Research on Motion Blur Image of Infrared Target Deblurring Based on Wavelet Transform

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Abstract. Aiming At Removing the Motion Blur to Restore Images, a deblurring Method of Infrared Image Based on Wavelet Transform is Proposed. Determining Whether There is Motion Blur by Using Wavelet Transform to Extract and Analyze the High Frequency Information of Level Subband; Blur Direction and Blur Length Are Calculated by Rotating the Image; the Image Deblurring and Recovery Are Completed by the Optimization Program of Wiener Filtering Algorithm. the Experiments Show That the Proposed Method Can Effectively Removes Motion Blur, and Provide Clear Infrared Images for the Next Image Processing, It Has the Characteristics of Strong Robustness, Good Real-Time Capability and Higher Application Value.

1. Introduction
One of the key technologies of infrared moving target detection and tracking is how to effectively segment the target from the complex background. Because of the motion of the target, the blurred image may affect the accuracy of segmentation and recognition. In order to restore fuzzy images, literature [2] deeply studied the gradient distribution of fuzzy images and non-fuzzy images, and proposed a de-fuzzy algorithm based on the gradient distribution model. Literature [3] proposed a method of low-frequency energy equation based on the low frequency of fuzzy image in the fuzzy direction, which was used to detect the fuzziness and calculate the fuzzy parameters. According to the imaging principle of the image, literature [4] used impact filter, bilateral filter r-map to extract the edges with large gradient of the fuzzy image to predict the relatively clear image, divided the image into several sub-images according to the homographic matrix, established the energy equation, and continuously predicted the image until the image was clear through iteration. In literature [5], by establishing the mathematical model of fuzzy kernel of moving fuzzy image, two-dimensional discrete wavelet transform and auto correlation are adopted to obtain the point diffusion function of fuzzy image, and the image restoration equation is proposed according to the principle of maximum posterior probability and inverse wavelet transform. These methods have achieved remarkable results in fuzzy image processing. Literature [2] provides a new silk road for the restoration of a single image, but its algorithm complexity is high. Literature [3] misidentified the solid color region of the image as a fuzzy region. The mathematical model in literature [4] is relatively complex, and it requires at least 20 iterations to restore an image, with low efficiency. In reference [5], the number of wavelet transform is related to fuzzy scale, the fuzzy kernel can be accurately estimated only when the size of fuzzy scale is known.
In this paper, haar wavelet transform [6] is used to extract the high-frequency information of horizontal sub-band to predict whether the image has motion blur. If so, the fuzzy scale is further deduced, and the fuzzy direction is identified by rotating the image. Finally, wiener filter is used to restore the image.

2. The Theoretical Analysis
The restoration of fuzzy image depends on the correct estimation of the point diffusion function, and the two parameters of the point diffusion function are fuzzy scale and fuzzy direction respectively. The fuzzy scale can be represented as the linear superposition of the points in the fuzzy direction, which is the relative motion direction of the moving target and the camera. Accurate estimation of fuzzy scale and fuzzy direction are the key to motion fuzzy image restoration. In this paper, first of all, samples of horizontal motion fuzzy images and clear images were established. Haar wavelet was used to decompose the sample images into first-order wavelet, and then the high-frequency information of the images was analyzed to estimate the fuzzy scale and fuzzy direction.

2.1 Haar Wavelet Transformation
Wavelet transform is a widely used technique in image processing in recent years. It is based on scaling and displacement of the basic wavelet function to obtain a set of wavelet bases and then represent or approximate a signal. The low-frequency portion of the signal is represented by coefficients generated by a large scaling factor, and the high-frequency component is represented by coefficients generated by a small scaling factor. The wavelet transform can show many characteristics of the signal, such as the trend of the signal, the break point, the discontinuity of the high frequency part and the auto-correlation.

Haar wavelet function is a common basic wavelet with simple calculation and convenient construction. The horizontal and vertical sub-band components obtained by image decomposition contain high-frequency information in different directions, including image edge information, correlation information and mutation information.

The common definition of haar wavelet is shown in equation (1):

$$\psi_{(i)}(t) = \begin{cases} 
1, & 0 \leq t \leq \frac{1}{2} \\
-1, & -\frac{1}{2} \leq t \leq 1 \\
0, & \text{other} 
\end{cases}$$  \hspace{1cm} (1)

According to the Fourier transform, its spectrum can be written as equation (2):

$$\psi_{(\omega)} = \frac{1 - 2e^{j\omega m} + e^{-j\omega m}}{j\omega}$$  \hspace{1cm} (2)

According to equation (1), the corresponding binary expansion translation is:

$$\psi_{m,k}(t) = 2^\frac{m}{2} \psi((2^{-m}t-k))$$

$$\begin{align*}
2^{-\frac{m}{2}}, & 2^{-m}k \leq t \leq (2k + 1)2^{-m-1} \\
-2^{-\frac{m}{2}}, & (2k + 1)2^{-m-1} \leq t \leq (k + 1)2^{-m} \\
0, & \text{other} 
\end{align*}$$  \hspace{1cm} (3)

Where, \( m \) is the scale factor, and changing it can enlarge and shrink the function image. \( k \) is the translation parameter, and changing it can shift the function in the \( x \) direction. Constant factor is
used to satisfy that the inner product is 1, and this value will change if the wavelet function is not defined in interval $[0, 1)$.

