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Color Image Enhancement using Multiscale Retinex with Modified Color Restoration Technique

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Abstract

In this paper, a new technique for the enhancement of color image using multiscale retinex with modified color restoration has been proposed. The basic steps of multiscale retinex algorithm have been analyzed, modified and various operations are performed in an orderly manner. The enhancement effects are visually effective. In addition, it adds true color constancy to an image. The experimental results show that multiscale retinex method based on color restoration technique is an efficient and computationally inexpensive. The proposed method not only provides true color fidelity for poor quality images but also averages the color components to gray value for balancing colors.

Keywords: Image Enhancement, Multiscale Retinex, Color Restoration, Gaussian function.

1. INTRODUCTION

Color image enhancement plays an important role in Digital Image Processing [1]. The purpose of image enhancement is to get finer details of an image and highlight the useful information. If a person acquires an image by using a digital camera or mobile, the illumination such as fluorescent lamp in a room or sunlight in an open air is apt to be uneven and uncontrolled. As a result, the image degrades leaving excessively dark or brighter regions in an image. Many image enhancement methods were proposed to enhance images degraded by irregular illumination: intensity transformation, histogram modeling, homomorphic filtering and Retinex [2]. Human vision system is able to adapt to the changes of lighting conditions but machine vision cannot adapt itself to the color changes. Therefore, discrepancies often exist between direct observation of scenes and recorded color images.

D. Brainard et al. [3] proposed theoretical study of retinex based on convergence properties of Land's retinex theory and showed that the pixel values converge to simple normalization when both path and length keep increasing. However, the retinex path based methods have high computational complexity. B. Funt et al. [4]

proposed an iterative version of retinex which uses 2D extension of path version. In this work, a new value for each pixel is computed by iteratively comparing pixels in an image. However, the number of iterations is not defined and thus affects the final results.

Daniel J. Jobson et al. has proposed multiscale retinex [5], which fills the gap between color images and the human observation of scenes. The enhanced image has good dynamic range compression and color constancy. The algorithm provides results that are favorable for human visual perception and improves contrast. In this work, the number of image processing tasks is performed simultaneously without sufficient regard to the interactions occurring between the tasks. Further, the operations like gamma adjustment, color balance, color enhancement, dynamic range compression, etc. are not specified in proper order. The method fails to produce good color rendition for a class of images that contain violations of the gray world assumptions as pointed by Barnard and Funt [6]. Although Barnard's method overcomes gray world problems, color restoration is not efficient.

Hongqing Hu et al. [7] proposed an improved retinex image enhancement algorithm. The algorithm has very good performance in color constancy, contrast and computational cost. However, the retinex based image enhancement is done in HSV color space rather than RGB space. Thus an additional step is necessary to convert an image from RGB to HSV color space and vice-versa.

Youhei Terai et al. [8] proposed a retinex model for color image contrast enhancement. The luminance signal is processed to reduce the computation time without changing color components. But the computation time of this approach is still large due to large scale Gaussian filtering. The algorithm performs better for gray images rather than color images, since color components are preserved.

An image enhancement algorithm based on retinex theory proposed by Li He et al. [9] replaces brightness value of each pixel by the ratio of brightness value to the average values of the neighboring pixels. The enhancement based on Retinex is suitable for images that are complicated, weakly illuminated, enlarged dynamic range.

A new color image enhancement algorithm based on human visual system based on adaptive filter is proposed by Xinghao Ding et al. [10]. The algorithm utilizes color space conversion to obtain a much better visibility. The algorithm has better effectiveness in reducing halo and color distortion. However, the algorithm may not be efficient from computation point of view.

The drawbacks mentioned earlier are overcome in the proposed method in an efficient way. To start with, the fundamental steps of standard retinex method have been analyzed. In the next step, various operations are performed in a systematic way so that their effects can be observed and true color constancy is maintained. The proposed method has few parameters to be assumed and provides true color fidelity. Moreover, the algorithm is computationally inexpensive, since an additional step is not necessary to solve the gray world violation problem.

