Tone mapping infrared images using conditional filtering
based multi-scale retinex

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ABSTRACT

Tone mapping can be used to compress the dynamic range of the image data such that it can be fitted within the range of the reproduction media and human vision. The original infrared images that captured with infrared focal plane arrays (IFPA) are high dynamic images, so tone mapping infrared images is an important component in the infrared imaging systems, and it has become an active topic in recent years. In this paper, we present a tone mapping framework using multi-scale retinex. Firstly, a Conditional Gaussian Filter (CGF) was designed to suppress “halo” effect. Secondly, original infrared image is decomposed into a set of images that represent the mean of the image at different spatial resolutions by applying CGF of different scale. And then, a set of images that represent the multi-scale details of original image is produced by dividing the original image pointwise by the decomposed image. Thirdly, the final detail image is reconstructed by weighted sum of the multi-scale detail images together. Finally, histogram scaling and clipping is adopted to remove outliers and scale the detail image, 0.1\% of the pixels are clipped at both extremities of the histogram. Experimental results show that the proposed algorithm efficiently increases the local contrast while preventing “halo” effect and provides a good rendition of visual effect.

Key words: Tone mapping, High dynamic range image, infrared imaging, Multi-scale retinex, Image enhancement, Conditional Gaussian Filter (CGF), Conditional Filtering Based Multi-Scale Retinex (CFBMSR)

1 INTRODUCTION

Infrared image tone mapping is a key step in infrared imaging systems; it is an important topic in the area of image processing because its performance is determines the ability of target detection and recognition for the infrared imaging systems. On the other hand, infrared image is also a kind of typical high dynamic range image. The typical temperature resolution of infrared detector is less than 0.02K, but the difference of temperature radiation usually can reach more than 30K in nature scene, sometimes even can reach above 100K, that is to say, infrared image grayscale distribution range is usually more than 1000. While the gray-level of general displayer is about 256, and the human eye can distinguish about 64 gray-level, so that the infrared image tone mapping is a typical mapping from high dynamic range image to the low dynamic range image.

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Classic tone mapping methods include linear mapping and histogram adjustment based mapping are global processing, so the performance is not ideal. Especially for Linear mapping method, the greater the range of radiation distribution, the lower the resolution of the output image to radiation, and the lower the identification ability to the scenery detail, leading to the lower ability of target detection and recognition. In recent years, many tone mapping algorithm have been proposed. Literature [1] presented a method of compressing the dynamic range of wide dynamic range scenes. The proposed method was based on the multi-scale retinex algorithm. By retaining part of the original image information, 3 scales retinex algorithm was adopted to realize high dynamic image tone mapping, and good result has been achieved with that “halo” effect is weaker and the natural impression of the image is not lost. But this method needs larger convolution kernels to eliminate the "halo" effect, which needs more computation power and does few contributions on image enhancement. In literature [2], an example-based contrast enhancement algorithm which works in the gradient domain was proposed. They utilize Gaussian Mixture Model (GMM) to describe the gradient distribution of an image. Then a GMM-based gradient mapping method was proposed to transfer the gradient of a reference image to the source image. Experimental results showed that the proposed algorithm can enhance the contrast of source images prominently. However, solving the Poisson equation directly will consume lots of CPU time, so it is not suitable for actual imaging systems. Literature [3] presented an adaptive tone-mapping method for high dynamic range images; the image is divided into K different regions using a K-means clustering. And then, each divided region is applied to different global tone mapping operators respectively. In order to reflect local characteristics of the image in the process, they use a logarithmic tone mapping with a different parameter calculated with a centroid of the regions. However, this method does not take the boundary of the adjacent partitions into account, so there will be a border effect inevitably. In Literature[4], a novel filter is proposed for edge-preserving decomposition of an image. And multi-scale decomposition with this filter is proposed to tone mapping a high dynamic range image, which has three detail layers and one base layer. Experimental results showed that the proposed algorithm is good at compressing the high dynamic range while preserving local tiny details, but the selection of scale parameters has a great influence on the result, and there will be a serious "halo" effect when applying to gray images.

