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Non-Linear Masking based Contrast Enhancement via Illumination Estimation

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Abstract

Contrast enhancement which is an important part of digital image processing has been studied for a long time and widely used in various fields such as digital photography or medical imaging. The purpose of contrast enhancement is to improve the overall contrast of the image and details on the local area. Contrast enhancement algorithms are classified into histogram based methods, tone mapping based methods, and retinex theory based methods. Particularly, retinex theory is widely applied at the spatial domain contrast enhancement. In this paper, we propose the contrast enhancement algorithm using the estimated illumination. Different from conventional retinex based algorithms, the estimated illumination serves as the tone mapping criterion and masked with original image. The intensity of estimated illumination image is adaptively modulated according to original image to improve the contrast of image effectively. Experimental results show that both global and local contrast are enhanced simultaneously with the proposed algorithm. Objective assessment using performance metrics also shows that the proposed method has the highest scores compared to the conventional methods.

Introduction

Recently, digital images are commonly obtained from various ways such as mobile phones and digital cameras. But captured images sometimes have unintended problems like low dynamic range or under exposure because capturing devices have limited hardware performance compared to the human eye. For example, if photo is taken from the low light environment, overall image is shaded and details are hard to be recognized. At the high light environment, conversely, image intensity is biased to high level and it is also hard to be detected. To solve these problems, various contrast enhancement algorithms are proposed. The main purpose of the contrast enhancement is to improve the contrast of the image by adjusting the intensity. Contrast of the image can be divided into the global contrast which related to overall brightness and the local contrast which has to do with details of the image.

The contrast enhancement algorithms are classified into histogram methods, retinex theory based methods, and tone mapping methods. Histogram based methods are widely used at various fields such as medical imaging and texture synthesis due to their simple application. Histogram equalization (HE) has been the basic histogram based method since its proposition. However, HE may produce unsatisfactory results such as noise amplification, excessive enhancement at the dark space and washed-out appearance. Later, advanced methods based on HE which solve these problems have been proposed: separating histogram as several sub histograms, modifying probability density function (PDF) by grouping bins and obtaining histograms locally [1].

There are various methods to estimate illumination based on retinex theory. All of these methods are based on the concept that observed image can be decomposed into the illumination and the reflectance:

$$S = R \cdot I \,, \tag{1}$$

where S is the observed image, R is the reflectance, and I is the illumination. As mentioned above, since reflectance is the intrinsic characteristic of the object, contrast enhancement is achieved by adjusting the illumination. Retinex-theory based algorithms are classified as follows: Homomorphic filtering, iterative algorithm and optimization based algorithm. Homomorphic filtering is based on the concepts that the illumination is the smooth version of the luminance and Gaussian kernel is used for the blurring. Single-scale retinex (SSR) [2] and multi-scale retinex (MSR) [3] are the examples of homomorphic filtering. McCann et al. proposed the method to estimate the illumination by iteratively combining center pixel with neighbor pixels. Although estimation result is somewhat similar with the result of homomorphic method, overall procedures of the algorithms are different in the way that iteration is used and the characteristic of the convergence. Because these methods have the sameness in terms of weighted averaging, result images necessarily have the halo effect. So, advanced algorithms which use exquisite blurring and consider the edge of the image simultaneously. Optimization based algorithms [4] [5] have to do with minimizing the penalty function. The penalty function has several terms which signify the smoothness, edge preserving, and the similarity of luminance and illumination of the image. The procedure of the enhancement goes through the modification of the estimated illumination using the gamma function or the power function.

Tone mapping, other area of the contrast enhancement, is a method of making a transformation function to match an input value to an output value. These are used for dynamic range compression as well as contrast enhancement. The most common tone mapping methods are gamma function and log function. Although these methods are simple and easily applied, algorithms are applied on all images with the same effect so this cannot ensure the improvement of local areas. For solving these problems, advanced methods using separating tone mapping curve as sub curves have been proposed [6]. Sub curves are applied to the bright area and the dark area respectively and improve both global and local contrast simultaneously.

