Non-uniform Illumination Image Enhancement Based on Retinex and Gamma Correction

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Abstract. Since ambient light or reflection from the surface of the object, the phenomena of none-uniform illumination exist in images. At present, some problems may appear in the image after the non-uniform illumination image processed by conventional algorithms, such as unnatural, the compressed dynamic range of brightness and halo artifacts in strong edge. To effectively process non-uniform images, the image enhancement based on Retinex theory and gamma correction was proposed. First, the bilateral filter is used to decompose the original image into an illumination and reflectance, to avoid halo artifacts in the reflectance. Second, Gamma correction and are used to equalize the dynamic range of brightness and extended brightness. Finally, the reflectance and the illumination are re-fused to restore the detail and naturalness of the image. The experimental results show that the proposed method effectively enhances the image and maintains the naturalness of the image. The objective evaluation index and computation time are also significantly better than other algorithms.

1. Introduction
The purpose of image enhancement is to make the processed image more suitable for human visual characteristics or easy for machine recognition[1]. Image enhancement has been applied in various scientific and engineering fields, such as atmospheric science, bio-medicine, and computer vision. Under the influence of ambient light or the reflection of the surface of the object, the phenomena of non-illumination exist in captured images, which brings a bad visual effect to the image. In recent years, many image enhancement algorithms have been proposed, such as histogram equalization algorithm, wavelet transform algorithm and Retinex theory based algorithm. However, these algorithms are not suitable for non-uniform illumination image enhancement.

Histogram equalization (HE) is widely used for image enhancement. Many improved HE algorithms have been proposed, such as brightness preservation and contrast limitation[2]. However, for non-uniform illumination images, brightness preservation algorithms are not suitable for enhancing areas where the contrast between light and dark contrasts is large (e.g., dark areas). Since the histograms of different regions are completely different, contrast limitation algorithms is difficult to apply to images with severe non-uniform illumination. The wavelet transform (WT) algorithm decomposes the image into low-pass terms and high-pass terms[1]. However, due to the different degrees of the low frequency and high frequency coefficients, the enhanced image will produce different visual effects while the noise is amplified.

Retinex theory assumes that an image can be decomposed into a reflectance and illumination[3]. Since estimating the illumination from an image is a high ill-posed
problem, Retinex-based illumination estimation is developed by various priors assumptions. Based on the idea of removing the ambient illumination in the original image, a Gaussian center/surround function algorithm was proposed [3], which uses the reflectance as the enhancement result. However, for non-uniform illumination images, halo artifacts may occur near the decomposed reflectance edge. For this reason, a linear guidance filter is used to estimate the illumination [4], which can effectively eliminate halo artifact. Although they can significantly enhance the details, it is impossible to completely eliminate the influence of illumination that are not smooth and have a strong contrast between light and dark. Based on the fact that the illumination is spatially smooth and the reflectance is a piece-wise continuous a priors assumptions, a weighted variation algorithm have proposed by [5], which uses an alternating minimization algorithm to estimate the illumination and the reflectance. But the logarithmic transformation may make the decomposed reflectance lose detail and unnatural. In order to enhance the image while maintaining the naturalness of the image, a bright-pass filter is used to estimate the illumination [6]. However, the computational cost is high.

In order to make the non-uniform illumination image have good visual and ensure a low computational cost, this paper proposes a non-uniform image enhancement algorithm based on Retinex theory and gamma correction. As shown in Fig.1. The first one, the illumination and the reflectance are decomposed from the original image by a bilateral filter. The second one, illumination is corrected to adjust balance between light and dark areas in the image. Last, the reflectance and the illumination are re-fused restore the detail and naturalness of the image.

![Fig.1 The flow chart of our proposed method](image)

2. The proposed Algorithm

2.1. Retinex theory

Retinex theory assume that an image is the product of reflectance and illumination [3], as follows:

\[ I(x,y) = L(x,y) \cdot R(x,y) \]  

(1)

Where \((x,y)\) denote coordinates, \(I(x,y)\) denote original image, \(R(x,y)\) denote reflectance, and \(L(x,y)\) denote illumination. The reflectance represent the color characteristics of the object itself, corresponding to the local details and high frequency information of the image. The illumination represent the ambient brightness, corresponding to the global natural and low frequency information of the image.

