Stripe Noise Removal for Infrared Images Using Guided Filter

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ABSTRACT

Pixels of different columns in the infrared focal plane array (FPA) have different readout circuit channel, amplifiers in different channel different 1/f noise characteristics. Such noise may cause obvious stripe noise in the infrared images and degrades the quality of captured images. Firstly, analyzed a stripe noise removal method making use of blurred infrared image based on average filter and pointed out the limitation in this method. Then gave the reason that lead to the limitation. On the basis of this, introduced guided filter, and come up with an acquiring strip noise correction term method using 1D guided filter to handle the average row vector of the blurred image. The simulation experiment shows that this method is effective and efficient in removing stripe noise. Moreover, this method has a low time complexity, and can be easily implemented in the project.

Keywords: Non-Uniformity Correction, Stripe noise, Blurred image, Guided filter

1. INTRODUCTION

Uncooled infrared focal plane array (IRFPA) receive the thermal radiation information of field objects and convert them into infrared image. It is a popular infrared thermal detector. For an infrared focal plane array, the pixels in different column have different channel in the readout circuit[1], amplifiers of different channels have different 1/f noise characteristics influenced by time/temperature drift[2]. This difference tends to cause obvious stripe noise in infrared images. The stripe noise degrades image quality by damaging the edges or textures information of infrared images. It has an impact on the observation of scene information and the recognition of target object.

Because strip noise removal is easily affected by scene information, conventional methods are difficult to entirely remove stripe noise without blurring edges or textures information in infrared images. Mark N et al. reported a stripe noise removal method using blurred infrared images[2]. After the remained edges or textures are labeled in the blurred image using a threshold, the stripe noise can be determined by considering difference between horizontal neighboring pixels. This method can remove stripe noise to some extent, but there are still some stripe noise remains in a corrected infrared image. At the same time, the removal result is strongly affected by the threshold that is used to label the edges and textures in the blurred image. Different from the above method, our method introduces guided filter to handle the blurred image, and can remove stripe noise while retaining the edges and textures information well. Also, our method can reduce the remained stripe noise in a corrected infrared image.

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The paper is organized as follows: Section 2 discusses some related work. Section 3 reviews Mark N et al.'s stripe noise removal method and point out the limitation in that method. Section 4 explains the guided filter and introduce it to our noise removal method. The experimental results with comparisons are provided in Section 5. Finally, the conclusions of this paper are presented in section 6.

2. RELATED WORK

Calibration-based nonuniformity correction method cannot update the correction parameters in real time, influenced by time/temperature drift, stripe noise would appear gradually after the parameters adjusted\cite{3}. Traditional scene-based nonuniformity correction method can update the correction parameters\cite{4} in real time, but there are still some remained stripe noise in a corrected image. Especially in some images that contain vertical edge information, the process of removing stripe noise would damage the vertical edge information. Aiming at this problem, a number of papers have been published on techniques for removing stripe noise in infrared images. The approach in \cite{5} apply a threshold parameter, which distinguishes image edges and stripe noise. By setting adaptive threshold value, eliminating the influences of image edges and system noise, the approach can achieve the precise gain and offset parameters and complete the elimination for stripe noise. Cao Y P et al. in \cite{6} discover a polynomial curve model between infrared data and stripe noise of sensor detectors within a column through a set of thermal calibration. Then the stripe noise can be separated from image texture and be removed without blurring the image texture. Wang S P et al. in \cite{7} analyze the influence of column voltage bias on the readout circuit of IRFPA, and propose to estimate the stripe noise using bilateral filter (DMBF). Tendero et al. in \cite{8} \cite{9} compute up with an effective stripe noise removal approach based on column-wised midway histogram equalization (MIRE). These methods work by adjusting intensity distribution of pixels within a column, and can effectively remove stripe noise without blurring image details. However, MIRE need to perform column-based histogram and inverse histogram computations which have a high time complexity, so it is not suitable for real-time implementation in project.

3. LPSF ALGORITHM

In order to reduce the loss of edge information in the process of correction, this method\cite{2} get the stripe noise correction term using blurred image. A threshold is set to detect the motion images and the accumulated motion images are averaged to output a blurred image. While the scene information is moving, a sequence of images are captured and averaged. So in the average image, the scene information becomes blurred but the stripe noise remains prominent. This average image is previously called “blurred image”.