In this paper, we propose the contrast enhancement method which uses the estimated illumination and non-linear masking to improve global and local contrast according to features of the image. In the section of proposed method, contrast enhancement algorithm which combines the retinex-theory and the non-linear masking is described. In the experimental results section, we conduct objective evaluations of our proposed method with conventional in terms of contrast enhancement with various image quality metrics. Lastly, we

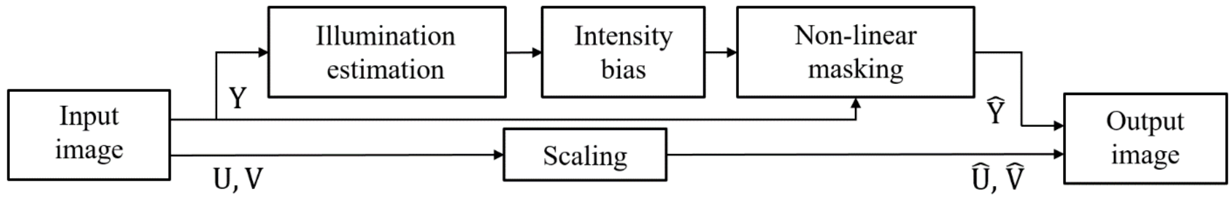

Figure 1. The Block diagram of the proposed method.

discuss the proposed method and conclude our paper in the conclusion section.

Proposed method

Illumination estimation

The proposed algorithm consists of two steps, the first is the illumination estimation and the second is the non-linear masking of the original image and the estimated illumination. Figure 1 shows the block diagram of the proposed method. Illumination estimation and non-linear masking is processed at YUV domain. Illumination estimation algorithm is based on Song's algorithm [7]. The illumination is obtained through the adaptively weighted sum of local blurring and global blurring the image.

At the non-linear masking process, the brightness of the illumination is closely related to the result: the region of the input image where high illumination is masked becomes relatively bright as the result image, and vice versa. To improve global contrast with this effect, the estimated illumination is modified according to the image histogram distribution with transformation as follows:

$$\hat{I} = \begin{cases} \frac{1}{255}(\alpha \cdot I) & \text{if} \quad \gamma < 128 \\ \frac{(255-\alpha)}{255} I + \alpha & \text{if} \quad \gamma \geq 128 \end{cases}, \tag{2}$$

where I is the estimated illumination, $\hat{I}$ is the intensity biased illumination, α is the value which can be obtained by histogram distribution of image, and γ is the average brightness of the estimated illumination. If γ is less than 128, it is assumed that the image is dark and if γ is 128 or more, it is assumed that the image is bright. If the image is dark, the distribution of the intensity is adjusted be in the range of α ~ 255 and conversely if the image is bright, the intensity distribution is adjusted to be in the range of 0 to α. If the distribution of the histogram is left sided, set the α as the bottom 20% of the histogram bin value and in the opposite case, set the α as top 20% of histogram bin value. Figure 2 shows a function that matches the range of illumination according to image brightness.

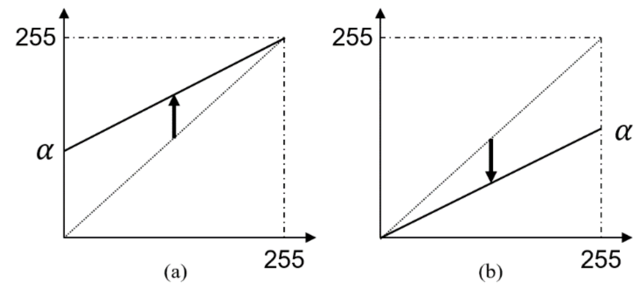

Figure 2. Transformation of the estimated illumination: (a) transformation when γ is less than 128, (b) transformation when γ is greater than 128.

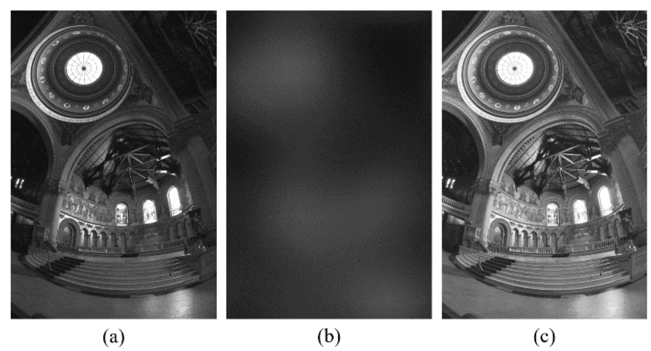

Figure 3. (a) Luminance of the input image, (b) The estimated illumination, (c): the result of non-linear masking.