2.2. Image decomposition

First, the illumination is estimated, and the maximum values of the three channels R, G, B are taken as the coarse illumination. The coarse illumination \(L_w(x,y)\) is:

\[ L_w(x,y) = \max_{m \in \{R, G, B\}} I^m(x,y) \]  

(2)

Since the coarse illumination contains too much high frequency information, this violates the theoretical assumption that the illumination is spatially smooth. Therefore, it is necessary to refine the coarse illumination. In this paper, the illumination image is extracted using a bilateral [7] filter with edge hold function, and the final estimated illumination image \(L_d(x,y)\) is:

\[ L_d = BF[L_w] = \frac{1}{W_p} \sum_{a \in \Omega(p,q)} |p - q_x| \cdot |q_y| \cdot L_w \]  

(3)
\[ W_p = \sum_{q \in d} G_d(\|p-q\|) G_i(|p-I_q|) \]  \hspace{1cm} (4)

where \( q \) is the center point of the local neighborhood \( q, G_d \) is the spatial distance weight, \( G_i \) is the weight of the two pixel point difference, \( \|p-q\| \) is the Euclidean distance of the pixel point, \(|p-I_q|\) is the pixel difference value, \( W_p \) is a normalization factor, \( G(x) \) is a two-dimensional Gaussian function, and each scale parameter \( \sigma \) is adaptive. The illumination refined by the bilateral filter has the characteristic of maintaining the image smoothness while maintaining the edge, and then separating the reflectance image \( R_c(x,y) \) according to the formula (1) is:

\[ R'(x,y) = I'(x,y) / L_c(x,y), \quad c \in \{R,G,B\} \]  \hspace{1cm} (6)

### 2.3. Illumination remapping

In order to make the illumination image smoother and maintain its shape, the \( L_c(x,y) \) was compressed by the Gamma correction. The remapping illumination image \( L_g(x,y) \) is:

\[ L_g(x,y) = (L_c(x,y))^\gamma \]  \hspace{1cm} (7)

Where, \( \gamma \) is a constant number. As shown in Fig.2, when \( \gamma = 0.8 \), it means that the low gray level of the image can be enhanced, and the high gray level of the image is suppressed.

![Gamma correction](image)

Since the illumination contains the lightness information, the illumination adjusted by Gamma can generate visually pleasing results for dark and high light area, as shown in Fig.2. However, the dynamic range was compressed, it is necessary to appropriately perform grayscale stretching[8] to expand the illumination. The entire dynamic range of the image, to improve the visual effect, the final illumination \( L_m(x,y) \) is follow. Where \( L \) is the gray level range, let \( L = 256 \).

\[ L_m(x,y) = \frac{L-1}{\max_{(x,y)} L_c(x,y)-\min_{(x,y)} L_c(x,y)} \left( L_c(x,y) - \min_{(x,y)} L_c(x,y) \right) \]  \hspace{1cm} (8)

### 2.4. Synthesis of Reflectance and Corrected illumination

As mentioned above, the conventional algorithm uses the reflectance as the final enhanced image by removing the illumination, such as SSR, which makes the image lost its naturalness and the visual effect is poor. Therefore, \( L_m(x,y) \) and \( R_c(x,y) \) are re-fused to restore the detail and naturalness of the enhanced image.

\[ I'_c(x,y) = L_m(x,y) \cdot R'(x,y), \quad c \in \{R,G,B\} \]  \hspace{1cm} (9)

### 3. Experimental Results and Discussions

The algorithm is compared with SSR algorithm[3], WT algorithm[1], DPDHE algorithm[2], NPEA algorithm[6]. It is discussed from subjective and objective aspects, and the running speed of various algorithms is tested. The experimental operating environment is 3.7GHz CPU, 4GB RAM, Matlab2014.