In this paper, we present a novel infrared image tone mapping method using Conditional Filtering Based Multi-Scale Retinex(CFBMSR). Firstly, a CGF is using to deal with the problem of classical multi-scale retinex model’s "halo" effect and improving the model of multi-scale retinex. Then, the tone mapping from high dynamic infrared images to the low dynamic infrared images is achieved by using the improved multi-scale retinex model. Experimental results show that the proposed algorithm efficiently increases the local contrast while preventing “halo” effect and provides a good rendition of visual effect. In addition, the proposed algorithm uses the smaller Gaussian convolution kernels, which benefits for image enhancement and the time-consuming problem, so that it can be widely used in the actual infrared imaging systems.

2 ALGORITHM

2.1 Original multi-scale retinex

Multi-scale retinex algorithm is a tone mapping operator, the idea of retinex was proposed by Edwin Land\cite{5}\cite{6}\cite{7} as a model of the lightness and color perception of human vision. retinex estimates scene reflectance from the ratios of scene intensities to their local intensity averages. Firstly, the original image is decomposed into a set of images that represent the mean of the image at different spatial resolutions by applying Gaussian filters of different sizes. Secondly, a set of images that represent the scene reflectance is produced by dividing the original image pointwise by the decomposed images. Finally, the output image is obtained by fuse the reflectance images. The equation that describes the calculation
of a Single-Scale Retinex (SSR) is \[1\]:

\[
R(x, y) = \log I(x, y) - \log \left[ F(x, y) * I(x, y) \right],
\]

where \( I(x, y) \) is the original image, \( * \) is the convolution operator, and \( F(x, y) \) is the surrounding function:

\[
F(x, y) = ke^{-(x^2+y^2)/\sigma^2},
\]

where \( \sigma \) is the Gaussian-shaped surrounding space constant and \( k \) is selected such that:

\[
\int \int F(x, y) dxdy = 1.
\]

And then, the equation that describes the calculation of Multi-Scale Retinex (MSR) is:

\[
R_m(x, y) = \sum_{n=1}^{N} w_n R_n(x, y),
\]

where \( R_n(x, y) \) are different scale SSRs (obtained with different Gaussian functions) and \( w_n \) is the weight of each SSR.

### 2.2 Conditional Gaussian Filter (CGF)

Actually, a serious problem of multi-scale Retinex is the "halo" effect, which is due to Gaussian filter can’t correctly estimated the luminance of current pixel when there are some pixels whose gray-level is serious departure from current pixel in the neighborhood, although literature [1] has proposed two different solutions, but unfortunately, they still unsatisfied for high dynamic infrared image. Firstly, when applying the original multi-scale retinex algorithm to high dynamic range images, four scales(two small, one middle, and one large) were found to give the best results. Although the “halo" artifacts are suppressed, there are still slight “halo" artifacts at the edges. Another problem is that the image looks too bright and the global contrast of brightness [1]. Secondly, literature [1] proposed a second method to suppress the "halo" effect, the main principle is recombination the reflectance with original image, while it is possible to obtain ideal effect, but this method needs a larger Gaussian filter kernel, which is difficult to implement in actual imaging systems. In this paper, a Conditional Gaussian Filter (CGF) was designed to solve these problems.

Suppose \( G(i, j) \) is the gray-level of current pixel whose coordinate is \((i, j)\), and \( F(k, l) \) is the convolution kernel of Gaussian filter, the processing flow of CGF is as follows:

1) Find the neighborhood center to \((i, j)\) which is size of 3\( \times \)3 and mark it as \( C(m, n) \), \( m=\{i-1,i,i+1\}, n=\{j-1,j,j+1\}; \)
2) Calculate the median value of \( C(m, n) \) and denote as \( M_c \);
3) Find the neighborhood center to \((i, j)\) whose size is equal to \( F(k, l) \) and denote it as \( T(k, l); \)
4) Modify the Gaussian kernel using formulation(4):

\[
F_{CGF}(k,l) = \begin{cases} 
F(k,l), & M_c-th \leq T(k,l) \leq M_c+th \\
0, & \text{otherwise} 
\end{cases},
\]

where \( th \) is a selected threshold

5) Reevaluate the coefficients of Gaussian filter’s kernel \( F(k,l) \) by formulation (5):

\[
F_{CGF}(k,l) = F_{CGF}(k,l) / \sum F_{CGF}(k,l).
\]

6) Apply the modified Gaussian filter\( F_{CGF}(k,l) \) to convolution with \( T(k,l) \) and get the filtering result of \( G(i,j) \).