After obtained the blurred image, the method introduce a weight function \(\omega(k)\) to distinguish stripe noise from the remained image texture information, where is:

\[
\omega(k) = \begin{cases} 
1, & \left| f_y(i,j) - f_y(i,j+k) \right| < \alpha \\
0, & \left| f_y(i,j) - f_y(i,j+k) \right| > \alpha 
\end{cases},
\]

where \(f_y(i,j)\) is one pixel in the blurred image, \(\alpha\) is the threshold to distinguish stripe noise from the remained image texture information, \(i, j\) is the row and column coordinate in the image, \(k \in [-4, 4]\) and \(k \neq 0\). For one pixel, compute the value difference between it and its horizontal neighbor pixels in one row, then obtain these weighted average value using weighted function \(\omega(k)\) as the stripe noise estimated term \(f_y(i,j)\). Here,
\[ I_r(i, j) = \frac{1}{|w|} \sum_{k=-4}^{4} \omega(k) \left[ I_f(i, j) - I_f(i, j + k) \right], k \neq 0, \] (2)

where \(|w| = \sum_{k=-4}^{4} \omega(k)\).

Then we can obtain all stripe noise estimated term \(I_r(i, j)\) in a column according to (2). After accumulate and average these correction term, we can acquire the stripe noise correction term \(\bar{V}_r(j)\) for one column, and the \(\bar{V}_r(j)\) is given by:

\[ \bar{V}_r(j) = \frac{1}{M} \sum_{i=1}^{M} I_r(i, j), \] (3)

where \(M\) is the row number of blurred image. Then we calculate the stripe noise estimated term \(\bar{V}_r(j), j \in [1, N]\) for every column in blurred image, so that we obtain the stripe noise estimated vector \(\bar{V}_r, \bar{V}_s \in R^N\).

Last, the stripe noise estimated vector \(\bar{V}_r(j)\) is extended along column direction to form a stripe noise matrix \(S\) which has the same size as the original infrared image,

\[ S = \bar{e} \cdot \bar{V}_r, \] (4)

where \(\bar{e} = [1,1,\ldots,1]^T_M, S \in R^M\). Therefore, we can use the stripe noise matrix to remove the stripe noise in the infrared images.

The process of LPSF algorithm shows in Figure 1. Here, Figure 1(a) is the stripe noise image which is obtained by adding stripe noise to an ideal infrared image; Figure 1(b) is the blurred image; Figure 1(c) is the stripe noise corrected term \(S\) computed by LPSF; Figure 1(d) is the corrected image, as we can see, there are still some remained stripe noise in the image. As described in the following, there are three main reasons which cause the remained stripe noise.

i). There are still some remained edge information in the blurred image, as show in Figure 1(b). The remained edge information would been erroneously assumed to be stripe noise during LPSF filtering the blurred image to obtain stripe noise corrected term.

ii). The threshold \(\alpha\) of weight function \(\omega(k)\). When selecting a bigger \(\alpha\), it would take the edge information which has small amplitude for stripe noise, and lead to removing edge information wrongly. When selecting a smaller \(\alpha\), it would take the stripe noise which has big amplitude for edge information, and lead to remaining stripe noise wrongly.

iii). The method for computing the stripe noise estimated term. Equation (2) is used to computing the stripe noise estimated term. The estimated term has error for the limitation of average filter. So it would cause an error in the stripe noise corrected term \(S\).

4. PROPOSED STRIPE NOISE REMOVAL METHOD

Our proposed infrared image stripe noise removal method derived from LPSF algorithm [2] and modified reasonably.
In our method, we accumulate the blurred image pixel values along the column direction and obtain a row vector by averaging the accumulated pixel values. Then we use 1D guided filter to extract the stripe noise vector from the row vector. So that we can acquire the stripe noise corrected term which has the same size as the original infrared image by extending the stripe noise vector along column direction.