#### 3.1. Subjective evaluation

Fig 3-5(a) shows the non-uniform illumination images in different lighting environments. Due to uneven illumination, the highlighted areas and shadow areas are not clear enough. Each algorithm has a certain enhancement effect compared to the original image.
Fig 3. Image Girl enhancement results

Fig 4. Image Rail enhancement results

Fig 5. Image Fireworks enhancement results

The DPDHE preserves the brightness of the original image, resulting in less efficient to the low-light areas. Since SSR take reflectance as the final results, the light distortion and halo effect of enhancement images are exist, as Fig3(b) and Fig4(b). Although the WT algorithm enhances the local details but amplifies the noise, excessive enhancement occurs as Fig5(e). The NPEA algorithm has better enhancement effect. However, the dynamic range of illumination is compressed, and the enhancement effect of dark regions of some images is not obvious, as Fig 3(e), the areas of the shadows are not clear enough. The algorithm in this paper effectively enhances the details of the image, the image has a better dynamic range of brightness, and the pleasing visual effect.

3.2. Subjective evaluation

Objective evaluation is usually used to explain some important characteristics of images. In this paper, information entropy and VE (visible edge) are used to objectively evaluate the image. The mean value is used to evaluate the brightness of the image. Information entropy is used to evaluate the amount of information in an image, the larger the value indicating more detail. VE is used to evaluate the improved quality of the image contrast after enhancement, which is the higher the contrast of the image.

| Images   | Original | SSR | WT  | DPDHE | NPEA | our |
|----------|----------|-----|-----|-------|------|-----|
| Girl     | 7.21     | 7.71| 8.12| 7.41  | 7.71 | 8.09|
| Rail     | 5.71     | 5.88| 6.04| 5.88  | 6.20 | 6.13|
| Fireworks| 3.67     | 3.58| 3.74| 3.77  | 3.95 | 3.88|
| Average  | 5.53     | 5.72| 5.96| 5.68  | 5.95 | 6.03|

| Images    | Original | SSR   | WT   | DPDHE | NPEA  | our |
|-----------|----------|-------|------|-------|-------|-----|
| Girl      | 1        | 2.24  | 2.45 | 1.72  | 2.24  | 2.45|
| Rail      | 1        | 1.32  | 3.52 | 1.70  | 1.84  | 1.79|
| Fireworks | 1        | 2.13  | 1.94 | 1.41  | 2.13  | 1.94|
| Average   | 1        | 1.89  | 2.63 | 1.61  | 2.07  | 2.06|

Table 1, and Table 2 show the mean and VE. In Table 1, it can be seen that NPEA has a higher information entropy, and the information entropy of DPDHE is lower because the high-density gray level in the histogram combines adjacent gray levels. Since the compressed illumination is expanded
again,NPEA lower than our. In Table 2.WT has the highest VE value because WT has a significant enhancement to high-frequency information, but part of the reason is also caused by over-enhancement. Objective evaluation, proposed algorithm is obviously superior to other algorithm.

3.3. Algorithm running time-consuming
In this paper, two different sizes of images are taken as examples to test the time consumption of the three algorithms. DPDHE and SSR algorithm is also relatively time consuming. However, these algorithms have poor visual effects in processing non-uniform illumination images. Because the algorithm uses the bilateral filtering estimation with low computational requirements. The results show that the proposed algorithm is faster than several of them.

| Image     | DPDHE  | SSR   | WT     | NPEA   | our    |
|-----------|--------|-------|--------|--------|--------|
| 476x750   | 0.07s  | 0.18s | 0.21s  | 13.45s | 0.12s  |
| 2352x3136 | 0.35s  | 2.43s | 4.11s  | 85.42s | 2.23s  |

4. Conclusion
Based on the experiment results and discussions, the conclusions are obtained as below:

(1) Based on the characteristics of non-uniform illumination images, an enhancement algorithm based on Retinex is proposed. Experiments show that the proposed algorithm make a balance between details and naturalness. The proposed algorithm is more effective in enhancing the non-uniform illumination image than the several of conventional algorithm.

(2) The illumination is estimated using a bilateral filter. The feature that the non-uniform illumination image changes greatly in the edge region is fully considered. Avoid the occurrence of halo artifacts.

(3) Gamma correction and gray scale extension. The illumination is effectively balanced between the highlight and dark regions.

(4) After objective testing, the proposed algorithm of is significantly faster than other algorithms, which can meet the real-time requirements of video.

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