The principle diagram of CGF is showed in fig.1, a) is the original image, and b) is the modified Gaussian filter convolution kernel.
2.3 Conditional Filtering Based Multi-Scale Retinex (CFBMSR)

Hence, we modify the original multi-scale retinex to conditional filtering based multi-scale retinex by apply the CGF instead of the Gaussian filter in equation (1), and recombination the reflectance with original image. So the equations that describe the calculation of CFBMSR are:

**Conditional Filtering Based Single-Scale Retinex (CFBSSR):**

$$R(x, y) = \log I(x, y) - \log \left[ F_{CGF}(x, y) \ast I(x, y) \right],$$  \hspace{1cm} (6)

**Conditional Filtering Based Multi-Scale Retinex:**

$$R_M(x, y) = \sum_{n=1}^{N} w_n R_n(x, y) + w_{\text{orig}} \log I(x, y),$$  \hspace{1cm} (7)

where $w_{\text{orig}}$ is the weight of original image.

And then, the output image of CFBMSR can be computed by the following equation:

$$I_R(x, y) = \exp \left[ R_M(x, y) \right].$$  \hspace{1cm} (8)

2.4 Remapping $I_R(x,y)$

We adopt adaptive linear tensile method to do amendment processing to $I_R(x, y)^{[8]}$. For normal random variables in Gaussian distribution, it is almost certain that the value falls in interval $[\mu - 3\sigma, \mu + 3\sigma]$ ($\mu$ is the mean of $I_R(x, y)$, and $\sigma$ is standard deviation), that is called $3\sigma$ rules. According to $3\sigma$ rules, pixel values whose distance to $\mu$ is larger than $3\sigma$ can be neglected. Thus, low saturation point $L_{\text{low}} = \mu - 3\sigma$ and high saturation point $L_{\text{high}} = \mu + 3\sigma$ are taken out to do linear tensile processing, that is to say:

$$I_O(x, y) = \begin{cases} 
0, & I_R(x, y) \leq L_{\text{low}} \\
\frac{255 \left[ I_R(x, y) - L_{\text{low}} \right]}{L_{\text{high}} - L_{\text{low}}}, & L_{\text{low}} < I_R(x, y) < L_{\text{high}} \\
255, & I_R(x, y) \geq L_{\text{high}}
\end{cases},$$  \hspace{1cm} (9)

where $I_O(x, y)$ is the output image of CFBMSR, and $I_R(x, y)$ is the output image after amendment.

3 EXPERIMENTAL RESULTS

In order to evaluate the proposed method, we adopted two high dynamic range scenes, and compared with linear mapping, the method of literature [1], and the method of literature [4], the experimental results are shown in fig.2 and fig.3. In fig.2, the two methods use the same convolution kernels. In this experiment, the scale factor is $\sigma = 1, 5$ and $9$, respective convolution kernel size is $3 \times 3$, $15 \times 15$ and $27 \times 27$, the method in [1] appeared obvious "halo" effect, and our
method well suppress the "halo" effect and enhance the image detail at the same time. Fig. 3 shown the results of our method and the other three algorithm, where the scale factor in our method is 1, 5 and 9, and scale factor of the method in [1] is 13, 38, 102, corresponding convolution kernels size is 39×39, 114×14 and 306×306. As shown in the pictures, some details are missing by using Linear mapping method, method in [4] is not only weaker on the image enhancement, but also has a serious "halo" effect. Although method in [1] better solve the "halo" effect, but because of applying larger Gaussian filter kernels, the details enhancement is not obvious. Our method not only solves the "halo" effect problem well, and better highlights the details of the scenes.
4 CONCLUSION
This paper presents a tone mapping framework using conditional filtering based multi-scale retinex. A novel conditional Gaussian filter is proposed here which is adopted to improve estimation of the luminance, balance the details enhancement and "halo" effect suppression, improving the image contrast by enhancement image details. In addition, because the method does not need the larger Gaussian convolution kernels, which benefit for image enhancement and the time consuming problem, so that this method can be used in the actual infrared imaging systems and the other types imaging systems such as visible imaging systems and so on.

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