In order to test the algorithm, standard test images have been used and test results are compared with other retinex based image enhancement methods. In the proposed method, four parameters are used to test the image enhancement performance. Based on histogram comparison, contrast enhancement performance, luminance enhancement performance and Peak Signal to Noise Ratio (PSNR) performance are measured.

This paper is organized as follows: Section 2 gives a brief review of original Multiscale Retinex Algorithm. Section 3 describes the proposed Multiscale Retinex method based on modified color restoration. Section 4 provides simulation results. Finally conclusion is made in Section 5.

2. MULTISCALE RETINEX ALGORITHM

A color component from conventional image formation model can be represented as follows:

$$f_i(x, y) = l_i(x, y)r_i(x, y), i \in \{R, G, B\} \quad (1)$$

where $0 < l_i(x, y) < \infty$ denotes the illumination component of an image and $0 < r_i(x, y) < 1$ denotes reflectance component of an image. This model assumes that the illumination varies slowly such that its frequency spectrum lies in the low frequency part of the image and reflectance varies rapidly such that its frequency part lies in the high frequency part of the image. Based on image formation model as described by Equation (1), image enhancement can be applied to RGB color components. In Single Scale Retinex method proposed by Jobson et al. [5], the illumination $l_i(x, y)$ is estimated by applying a linear Low Pass Filter (LPF) for an input color image, $I_i(x, y)$. The output color image $R_i(x, y)$ is obtained by subtracting the log signal of the estimated illumination, which is 2D convolution of Gaussian surround function and original image of i^{th} component as per Equation (2):

$$R_i(x, y) = \log I_i(x, y) - \log[F(x, y) \otimes I_i(x, y)] \quad (2)$$

where $i \in \{R, G, B\}$, $R_i(x, y)$ is the retinex output for channel ' i ', $I_i(x, y)$ is the image value for i^{th} channel, \otimes denotes convolution and $F(x, y)$ is a Gaussian surround function. The convolution $[F(x, y) \otimes I_i(x, y)]$ represents illumination estimation and is a convolution of Gaussian functions with original image.

The Gaussian Surround Function $F(x, y)$ is given by Equation (3).

$$F(x, y) = K_n \times F_n(x, y) \quad (3)$$

$$F_n(x, y) = e^{-\left(\frac{x^2 + y^2}{cn^2}\right)}$$

where x & y are spatial coordinates, c is the standard deviation of Gaussian distribution that determines the scale which is assumed as 80, 120 and 250 for three channels.

$$K_n = \frac{1}{\sum \sum F_n(x, y)}$$

where n is the number of scales, $n=1$ for red color component, 2 for green color component and 3 for blue color component.

The Multiscale retinex is given by Equation (4):

$$F_{MSR_i}(x, y) = \sum_{n=1}^N W_n R_n(x, y) \quad (4)$$

W_n is the weighting factor assumed as 1/3 in Ref. [5], since total value becomes approximately unity for the three color components.

The Multiscale retinex with color restoration is given by Equation (5):

$$F_{MSRCR_i}(x, y) = C_i(x, y) F_{MSR_i}(x, y), i \in \{R, G, B\} \quad (5)$$

$$C_i(x, y) = \beta \{ \log[\alpha I_i(x, y)] - \log[\sum I_i(x, y)] \}$$

β = gain constant, α = strength of non-linearity.

