-Scale Fusion

Multi-scale fusion is divided into two steps: dot product operation and threshold segmentation. Firstly, the results of three different scales processing will be obtained after processing in the discrete cosine transform domain, and the image obtained from each scale will be normalized, and the definition of normalization is shown in Eqution (5).

$$f(x,y)=\frac{f(x,y)-f_i}{f_a-f_i} \tag{5}$$



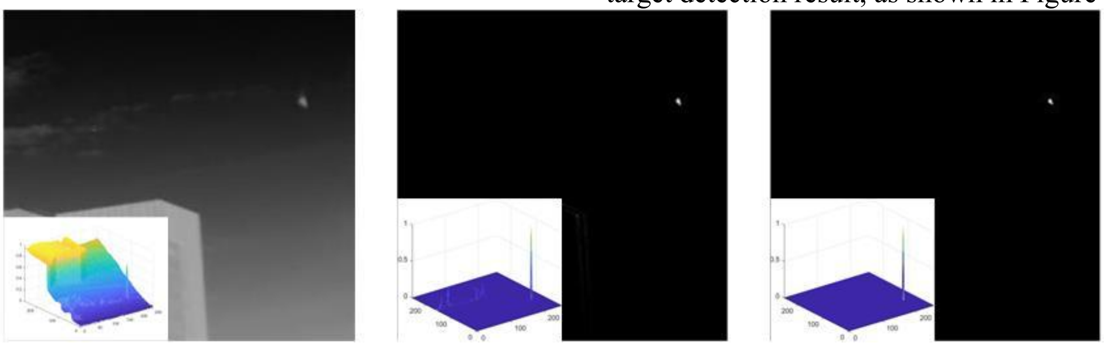
Original image 8× 8 10× 10 12× 12

Figure 4. Multiscale Discrete Cosine Transform Results

Where $f(x,y)$ is the result of three different scales of DCT transform processing, f_i is the minimum value of the resultant map processed, f_a is the maximum value of the resultant map processed, and Eqution 5 is utilized to convert the image pixel value distribution interval to within the [0,1] interval. After normalization, using the three different scales of the image, the dot product operation at the corresponding position in the null domain is performed to further suppress the pixels in the background region, and finally the dot product result map is further thresholded for segmentation, and the threshold G_{TH} is calculated as in Eqution (6)[8]:

$$G_{TH}=f_{avg}(x,y)+H\times f_{std} \tag{6}$$

Where $f_{avg}(x,y)$ is the mean value of the dot product result map and f_{std} is the standard deviation. The dot product result map is further threshold segmented, pixels smaller than the threshold are set to zero, and pixel values larger than the threshold are retained to obtain the final target detection result, as shown in Figure 5.



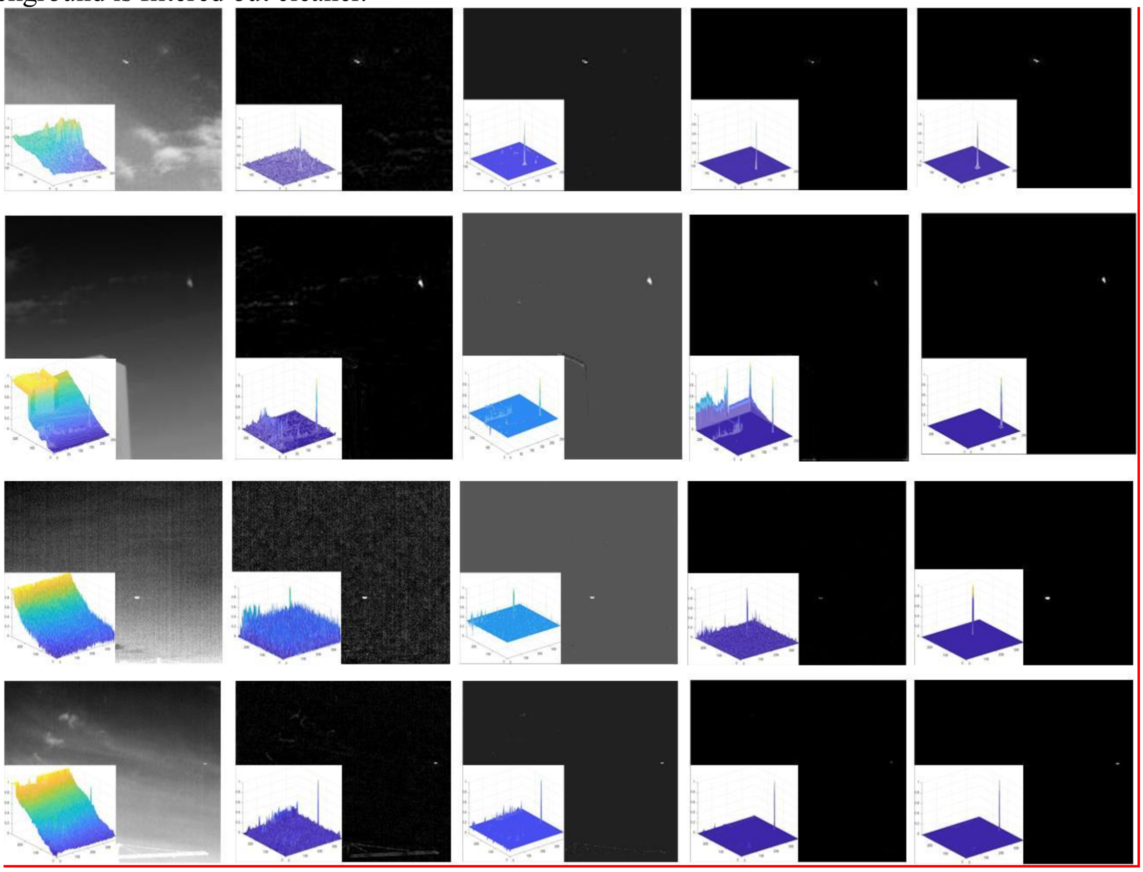
(a) Original Image (b) Dot Product Results (c) Threshold Segmentation Result

