A new detail enhancement method for high dynamic range infrared image

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Abstract. Due to the width limitation of 8-bit data used in traditional display device, the local details and contrast of the infrared image are compressed. To cope with these limitations, a novel infrared image enhancement method based on CLAHE and multi-scale approach of DoG is proposed. First, the guided image filter is utilized to separate the base layer and detail layer of the image. Then, the improved CLAHE is used to adjust the base layer global contrast and the multi-scale detail boosting is used to enhance the detail features; for the detail layer, multi-scale fast median filter is used for noise reduction. Finally, the two layers are fused according to the weight of the detail layers’ noise level. Comparing with the real-time enhancement methods both in qualitative and quantitative aspects, our proposed method shows the better performance in experiment results.

1. Introduction

Infrared imaging technology, due to its strong anti-interference and all-weather working characteristics, has been widely used in intelligent monitoring, automatic driving and other fields. With the improvement of display accuracy, infrared imaging systems have been applied to HDR (14~16 bit) detectors. However, the traditional display devices only support 8-bit data width, so it is necessary to compress the image to an 8-bit display range, leading to the loss of the image detail information. Existing infrared image detail enhancement methods can be divided into two main categories: mapping and hierarchical processing.

Enhancement methods based on mapping processing, such as histogram equalization(HE)[1], contrast-limited adaptive histogram equalization(CLAHE)[2], plateaus histogram equalization(PHE)[3], are fast and simple, but the enhancements to the details are not obvious and the noises are over-enhancement[4]. Enhancement methods based on hierarchical processing, usually layer the images through guided filter(GF)[5] or bilateral filter(BF)[6], and then uses Gamma calibration[7] or HE methods for different layers. In addition to the above two types of detail enhancement methods, there are also complex methods such as LEPF[8], Retinex-MSR[9], and integrated learning[10]. Although these methods are effective in detail enhancement, there are problems that they cannot be real-time.

For the halo effect[8] and gradient inversion[8] problem that occurs during image enhancement, but bilateral filtering can only be suppressed by other complementary algorithms. In addition, for larger size images, the guided filtering has lower method complexity than bilateral filtering because it does not consider the position between pixels.

In this work, a novel infrared HDR image detail enhancement method based on guided filter and multi-scale approach is proposed. For the base layer, the global contrast histogram is first used to optimize the local contrast over-enhancement problem of CLAHE; then multi-scale decomposition is
used to enhance the local detail. For the detail layer, noise reduction is achieved by asymmetric multi-scale fast median filtering. Finally, adaptive soft weights are built based on the noise level to weight the base layer image and the detail layer image. The method scheme proposed in this paper is shown in figure 1.

Figure 1. The scheme of the proposed method

2. Mechanism Of The Proposed Method
This section will enhance the background and detail layers based on the results of the guided filtering. For the theory of guided filter stratification, please refer to the literature[5].

2.1. Noise Reduction of Detail Layer
Generally, in the infrared image enhancement method, texture information and local contrast information are of great significance. Besides these, the detail noise is also a major factor affecting the quality of the details[11]. Infrared image noise is mainly divided into two categories, Gaussian noise (including thermal noise, shot noise) and impulse noise. A noise model of the infrared image can be constructed according to different noise types:

\[ v = \begin{cases} 
S & \text{Probability is} : p \\
 u + n & \text{Probability is} : 1 - p 
\end{cases} \]  

(1)

Where \( v \) is the observed image, \( u \) is the ideal noise-free image, \( n \) is the additive noise that conforms to the Gaussian distribution, \( S \) is the impulse noise, and the probability of the impulse noise is \( p \). Based on the above model, the following process is proposed: step 1, Gaussian filtering; step 2, global normalization; step 3, median filtering.

2.1.1 Improved Fast Median Filter
Optimized filter operators usually achieve higher accuracy, but for block impulse noise in infrared images, local statistical information needs to be considered. Therefore, it is necessary to optimizing the traditional filter operator in the detail layer enhancement method. HSIEH have proposed an efficient median filter operator[12]. However, when the noise density is too high, real-time processing cannot be realized and the noise reduction effect will decrease. Therefore, an optimized filter operator is proposed, as shown in Figure 2. Empirically, the left operator is used as the noise density is less than 50%, whereas the right operator is applied for the other noise densities.