Non-linear masking

With adjusted illumination, non-linear masking is processed with the luminance and the estimated illumination. Moroney proposed the algorithm [8] to improve contrast through non-linear masking of input image and mask image. However, since the mask image has to be blurred, the halo effect is inevitably generated in the resultant image, and there is a limitation in enhancing the local contrast because surroundings are not considered. The proposed method uses estimated illumination to reflect the image characteristics and the non-linear masking algorithm is applied differently according to the luminance value for effective contrast enhancement. The non-linear masking algorithm is as follows:

$$\hat{Y}_{x,y} = \begin{cases} \frac{2 \cdot Y_{x,y} \cdot (255 - \hat{I}_{xy})}{255} & \text{if } Y_{x,y} \geq 128 \\ 255 - \left(\frac{\hat{I}_{xy} \cdot (255 - Y_{x,y})}{255} \right) & \text{otherwise} \end{cases}, \tag{3}$$

where $\hat{Y}$ denotes the final adjusted luminance which is to be combined with U and V, $\hat{I}$ denotes the intensity adjusted illumination, and Y denotes the luminance of the image. We divided the non-linear masking process into two parts with 128 values of luminance.

By applying different equations to each area separately, we can improve the contrast effectively. In the dark region, the estimated

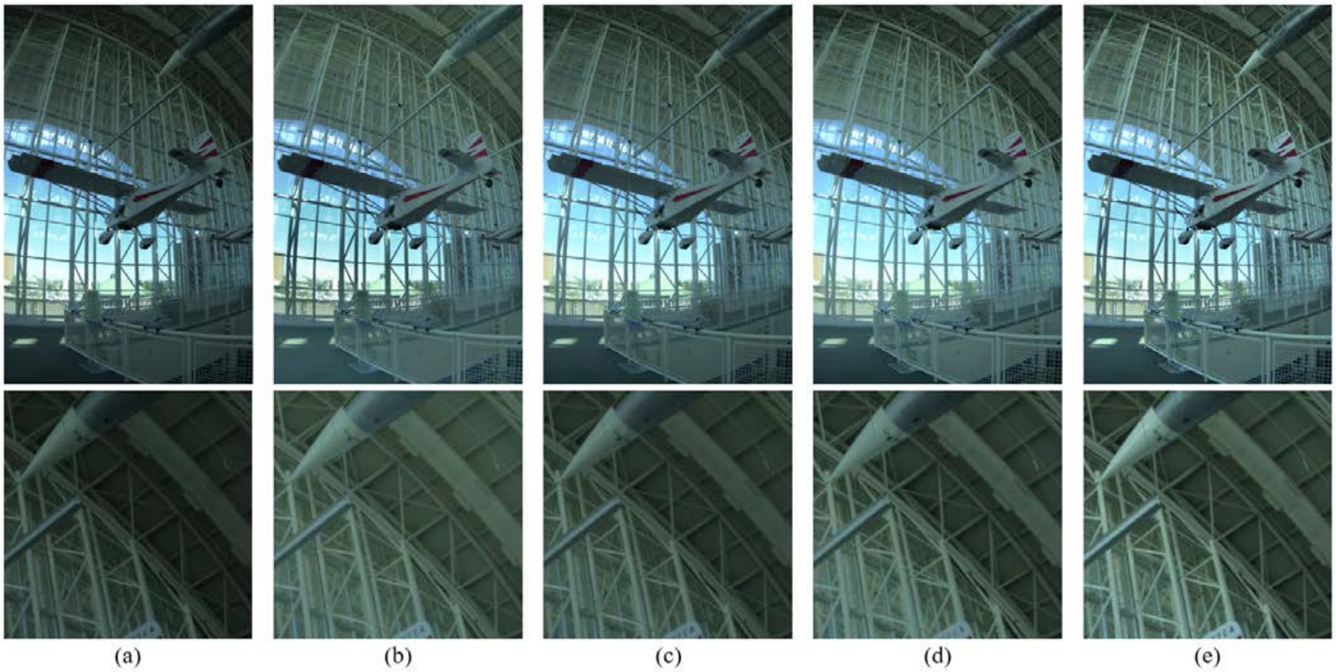

Figure 4. The Original image and results of conventional methods and the proposed method. (a) The original image, (b) CM1 [8], (c) CM2 [9], (d) CM3 [10], and (e) PM.