Figure 5. Multi-Scale Fusion of 2D and 3D Plots of Each Step.

3. Experimental Results and Analysis

This paper randomly selects four infrared small target pictures with different backgrounds for processing, and at the same time combines the classical Tophat, IPI-APG, and three different scales of DCT dot product three algorithms with the algorithm proposed in this paper to compare, in three different dimensions to objectively analyze the detection effect of the algorithms on infrared small targets.

First of all, comparing the two-dimensional and three-dimensional diagrams of various algorithms as shown in Figure 6. It is not difficult to find that the Tophat algorithm has a better detection effect under the background of the sky, but under the complex backgrounds of various types of buildings, people, etc. the processing results still contain a large number of clutter; IPI-APG algorithm has a small amount of clutter not filtered out in the final detection results of each image; the three different scales of the DCT dot product operation has a better detection effect under the background of the sky and clouds; The three different scales of DCT dot product algorithm in the sky background detection effect is better, but other complex buildings as the background of the detection results still have a small amount of clutter exists, especially in the second picture there is a serious leakage of the alarm and false alarms; this paper's algorithms in the detection of the four images are better performance, there is no false alarms and leakage of the alarms, the background is filtered out cleaner.



(a)Original image (b) Tophat (c) IPI-APG (d) DCT (e) This Paper

Figure 6. 2D and 3D Matlab Simulations of Four Different Algorithms

Secondly, in order to objectively compare the detection effect of the four algorithms on the small targets in four images, this paper introduces the two parameters of signal-to-heterodyne ratio gain (SCRG) and background suppression factor (BSF), the higher the value of SCRG and BSF in the different algorithms indicates that the algorithms are more effective in detecting the detection effect and the better the background suppression effect, and the definitional formulas of the parameters are as shown in Equation (7) and Equation (8)[9].

$$SCRG = 20\times \lg\left\{\frac{(Se/B)_{out}}{(Se/B)_{in}}\right\} \tag{7}$$

$$BSF = 20\times \lg\left(\frac{B_{in}}{B_{out}}\right) \tag{8}$$

Where Se represents the difference between the average gray value of the target and the average gray value of the background, B represents the standard deviation of the background, and the subscripts out 、 in represent the small target image output by the algorithm and the original image input, respectively. The values of SCRG and BSF for the algorithm of this paper and the three compared algorithms are shown in Table 1 and Table 2.

Table 1. BSF Values for Four Different Algorithms

algorithm	1	2	3	4
Tophat	19.1170	21.8702	7.2867	18.9844
IPI-APG	25.8799	25.6813	26.1125	29.7248
DCT	27.9768	19.2897	25.0968	32.5905
This Paper	**28.8010**	**30.8947**	**31.0649**	**34.5199**

Table 2. SCRG Values for Four Different Algorithms

algorithm	1	2	3	4
Tophat	26.6126	32.2189	11.2142	29.0308
IPI-APG	31.3250	29.4492	27.6480	38.1748
DCT	35.6350	29.7051	30.3828	42.8835
This Paper	**36.4609**	**41.3696**	**36.3849**	**44.8160**

Tables 1 and 2, 1~4 correspond to the four original infrared images with different backgrounds from the top to the bottom of column a in Figure 6, respectively, and it can be seen that the SCRG and BSF values of the algorithm proposed in this paper are generally higher than those of other algorithms, which proves that the algorithms proposed in this paper are better than the others in both target extraction and background suppression.

