A COLOR IMAGE ENHANCEMENT TECHNIQUE USING MULTISCALE RETINEX

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***Abstract*—In this work we develop a new technique to enhance color images using multiscale retinex theory. The proposed technique consists of four major steps. In first step Principal Component Analysis (PCA) is used on the input colored image to obtain the luminance channel. In second step luminance channel is enhanced using multiscale retinex. In third step the ratio of enhanced luminance to the original luminance is calculated. Meanwhile new red, green and blue values of images are computed by multiplying the luminance ratio with initial red, green and blue values of the colored image. In fourth step, contrast stretching is performed on each red, green and blue channel separately. Detailed experiments were performed on 81 colored images having non-uniform luminance. The results of proposed technique show that the brightness and the overall visual appearance of the image are increased as compared to conventional methods such as histogram equalization, histogram specification and gamma correction with less execution time.**

Index Terms—**PCA, Luminance, Contrast stretching, Histogram Equalization, Histogram Specification**

I. INTRODUCTION

In many cases, images obtained from the digital cameras suffer in quality such as unclear details, distorted colors, lighting level drops as the distance increases from the light source. Such effects occur because digital cameras lack in color constancy, color rendition along with broad dynamic range [1]. Color constancy failures and simultaneous contrast are two major phenomena which severely degrade the usefulness of colored (RGB) image. Generally color images have two major drawbacks due to scene lighting conditions. First is the dynamic range problem [2] which occurs when images captured and displayed by photographic and electronic cameras lose details and colors in shadowed zones. The other is color constancy problem [3] occurring due to loss of color distortions when spectral distribution of illuminant varies. Color constancy was first achieved and explained in Retinex Model which suggests that both Retina (eye) and Cortex (brain) participate in color perception. Most of the published work in literature is related to modifying retinex theory to achieve image enhancement along with color correction.

In the last four decades many algorithms have been proposed to enhance color images. In [4] authors claimed image enhancement by applying grey scale techniques to color images without disturbing hue of pixels. Published work does not explain about correcting distorted colors in images. In [5] researchers presented an image enhancement method using the quantum-behaved particle swarm optimization with an adaptive strategy by proposing Beeta transformation. Experiments were performed on well-known bench-mark images to evaluate the performance of enhancement algorithm. This strategy does not explain about RGB images having non-uniform lighting conditions.

In [6], the research group proposed single scale retinex (SSR) with implementation of center retinex theory. It had a drawback that for a small scale it had compression in dynamic range and for a large scale tonal rendition occurs. Researchers in [7] discussed retinex image enhancement techniques with superposition of different scales with weights and SSR to balance flaws encountered in [6] but it showed color distortion when applied to RGB images.

Conventional techniques such as histogram equalization, histogram specification and gamma correction are not always useful in practice because digital images can be spoiled by these techniques in certain cases. However, these techniques can be handy in some scenarios [8]. The authors in [9, 10] discussed multiscale values for retinex image enhancement with more experimental rather than hit and trial approach. Algorithm performs well on normal RGB images but suffers on dark images due to sun light. In [11] another effort is based on Mondrian Patterns which suggests the presence of lightness of the objects in the scenes independent of variations in the illumination. These calculations are based on psychophysical experiments and research results concluded that the lightness is processed independently in RGB images. Researchers in [12] proposed an adoption of retinex processed with Gaussian filter to enhance RGB images. The filter shape is adapted to follow regions of high contrast edges, trying to eliminate the artifacts introduced in the colored (RGB) images. The published work in [13, 14] have shown good basic results on classifying and identifying objects and microaneursyms for enhanced end user experience and early detection of diabetic

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retinopathy respectively to extend the work further for image enhancement.

In this paper, we develop a new technique based on multiscale retinex theory and PCA to enhance color images under non-uniform lighting conditions. After applying PCA we applied Multiscale Retinex (MSR) on the luminance image with different scale values. Then ratio of luminance was calculated with the original luminance and finally contrast stretching was performed for color restoration. Application of MSR with PCA revealed nice compression of dynamic range, color constancy and nice visual appearance of the colored image in less execution time. Fourier transform theory was also used in our algorithm to reduce the computational time. Experimental results show that proposed technique has better performance than the conventional techniques in terms of visual appearance and time execution. The developed technique is very simple and can be used in most cases to enhance colored images.