The color image enhancement proposed by Numan Unaldi et al. [11] provides color consistency between the original image and enhanced image and is described using equation (6):

$$\begin{aligned} R_{enh} &= \frac{I_{enh}}{I} R \\ G_{enh} &= \frac{I_{enh}}{I} G \\ B_{enh} &= \frac{I_{enh}}{I} B \end{aligned} \quad (6)$$

where I is given by $\max[R(x, y), G(x, y), B(x, y)]$,

I_{enh} is the enhanced intensity image and R_{enh} , G_{enh} , B_{enh} are the restored color components of original colors R , G , B respectively. Further in Ref. [11], in order to enhance color image, color restoration is accomplished using Equation (7):

$$\begin{aligned}
R_{enh} &= R \left(\frac{I_{enh}}{I} \right)^{\frac{1}{\gamma}} \\
G_{enh} &= G \left(\frac{I_{enh}}{I} \right)^{\frac{1}{\gamma}} \\
B_{enh} &= B \left(\frac{I_{enh}}{I} \right)^{\frac{1}{\gamma}}
\end{aligned} \quad (7)$$

In Ref. [11], the value of γ is assumed as 0.77. The restored image consists of halo effects due to the color decomposition. However the color constancy and color restoration obtained from this method is application specific.

3. PROPOSED MULTISCALE RETINEX METHOD BASED ON MODIFIED COLOR RESTORATION

The operational sequence of the proposed algorithm for multiscale retinex method based on modified color restoration technique is shown in Figure (1). The original image of poor quality is read in RGB color space. The color channels are separated followed by the estimation of Gaussian surround function using Equation (3). Single Scale Retinex (SSR) is obtained for each channel using Equation (2). Further, Multi-Scale Retinex (MSR) operation is carried out by using Equation (4). In the proposed approach, the color restoration block is modified in such a way that the number of operations is reduced. In order to get the image pixel values in the standard unsigned range of 0 to 255, the multiscale retinex image (F_{MSR_i}) of Equation (4) is multiplied by a factor 28.44, followed by a positive offset of 128 as shown in Equation (8). This operation translates image pixel values in multiscale retinex format from ± 4.5 range to 0 to 255, which is suitable for obtaining visually acceptable picture. Also an additional processing step is carried out using Equation (9) in order to solve the gray world violation (which means whitening of pictures as shown in Figure 2d later on). The $\log(1+x)$ is used in place of $\log(x)$ to ensure a positive result and also to overcome undefined range for $\log(0)$.

$$F'_{MSR_i} = F_{MSR_i} \times 28.44 + 128 \quad (8)$$

$$I'(x, y) = \log \left(1 + C \frac{I(x, y)}{\sum_{i=1}^3 I(x, y)} \right) \quad (9)$$

where $i \in \{R, G, B\}$. In Ref. [5], a value of 125 is suggested for the constant C . This value empirically settles to 100 for a specific test images. Further, $1/255$ is

multiplied in order to maintain the value of image in the range of 0 to 255 using Equation (10).

$$F'_{MSR_i}(x, y) = \frac{I'_i(x, y) \times F'_{MSR_i}(x, y)}{255} \quad (10)$$

$$F_{MSR_i}(x, y) = \{G \times F'_{MSR_i}(x, y)\} + b \quad (11)$$

where G is final gain, b is offset

The choice of scale is application dependent but for most of applications three scales are required. The multiscale retinex with color restoration is computed by using Equation (11). The result of the above processing will have both negative and positive RGB values and the histogram will typically have large tails. Thus a final gain-offset is applied to get an enhanced image. The gain of 2.25 and offset value of -30 is used in this method.

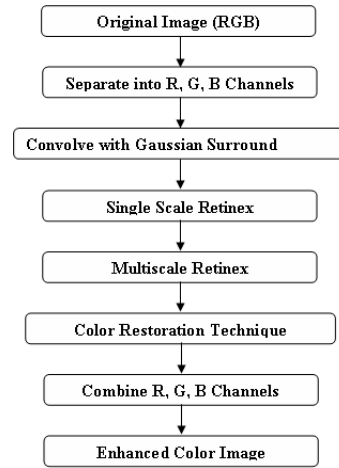


Figure (1) Flow Sequence of the Proposed Modified Color Restoration Method

4. SIMULATION RESULTS

Elaborate experiments were conducted by considering a number of poor quality test images. As examples, results for three different images are presented in Figure 2. The algorithm was coded and verified using Matlab version 7.0. The first column of Figure 2(a), (b), and (c) shows the original image. In Figure 2(a), the face of the person, books on shelf, color template behind the man is scarcely visible. In the second test image shown in Figure 2(b), the eyes of the girl and reflection in the window of car are barely visible. In the last test image of Figure 2(c), the darkness of the wall, adjacent greenery, color of the sky etc. are poor in quality.