In addition, this paper introduces the ROC curve to compare the false alarm rate and detection rate of each algorithm more intuitively. The ROC curves of the four algorithms are shown in Figure 7, where the horizontal axis is the misdetection rate and the vertical axis is the detection rate. It can be seen that in the four pictures shown in this paper, the detection rate of the algorithm proposed in this paper is higher with the same misdetection rate, and the area enclosed with the horizontal coordinate is the largest, which indicates that the algorithm proposed in this paper is better than the other algorithms.

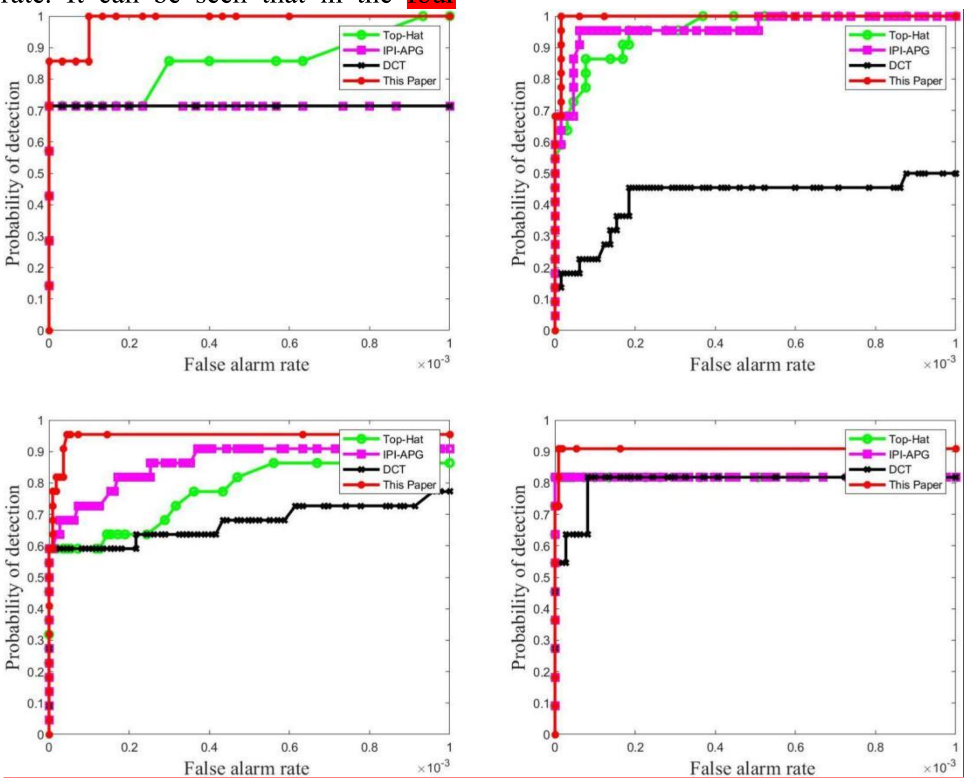


Figure 7. ROC Curves for Four Different Algorithms.

In summary, after analyzing the 2D diagram, 3D diagram, SCRG value, BSF value and ROC curve of different algorithms, it can be seen that this paper's algorithm is better than the comparison algorithm in both subjective qualitative analysis and objective quantitative analysis, and Compared with the classical infrared small target detection algorithm Tophat, the popular IPI-APG algorithm in recent years, and the direct DCT result dot-multiplication algorithm using different templates, the algorithm proposed in this paper is able to be stably applied to the infrared small target detection under the complex background, with a high detection rate and a low false detection rate, and a certain robustness.

4. Conclusion

This paper combines the different characteristics of infrared small targets in the airspace and frequency domain, at the same time, multi-scale analysis is introduced for the uncertainty of the target size to reduce the false alarm rate and improve the detection rate. First of all, the IPI chunking algorithm with different scales is used in the air domain to improve the correlation between the background pixels and the high-frequency characteristics of the target, so as to enhance the effect of DCT transformation to suppress the background; secondly, use block DCT transformation of different scales in the frequency domain to suppress the low-frequency coefficient to suppress the background, and at the same time one step uses IPI reconstruction to enhance the integrity of small target detection.Finally, integrating the effects of different scales for point multiplication and threshold segmentation can not only further suppress the background, but also effectively reduce the false alarm rate. The algorithms of airspace and transformation domain used in this article complement each other, and finally achieve infrared small targets.Compared with the use of DCT transformation alone, the detection avoids the risk of missed alarms and false alarms. Compared with the classical algorithm, the algorithm proposed in this paper has a better detection rate and background suppression effect, and has a certain degree of robustness and practicality.

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