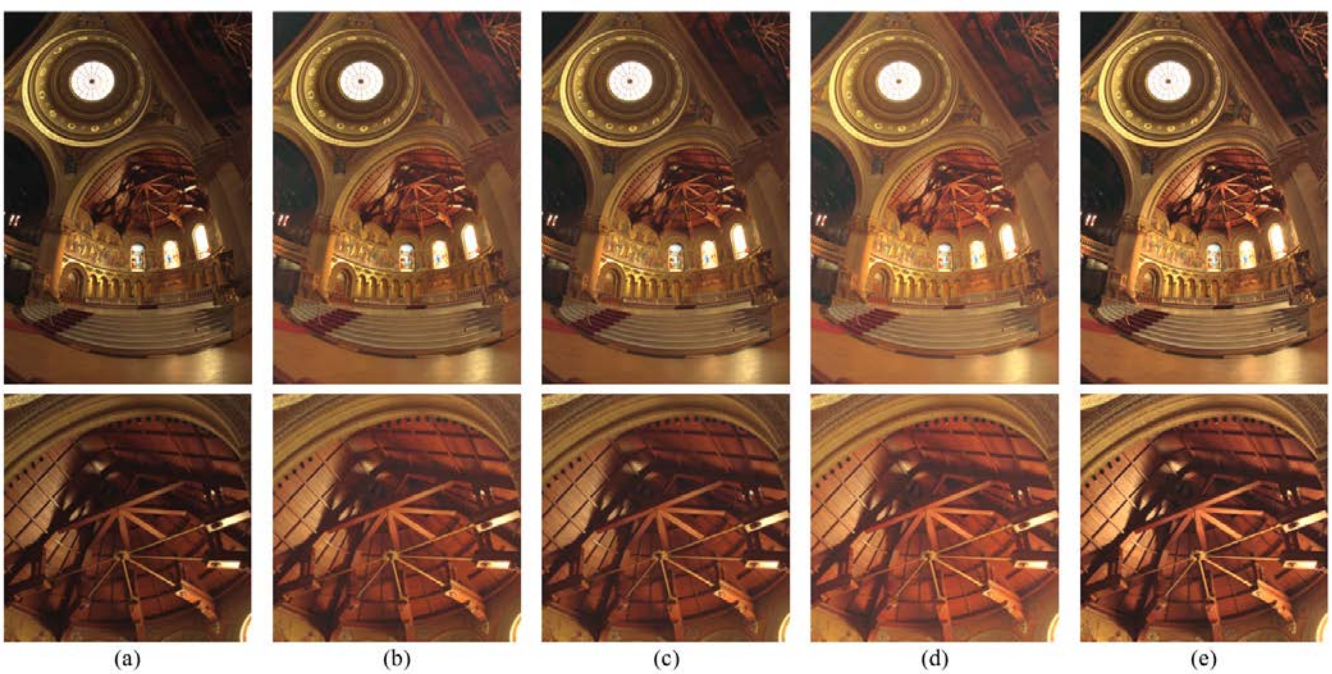

Figure 5. The Original image and results of conventional methods and the proposed method. (a) The original image, (b) CM1 [8]*, (c) CM2* [9]*, (d) CM3* [10]*, and (e) PM.*

illumination has a low value, so that the effect of increasing the brightness of the dark region from the non-linear masking algorithm can be obtained. In the opposite case, the effect of reducing the brightness can be obtained. Figure 3 shows the luminance of the image, the estimated illumination, and result of the non-linear masking. When comparing the luminance and the result of masking, the local contrast of the image and the global contrast improvement can be seen.

Combined with the adjusted *Y*, *U* and *V*, the adjustment of *U* and *V* is necessary. Since each YUV channel is derived from