4.1 Guided filter

Guided filter(GF)\cite{10} is a local linear filter, it plays an important role in image enhancement, high dynamic range compression and image dehazing. Guided filtering include input image \( p \), guided image \( I \) and the output image \( q \). The output image \( q \) is a liner transform of \( I \) in a window \( \omega_k \) centered at pixel \( k \):

\[
q_i = a_k I_i + b_k, \forall i \in \omega_k,
\]

where \( a_k, b_k \) are liner constant coefficients decided by pixels of input image \( p \) and guided image \( I \) in the window \( \omega_k \). The radius of the window \( \omega_k \) is \( \gamma \). Within the window \( \omega_k \), there is a constraint equation:

\[
E (a_k,b_k) = \sum_{i \in \omega_k} \left( (a_k I_i + b_k - p_k)^2 + \varepsilon a_k^2 \right),
\]

where \( \varepsilon \) is a regularization parameter penalizing large \( a_k \). Its solution is given by:

\[
a_k = \frac{1}{|w|} \sum_{i \in \omega_k} (p I_i - \bar{p}_k) \mu_k \quad ,
\]

\[
b_k = \bar{p}_k - a_k \mu_k .
\]

where \( \mu_k, \sigma_k^2 \) are the mean and variance of \( I \) in \( \omega_k \), \( \bar{p}_k \) is the mean of \( p \) in \( \omega_k \), \( |w| \) is the number of pixels in \( \omega_k \).

Generally, \( I \equiv p \), so we can obtain:

\[
a_k = \frac{\sigma_k^2}{\sigma_k^2 + \varepsilon} ,
\]

\[
b_k = (1 - a_k) \mu_k .
\]

4.2 Extract stripe noise using 1D guided filter

Known from the above analysis, the remained edge information in the blurred image is the main reason which cause remained stripe noise in the corrected image. For this problem, we accumulate the blurred image \( I \) pixel values along the column direction and obtain a row vector \( \overline{fV} \) by averaging the accumulated pixel values.

Now, we compare the row vector \( \overline{fV} \) with a random row of blurred image (such as 100 200 300 400), as shown in Figure 2. From the figure we can know that the row vector \( \overline{fV} \) obtained by accumulating the blurred image \( I \) pixel values along the column direction has a more slowly changed trend than any row pixel of the blurred image. It means that the remained edge or texture information in the blurred image could be further blurred in the row vector \( \overline{fV} \) and consequently the row vector contains almost no edge or texture information. Compared with stripe noise in the blurred image, the stripe noise in the row vector becomes more prominent. Therefore, extracting stripe noise from the row vector \( \overline{fV} \) can reduce the bad effect of the remained edge information in the blurred image, and to get a better filtering result.
So, after obtaining the accumulated average vector $\overline{V}_f$, we process it using 1D guided filter with proper parameters $\gamma$ and $\epsilon$. Then we can get the stripe noise estimated vector $\overline{V}_s$:

$$\overline{V}_s = (1-a_k)\overline{V}_f - b_k,$$

where $a_k, b_k$ are linear constant coefficients of guided filter, $\overline{V}_f \in R^N$. The stripe noise correction term $S$ can be computed using equation (4).

### 4.3 The process of the proposed method

The process of our method shown in Figure 3. First of all, we should make motion detection (MD) for the current infrared image $I_f$, difference matrix $d_t$ is calculated by the current image subtracting the last moving image:

$$d_t = I_t - I_{m-1},$$

where $I_{m-1}$ is the last moving image. Then we use a recursive learning approach to setting a noise threshold in order to...
distinguish between random fluctuation and actual movement for motion:

\[
\begin{align*}
T_0 &= \infty \\
T_t &= \min(T_{t-1}, \text{var}(d_t))
\end{align*}
\]  
(13)

Then there is a motion detection criterion:

\[
\text{var}(d_t) > 1.2T_t,
\]
(14)

If the above condition is satisfaction, we store the current infrared image as a new moving image and update the blurred image using the following recursive weighting (RW) function:

\[
I_f = (1 - \beta) \cdot I_f' + \beta \cdot I_m,
\]
(15)

where \(I_f'\) is the last blurred image, \(I_m\) is the current moving image, \(I_f\) is the new blurred image, \(\beta\) is the weighted coefficient. If the matrix \(d_t\) is not meet the above condition (14), that means the current infrared is not a moving image and do not update the blurred image.

For a new blurred, compute the new stripe noise corrected term using equation (10) (11) (4). Finally, we can use it to accomplish correcting the stripe noise image.