Figure 2(d), (e) and (f) show the color images enhanced by NASA's multiscale retinex method of Jobson's et al. The images enhanced by this method are better in quality but certain areas of the image get whitened due to inefficient color restoration. The image enhanced using color restoration of NASA is more

efficient than the other color restoration methods, but the details of the image are not clear. For instance, the girl's reflection in the car window shown in Figure 2(e) is not clear.

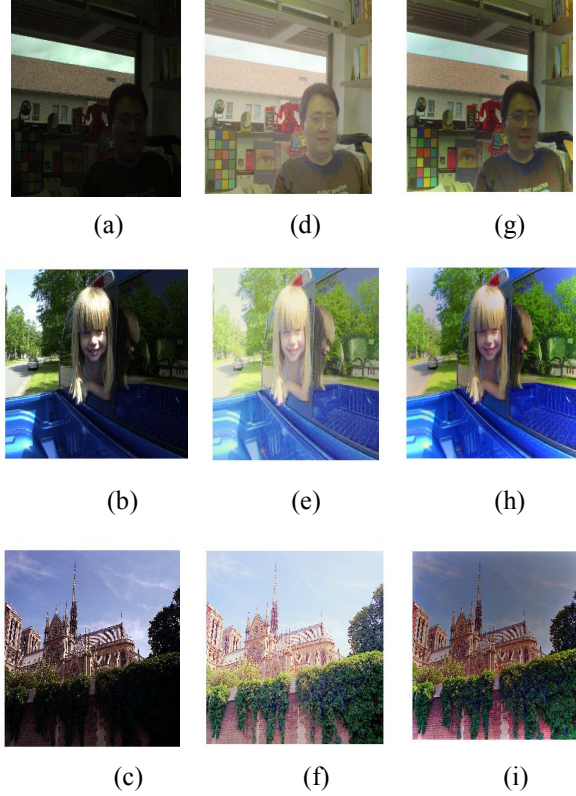


Figure 2 First Column: Original Image.
Second Column: NASA Retinex based Color Image Enhancement.
Third Column: Proposed Color Image Enhancement.

Figure 2(g), (h), and (i) show the results of image enhanced by the proposed color restoration technique. The face of the person, books on shelf, background etc. in Figure 2(g), the reflection in car window, eyes of the girl in Figure 2(h), and the wall, greenery etc. of Figure 2(i) are all enhanced much better than NASA method.

In order to evaluate the performance of the proposed method, we consider histogram plot, contrast enhancement performance, luminance enhancement performance and peak signal to noise ratio (PSNR). The contrast enhancement performance, C and Luminance enhancement performance, L and PSNR is evaluated using the equations:

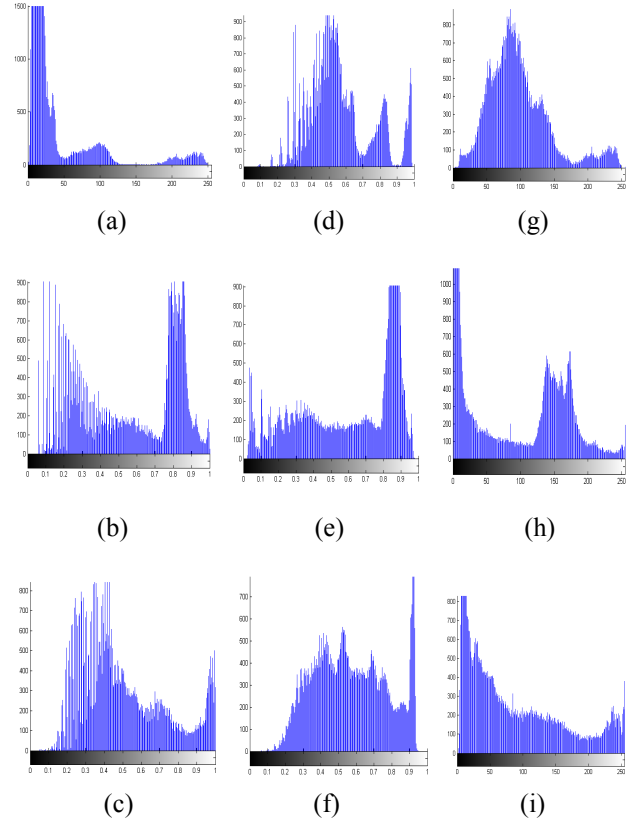
$$C = \frac{\sigma_{out} - \sigma_{in}}{\sigma_{in}} \quad (12)$$

$$L = \frac{I_{out} - I_{in}}{I_{in}} \quad (13)$$

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \quad (14)$$

The Mean Square Error (MSE) is given by

$$MSE = \sum_{x=1}^m \sum_{y=1}^n \frac{(E(x, y) - I(x, y))^2}{m \times n} \quad (15)$$



X-axis: Pixel intensity level Y-axis: No. of pixels
Figure (3) First Column: Histogram plots for original image. **Second Column:** Histogram plots for the image enhanced using NASA technology. **Third Column:** Histogram plots for the proposed method.

where σ_{out} is variance of the luminance value of the output image, σ_{in} is the variance of the luminance value of the input image, I_{out} is the mean of the luminance value of the output image, I_{in} is the mean of the luminance value of the input image, $E(x, y)$ is the enhanced gray pixel at position (x, y) , $I(x, y)$ is the original gray pixel at position (x, y) and, m and n denote the size of the gray image.

Table (1) shows the contrast, luminance and PSNR value comparison for images of Figure 2(d) and (g) respectively. Similarly, Table (2) shows the performance comparison for images of Figure 2(e) and (h) respectively. Likewise, Table (3) shows the contrast, luminance and PSNR comparison for images of Figure

2(f) and (i) respectively. From Tables (1) to (3), it is clear that the proposed method has nearly the same contrast performance and PSNR values as compared to NASA technology, whereas the luminance of the image is enhanced by 60% or more revealing greater details of the images.

Table 1 Performance Comparison of Figure 2(d) and Figure 2(g)

Parameter	NASA Method	Proposed Method
Contrast	0.8010	0.7384
Luminance	0.4966	0.7754
PSNR (dB)	42.5	42.5

Table 2 Performance Comparison of Figure 2(e) and Figure 2(h)

Parameter	NASA Method	Proposed Method
Contrast	0.7717	0.7362
Luminance	1.3281	1.8091
PSNR (dB)	37.6	37.8

Table 3 Performance Comparison of Figure 2(f) and Figure 2(i)

Parameter	NASA Method	Proposed Method
Contrast	0.7235	0.6913
Luminance	0.5899	0.8632
PSNR (dB)	37.3	37.3

This method provides a balance between contrast and luminance. The proposed method offers better pixel distribution compared to other methods as is revealed in the histogram analysis presented in Figure (3).

5. CONCLUSION

A novel method for color image enhancement using multiscale retinex with modified color restoration technique in RGB color space was presented. In this method, operation steps are organized in a systematic way so that their effects can be seen clearly. In addition, it adds true color constancy for an image. The proposed image enhancement method constitutes a successful enhancement of color images since the method improves the luminance of an image without sacrificing the contrast of an image. The performance of the proposed method was tested for contrast enhancement performance, luminance enhancement performance, peak signal to noise ratio and histogram. The image quality obtained using this approach was far better compared to standard existing methods. Currently, work is under progress for amending the algorithm for aerial images, medical images etc.

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