Figure 2. Employed filter operator; (a) low densities of noise ratio; (b) high densities of noise ratio
In order to remove block impulse noise effectively, the multi-scale filter operator in Fig 2 is iterated in the order of 9, 5, 3 until the amount of noise in the block is less than the threshold. First, the image is divided into blocks; then, the double threshold of the impulse noise is calculated based on the standard deviation and the mean of the block; finally, the pulse point is removed and the median value is calculated. Related parameters are calculated as follows:

\[ u_B = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} B_{i,j} \]  
\[ \sigma_B = \frac{1}{M \times N} \left( \sum_{i=1}^{M} \sum_{j=1}^{N} \left( B_{i,j} - u_B \right)^2 \right)^{1/2} \]  
\[ Th = \text{mid}(B) \pm 2\sigma \]

Where \( u_B \), \( \sigma_B \), and \( Th \) are mean of block, the block standard deviation, and the double threshold of image impulse noise, respectively. Based on the above method, the image impulse noise is attenuated.

2.2. Detail Enhancement of Base Layer

2.2.1. Improved CLAHE

The gray value of the infrared image is more concentrated than that of visible light image and the histogram usually has only one peak. The conventional CLAHE enhancement method causes over-enhancement in the high gray value region of the image and illumination changes in local area. In order to solve these problems, an optimization method for improving local illumination changes by using the illumination invariance of the global histogram is proposed, as shown in Figure 3a. The image contrast optimization formula is as follows:

\[ h_B = \eta h_G + (1-\eta)h_B, \quad \eta \in [0,1] \]

Where \( h_B \), \( \eta \), and \( h_G \) are histogram of block, weight coefficient, and the histogram of global image, respectively. Note: Optimize the local histogram first, then perform CLAHE processing. The effect of local contrast adjustment is obvious, as shown in Figure 3. Image contrast is effectively improved.

![Figure 3. Adjustment effect of different contrast methods](image)

2.3. Multi-Scale Detail Enhancement

The CLAHE enhancement method significantly improves image contrast, but it produces artifacts at the edge locations, such as halos or gray level saturation. It is commonly known that difference of Gaussians (DoGs) can remove image artifacts. Thus, we use the multi-scale method of DoGs to enhance detail. First, we obtain four different blurred images by applying Gaussian kernels with different standard deviations to the CLAHE enhanced image. Then, we extract the details according to the principle of DoG, given by

\[ D_k = I_{base} - F_k \ast I_F, \quad k = [1,2,3,4] \]

where \( F_k \) is the gaussian kernel with the different standard deviations, \( \sigma = [0.5,1,2,4] \), \( I_F \) is the result of the fusion of the detail layer and the background layer, and Symbol \( \ast \) is a convolution operation. Combine all the details \( D_k \) to generate the overall detail enhanced image, by
\[ D_{\text{base}} = (1 - \mu_s \times \text{sgn}(D_i)) \times D_i + \sum_{i=2}^{4} \mu_i \times D_i \]  

(5)

where \( \mu_1, \mu_2, \mu_3, \) and \( \mu_4, \) are fixed to 0.5, 0.5, 0.3, 0.25. \( D_i \) makes the edges of the details sharper, but may also cause gray level saturation. To overcome this problem, function \( \text{sgn}(\cdot) \) is introduced to control the gray scale magnification positively and negatively. Finally, the resulting detail image and the CLAHE enhanced image are linearly weighted. Figure 4 shows the effect of detail enhancement.

3. Experimental Results And Analysis

To verify the performance of the proposed method, it is compared with typical HDR infrared image enhancement methods, such as BFDDE[13], GFDDDE[14], Retinex and CLAHE. A large temperature difference indoor scenario and complex outdoor environment scenario were chosen as the test environment. All the methods are tested on a personal computer (CPU: Intel Core i5-7300, Memory: 8 GB) using MATLAB 2016a.