For two-dimensional images, the decomposition by haar wavelet transform is carried out independently by rows and columns, which can be divided into standard decomposition and non-standard decomposition. Standard decomposition refers to the transformation of rows first and then the transformation of columns. For nonstandard decomposition, rows and columns alternate. Considering that haar is an orthogonal matrix and has the property of separation transformation, it can be realized by using haar one-dimensional wavelet transform for two consecutive times, and rows and columns transformations can be decomposed by one-dimensional haar wavelet transformation.

By using the above idea, the image can be decomposed into four parts: an approximate image of the low-frequency component, a horizontal sub-band, a vertical sub-band and an angular sub-band of the high frequency by the row and column haar wavelet transform. In this paper, the coefficients of the horizontal sub-band are selected to analyze the high-frequency information of the image.

The coefficient distribution of each row of the horizontal sub-band of the clear image is shown in figure 1, while the distribution of the motion blurred image is shown in figure 2. The horizontal axis is the row pixel coordinates of the horizontal sub-band, and the vertical axis is the horizontal high-frequency coefficient value of the corresponding pixel.

![Figure 1](image1.png)

**Figure 1** the Horizontal Sub-Band Coefficient Distribution of Clear Image

![Figure 2](image2.png)

**Figure 2** the Horizontal Sub-Band Coefficient Distribution of Fuzzy Image

It is concluded that the coefficient distribution of each row of horizontal sub-band of moving fuzzy image obeys the law of periodic decrease, and the pixel length between the peak value and the peak value is the fuzzy scale.

### 2.2 The Estimation of Fuzzy Scale and Fuzzy Direction

The high frequency coefficients of each row of the selected horizontal sub-band are obtained, and the coefficients of the row are calculated by auto-correlation method. The calculation method is shown in equation (4):

$$R(i) = \sum X(n) \times X(n + k)$$

The $R(k)$ of the corresponding position of each row of the image is superimposed:

$$R_{\alpha,i}(k) = \sum_{-\alpha}^{\alpha} R(i) \quad (-\frac{N}{2} \leq k \leq \frac{N}{2})$$

Where $M$ is the number of rows of the source image, $N$ is the number of columns of the source image, and $R_{\alpha,i}(k)$ is the auto-correlation value of the corresponding position of each row.

According to the principle of auto-correlation, when the two peaks with opposite positive and negative values are auto-correlated, the minimum value is obtained, and the number of pixels between
the two minimal of the auto-correlation function is the required fuzzy scale. Figure 3 is the auto-correlation curve of the clear image, and figure 4 is the auto-correlation curve of the fuzzy image. The fuzzy scale calculation is shown in equation (6) below:

\[ \text{length} = |\lambda| + |-\lambda| = 2\lambda \]  

(6)

Further analysis shows that the correct fuzzy direction can be identified by rotating the image, wavelet transform the image in any direction and obtain the corresponding fuzzy scale, and the rotation direction of the maximum fuzzy scale is the fuzzy direction of the required solution. If the fuzzy scale of all directions is less than 4 (threshold), the image can be judged as clear.

3. Algorithm Implementation

The blur generated by the target motion is not a global blur. Firstly, the image is divided into several small sub-blocks, and then each sub-block is viewed as a small image. The operation is carried out on each sub-block to find out the fuzzy region and obtain the point diffusion function of the fuzzy region. Finally, the Wiener filter is used to remove the blur.

The flow chart of the algorithm is shown in figure 5:

As shown in Fig. 6, the fuzzy parameters of the region sub-blocks are obtained by rotating each
sub-block from 0 to 180 degrees in an interval of 1 degree and repeating the process shown in Fig. 5 to obtain the fuzzy scale of each direction. The maximum scale is the fuzzy scale of the required solution, and the corresponding rotation direction is the fuzzy direction of the required solution. If the fuzzy scale of the image sub-block rotation in all directions is less than 4 (threshold), the sub-block can be determined to be clear.

![Figure 6: Calculation Flow Chart of Fuzzy Parameter](image)

After correctly estimating the fuzzy scale and fuzzy direction, this paper adopts Wiener filtering method with optimal window to restore the motion blur in the fuzzy region.