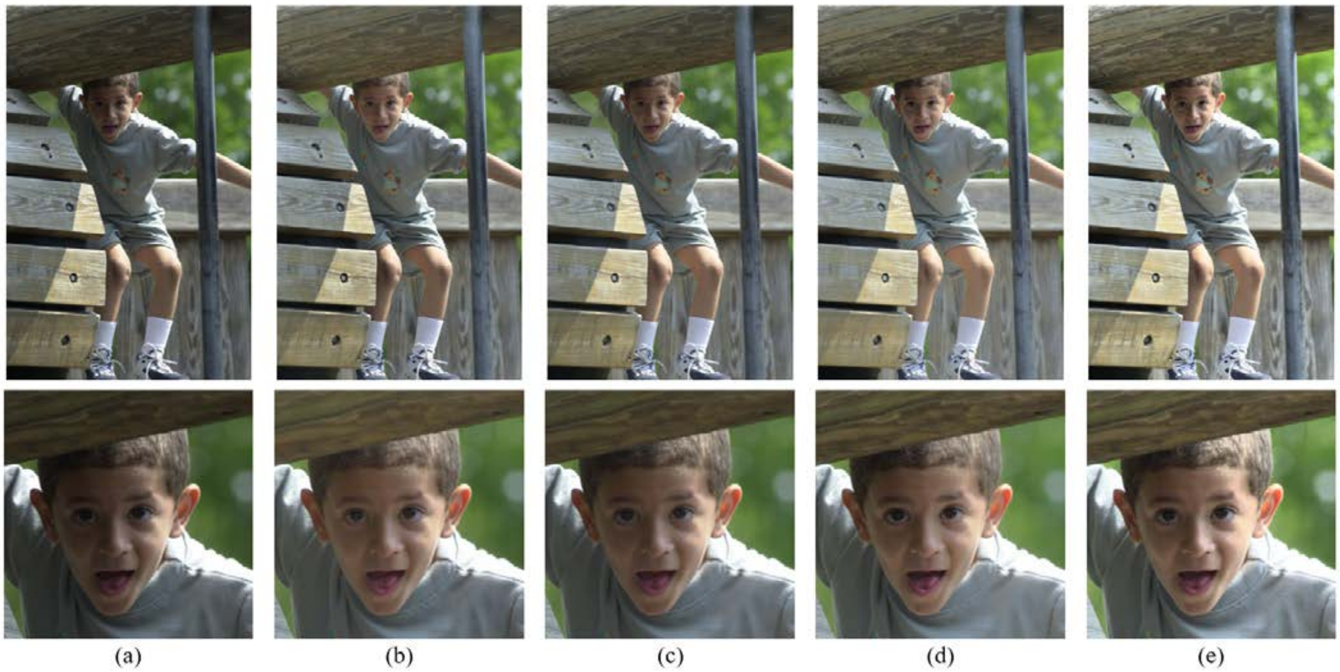

Figure 6. The Original image and results of conventional methods and the proposed method. (a) The original image, (b) CM1 [8]*, (c) CM2* [9]*, (d) CM3* [10]*, and (e) PM*

the correlation of the RGB channels of the image, the chroma component of the result image is inevitably distorted if the luminance is changed. So, the U and V channels need to be adjusted as much as the amount of change in the luminance, and the process is done from the power function as follows:

$$\hat{U}_{x,y} = \left(U_{x,y}\right)^{\frac{\hat{Y}_{x,y}}{Y_{x,y}}}, \quad (4)$$

$$\hat{V}_{x,y} = \left(V_{x,y}\right)^{\frac{\hat{Y}_{x,y}}{Y_{x,y}}}. \quad (5)$$

Experimental results

The proposed method is applied to image sets and compared with other conventional algorithms. The overall contrast of the image is improved and it can be seen that the proposed method is also effective to improve the contrast of the local area. In Figure 4-6 include a full-size image to show the global contrast enhancement of the image, and cropped images to show the local contrast enhancement. From subjective comparisons global contrast has been improved as with conventional methods and local contrast has been improved more effectively than these methods. Local contrast tends to be decreased because the difference in detail brightness is reduced in the local region through the global contrast enhancement. The proposed method shows strengths different from conventional methods in this respect and shows that local contrast is effectively improved at result images.

For objective comparisons, the results were evaluated using several image quality performance metrics such as DIQM [11], RME, RAMMG [12], and IQAJND [13]. Scaling of each evaluation index was adjusted to improve visibility. Table 1-3 show the results of the evaluation with these metrics. From evaluations with metrics, the proposed method has the highest scores of metrics compared the conventional methods. From evaluations with metrics, the proposed method generally has the highest value.

Table 1. Measurement result of Figure 4.

	CM1	CM2	CM3	PM
DIQM	3.46	3.10	2.82	3.21
RME	6.29	6.01	6.57	7.90
RMS	1.04	1.37	1.10	1.13
RAMMG	1.32	1.22	1.28	1.62
IQAJND	7.61	7.24	7.76	9.96

Table 2. Measurement result of Figure 5.

	CM1	CM2	CM3	PM
DIQM	4.21	4.17	3.86	4.30
RME	1.15	1.14	1.14	1.31
RMS	2.46	2.32	2.85	2.72
RAMMG	2.77	2.72	2.69	3.61
IQAJND	12.49	11.64	14.96	17.73

Table 3. Measurement result of Figure 6.

	CM1	CM2	CM3	PM
DIQM	2.87	2.73	2.55	2.70
RME	0.41	0.41	0.40	0.53
RMS	1.03	1.06	1.14	1.24
RAMMG	0.95	0.92	0.92	1.16
IQAJND	6.08	6.14	6.34	8.80

Conclusion

We proposed contrast enhancement method uses the estimated illumination and non-linear masking with tone mapping to improve global and local contrast according to features of the image. Different from the conventional method, the proposed method has the advantage. By using the estimated illumination, the information of the light source can be used to the contrast enhancement and also the halo effect can be reduced. The proposed method not only has versatility to images but also has better contrast enhancement results over the other algorithms.

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