4.4 Parameter selection of the proposed method

The radius \(\gamma\) of the window and regularization parameter \(\varepsilon\) make an important influence on the performance of guided filter. From the equation (8) (9), we can know that if \(\varepsilon = 0\), then \(a_k = 1, b_k = 0\) and the output \(q = I\). If \(\varepsilon > 0\), we can consider two cases.

i). Texture region. If the image \(I\) changes a lot within \(\omega_k\), we have \(\sigma^2_I \gg \varepsilon\), so \(a_k \approx 1, b_k \approx 0\), the output \(q \approx I\).

ii). Flat region. If the image \(I\) is almost constant in \(\omega_k\), we have \(\sigma^2_I \ll \varepsilon\), so \(a_k \approx 0, b_k \approx \mu_k\), the output \(q \approx \mu\).

Also, if the regularization parameter \(\varepsilon\) is given, the radius \(\gamma\) of the window \(\omega_k\) would influence the variance of the signal in the window, and further influence the output. As shown in the Figure 4, region a contain noise information, region b contain edge information which amplitude is small, region c contain edge information which amplitude is big and changed trend is slow. If we select a big \(\gamma\), then we have \(\sigma^2_{k,a} \ll \sigma^2_{k,b}, \sigma^2_{k,c}\), so the region c can be reserved. If we select a small \(\gamma\), then we have \(\sigma^2_{k,a} \ll \sigma^2_{k,b}, \sigma^2_{k,c}\), so the region c and region b can be reserved. As the accumulated average vector \(\bar{V}_f\) has a slow changed trend, we can extract the stripe noise better by selecting a big radius \(\gamma\) of the window \(\omega_k\) and a proper regularization parameter \(\varepsilon\).

The weighted coefficient \(\beta\) influence the update ratio of blurred image. As the stripe noise is stable at short time, so we choose \(\beta\) during 0.02~1. In order to reducing the affecting to blurred image by random noise, we choose \(\beta = 0.03\).

5. EXPERIMENTS AND RESULTS

In this section, the performance of the proposed technique is thoroughly investigated, and further compared to other

Fig.4 The influence of window size on variance
stripe noise removal method using captured infrared images. First, we served the corrected image using two-point correction method for ideal infrared image. Then adding random stripe noise to the ideal image as noise image and correcting them using different method. Last, we introduce root mean square error (RMSE)\(^{(12)}\) as objective criterion to evaluating the result of different method. Here,

\[
RMSE = \sqrt{\frac{1}{M \cdot N} \sum_{i=1}^{M} \sum_{j=1}^{N} [I_o(i,j) - I_a(i,j)]^2},
\]

where \(I_o(i,j)\) is the ideal image, \(I_a(i,j)\) is the corrected image.

### 5.1 Performance of this method

In order to verify the adaptability of this method for different intensity of stripe noise, we add random stripe noise with different standard deviation (\(\sigma=10\ 20\ 30\ 40\)) to a same ideal infrared image. After that, we removal the stripe noise in the noise image with this method, the Figure 5 shows the result of our method, Table 1 shows the RMSE of the corrected image.

<table>
<thead>
<tr>
<th>(\sigma)</th>
<th>RMSE</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>2.2872</td>
</tr>
<tr>
<td>20</td>
<td>2.3934</td>
</tr>
<tr>
<td>30</td>
<td>3.0974</td>
</tr>
<tr>
<td>40</td>
<td>2.7577</td>
</tr>
</tbody>
</table>

As the Figure 5 and Table 1 shown, our method has the adaptability of different intensity of stripe noise, and can achieve a good corrected result for stripe noise with different standard deviation.

### 5.2 Compare of different method

In order to further state the ability of our method to remove stripe noise, we use different method such as LPSF\(^{(2)}\), MIRE\(^{(8)}\), DMBF\(^{(7)}\) and our method correcting the same noise image, and compare the result. As we can see in Figure 6, we add the same stripe noise (\(\sigma=30\)) to ideal infrared image with different scene information, and then correct them using the above method. After that, the corrected images’ RMSE are been calculated and shown in Table 2.
As the Figure 6 and Table 2 shown, our method can remove the stripe noise for infrared images with different scene information more entirely than the other methods.
6. CONCLUSIONS

This paper provides an efficient stripe noise removal method derived from LPSF algorithm for infrared image based on guided filter. Guided filter can smooth image while reserving the edge information, so it can extract the stripe noise without influencing by the edge information in the image. It has been verified by simulation experiments, the performance of the proposed method is better compared with LPSF algorithm and other different methods through a series of infrared images with stripe noise. However, we cannot select the parameters adaptively which is the main question to be solved following.

References