3.1. Quantitative Comparison

For objective evaluation, two metrics are used to evaluate the enhancement effects of different methods. The first one we chose the classic evaluation metric: PSNR[15], which is defined as

\[
\text{PSNR} = 20 \log \left( \frac{I_{\text{max}}}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} (I_{ij} - R_{ij})^2 / MN}} \right)
\]  

(6)

where \( I_{\text{max}} \) is the maximum intensity of the image before processing, \( R \) is the enhanced image. Higher PSNR indicates better suppression of noise. The second metric is the entropy of image. Higher values mean more detail information. The last metric is the single frame processing time of the method. The comparison results of these methods from different metrics are presented in Table 1.

From the table 1, we can see that CLAHE takes the shortest time on the time consumption metric, and the method proposed in this paper only takes 70ms. After porting through C language, the time is consumed at 13 ms, which means the real-time requirement can be satisfied. Due to the use of multi-scale detail enhancement method, the proposed method performs relatively well in the PSNR metric. The entropy metric of the image is more consistent with the subjective observation results of humans. It can be seen from Table 1 that the method proposed in this paper always maintains the best level of information entropy index, which denotes the image details are largely preserved through the proposed method.

| Scence   | Metrics | Proposed | CLAHE | BFCLAHE | GFCLAHE | MSR |
|----------|---------|----------|-------|---------|---------|-----|
| Indoor   | PSNR    | 12.3     | 11.17 | 11.14   | 12.6    | 10.9|
|          | Entropy | 6.97     | 6.90  | 6.66    | 6.69    | 6.95|
|          | Time (ms) | 70       | 15    | 100.2   | 60      | 177 |
| Outdoor1 | PSNR    | 24.1     | 25.5  | 24.9    | 26.6    | 19.8|
|          | Entropy | 7.95     | 5.71  | 5.55    | 5.59    | 6.2 |
|          | Time (ms) | 73.6    | 13.8  | 96.2    | 66.8    | 181.2|
| Outdoor2 | PSNR    | 20.98    | 19.82 | 20.7    | 24.81   | 16.87|
|          | Entropy | 7.96     | 7.81  | 7.52    | 7.49    | 7.90 |
|          | Time (ms) | 67      | 14.6  | 101.1   | 58      | 149.6|

3.2. Qualitative Comparison

In order to compare the local contrast of the image with the sharpness of the local details of the image, we chose three test scenarios, where the contrast between the indoor scene and the park scene is extremely low, the temperature difference range is large; and the outdoor scene is complex and the local
contrast is low. There are a lot of details in these three scenes. The detail enhancement results of the three scenarios shown in Figure 4 illustrate that our method achieves the best results in both detail and contrast aspects.

In scenario 1, the images after the process of BFCLAHE and GFCLAHE appear blurred in the white frame area as shown in Fig 4. In scene one, the edges of bicycles and streetlights in the white frame area are blurred. Bicycles and street lights can be clearly seen in the images processed by CLAHE and method of proposed in this paper. In scenario 2, due to the large ambient temperature range, all images processed by all algorithms have the problem of gray level saturation in detail enhancement. From the white frame area, the method proposed in this paper performs best in detail and local contrast, while the noise is also the highest; In scenario 3, the white frame area and the black frame area are tested for local contrast change and detail sharpness, respectively. It can be seen that the two methods of BFCLAHE and GFCLAHE have poor contrast in the leftmost white frame area, and the details are blurred. In the white frame area and the black frame area on the right side, the CLAHE and MSR methods have a local contrast over-enhancement. In the middle white box area, CLAHE has artifacts at the edge position, but the details of other algorithms perform well.

In conclusion, the proposed method basically realizes the expected goals, and achieves local contrast optimization and local detail enhancement of the infrared image. In futural research, we plan to integrate the salient features of the target and the idea of integrated learning to further optimize the clarity of the details.

![Figure 4. Qualitative comparison results of the proposed method](image)

4. Conclusion

In this paper, an infrared image detail enhancement method based on block rules is proposed. In order to improve the local contrast of the image, a CLAHE method incorporating global histogram information is used for the base layer image. In addition, in order to remove the noise of the detail area of the detail layer, a fast median filtering method is proposed, which adaptively selects the corresponding filter operator based on the noise density of the region. Finally, the multi-scale DoG method is used to remove artifacts in the detail area and enhance the sharpness of the local detail. Both qualitatively and quantitatively, experimental results demonstrate that the detail enhancement method proposed in this paper is excellent in local contrast optimization, detail enhancement and noise suppression at the detail layer.

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