### 4. Algorithm Time Optimization

The time complexity of the above algorithm is high, not only the auto-correlation function of each direction needs to be calculated, but also each sub-block needs to be calculated separately. If the system requires high real-time performance, the algorithm cannot meet the requirements. Therefore, in view of the problem of large time cost, this paper optimizes the algorithm.

1) According to the statistics of natural clear images, although the color distribution of the image scene varies greatly, the log transformation of the gradient obeys the heavy tail distribution. Since most of the image is a constant or gradual region, the continuity of the gradient is interrupted only when the gradient changes greatly near the boundary occasionally. For the fuzzy region, sharpening boundary is basically excluded. The gradient amplitude distribution is concentrated near the small value or zero value, and almost no large gradient value will appear. Therefore, the gradient distribution is mainly concentrated in the small value interval, and the probability of large gradient value is higher than that of Gaussian distribution. Therefore, gradient distribution can be used to detect blur. The log transformation distribution curve of natural clear image gradient is shown in figure 7.
Taking advantage of the fact that the log transform curve of the natural clear image gradient obeys the heavy tail distribution, this paper adopts the method described in [10] to locate the fuzzy area. The localization algorithm can greatly reduce the time cost of the algorithm.

2) The conjugate negative spikes of the auto-correlation curve are symmetrically distributed at both ends of the central positive spike, which satisfies the following equation (7):

$$R(k) = R(-k) \quad k \geq 0$$ (7)

Only half of auto-correlation curve needs to be calculated to obtain the fuzzy scale, thus the amount of calculation can be reduced by 50%.

3) As shown in Fig. 8, the motion fuzzy image established based on the motion fuzzy mathematical model has a horizontal fuzzy direction and a fuzzy scale of 20. Table 1 reflects the change of fuzzy scale after image rotation. It can be seen from table 1 that the fuzzy direction of the image is taken as the reference line, the image is rotated to both sides, and the fuzzy scale gradually decreases. Therefore, it is not necessary to obtain the auto-correlation value of each Angle to determine the fuzzy direction. Instead, the search method of dichotomy can be adopted to gradually locate the rotation direction to the direction with the largest fuzzy scale, so as to obtain the fuzzy direction. In this way, the calculation times can be controlled within a certain range, which greatly improves the operation efficiency.

| Rotation angle (°) | 0   | 15  | 30  | 45  | 60  | 75  | 90  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|
| Fuzzy scale (pix) | 20  | 18  | 18  | 16  | 12  | 10  | 10  |

| Rotation angle (°) | 115 | 130 | 145 | 160 | 175 | 180 |
|-------------------|-----|-----|-----|-----|-----|-----|
| Fuzzy scale (pix) | 12  | 12  | 14  | 16  | 18  | 20  |

**Figure 7** the Distribution Of Log Transform of Natural Clear Image

**Figure 8** a Horizontal Motion Blur Image with a fuzzy scale of 20

**Tab.1-1** The influence of rotation angle on the fuzzy scale calculated in FIG. 8

**Tab.1-2** The influence of rotation angle on the fuzzy scale calculated in FIG. 8
5. Experimental Results and Analysis

Figure 9 shows the infrared target detection scene in the fixed background, which requires to judge whether pedestrians have passed. In some detection algorithms, edge contour features of human body need to be extracted. If motion blur exists, it will blur the edge and affect the accurate recognition of the target. Figure 10 is the result of edge detection in figure 9. It can be seen from the edge detection diagram that the contour of the person on the left is quite vague, and it is difficult to determine whether the person is a pedestrian through the edge after the background difference.

The algorithm in this paper can effectively solve this problem. Firstly, the fuzzy region is detected, as shown in figure 11. Then the fuzzy direction and the scale of the region are calculated. Thus the pixel distance between the two minimum values of the auto-correlation curve is the required fuzzy scale. The fuzzy region of the image reaches the maximum fuzzy scale 22 pixel in the horizontal direction, as shown in figure 12. Therefore, the fuzzy parameters of the fuzzy region are: 0 degree in the fuzzy direction, and 22 pixel in the fuzzy scale. Finally, wiener filter with the optimal window was used to restore the image, and a relatively clear image could be obtained, as shown in figure 13. By using canny operator to extract the edge, a clearer human body contour could be obtained than that in figure 10, as shown in figure 14.
6. Conclusion
This paper presents an algorithm to remove the local motion blur of image. Based on the analysis of high frequency information of moving fuzzy images, an algorithm of extracting high frequency components by haar wavelet transform is proposed. According to the auto-correlation characteristics of the stationary signal, the auto-correlation value of the high-frequency signal is obtained, and the fuzzy scale and direction of the image are obtained by rotating the image. On the basis of ensuring the efficiency of the algorithm, the algorithm is optimized. The algorithm in this paper does not depend on the relationship between front and back frames of video, and can be used to deblur a single image. Experimental results prove the effectiveness and timeliness of the proposed algorithm, which can provide a clear image for further moving target recognition.
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