The paper is organized as follows: In section II we discuss conventional image enhancement methods. Section III explains Retinex theory, SSR, MSR with centre/surround Gaussian function. Section IV explains the proposed method. Experimental results are presented in section V. Finally conclusions and future research directions are given in section VI.

II. Conventional Approaches

Three conventional methods Histogram Equalization, Histogram Specification and Gamma Correction are briefly reviewed.

A. Histogram Equalization (HE)

In HE, contrast of the image is adjusted using image histogram. In our work HE was applied to each red, green and blue components of the RGB image. Histogram equalization was performed in following three steps.

1. Compute input image histogram.
2. Compute normalized sum of image histogram.
3. Transform original image to get resulting image.

B. Histogram Specification (HS)

In many cases histogram equalization does not provide the required results so in such cases, it is more useful to specify the final histogram. Histogram specification was performed in following three steps.

1. Equalize the initial histogram of image.

$$T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j) \qquad (1)$$

Where, r_k is the input intensity, L is the total intensities and p_r is the probability of particular intensity.

2. Equalize the target histogram.

$$s_k = G(z_q) = (L-1)\sum_{i=0}^{q} p_z(r_i) \qquad (2)$$

where s_k is the processed intensity for target histogram.

3. Obtain the inverse transform.

$$z_q = G^{-1}(s_k) = G^{-1}(T(r_k)) \qquad (3)$$

where z_q is the inverse mapping of the target histogram to original histogram.

C. Gamma Correction (GC)

Using GC transformations, brightness of an image can be improved. It maps closely to the brightness control on a cathode ray tube and adjust nonlinear responses in imaging sensors, display and film. Its mathematical representation is:

$$output = (input)^{1/\gamma} \qquad (4)$$

A gamma γ, of 1.0 results in the null transform. Gamma values less than 1.0 and greater than 0.0 create exponential curves that dim an image. For flat panel display monitors gamma values range from 1.4 to 2.8.

III. Retinex Theory

The retinex theory is based on the assumption that how the human visual system treats the images with three retinal-cortical systems, each processing the low, middle and high frequencies, thus producing the unique lightness values. Each lightness value is related to red, green, and blue planes. Fig. 1 shows the general behaviour of human visual system.

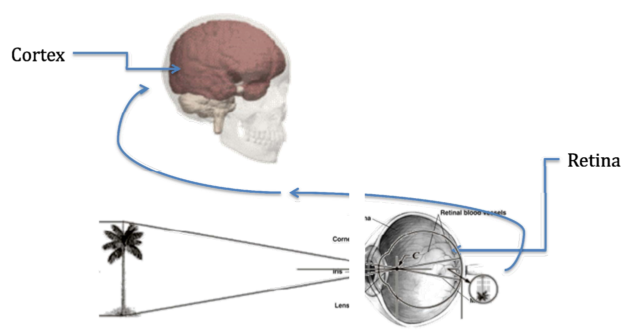


Fig. 1: Human visual system (HVS)

A. Single Scale Retinex (SSR)

Mathematical form of SSR is:

$$R_i(x,y) = log\, I_i(x,y) - log[F(x,y) * I_i(x,y)] \qquad (5)$$

where $I_i(x, y)$ is the image distribution in the i-th color band and $F(x, y)$ is the normalized surround function satisfying the condition as given by

$$\iint F(x, y)dxdy = 1 \quad (6)$$

Since image distribution is the product of scenes reflectance and illumination so

$$I_i(x, y) = S_i(x, y) * r_i(x, y) \quad (7)$$

where $S_i(x, y)$ is the spatial distribution of illumination and $r_i(x, y)$ is the distribution of scene reflectances. The convolution with surround function works as averaging in the neighbourhood given by:

$$R_i(x, y) = log\frac{(S_i(x,y)*r_i(x,y))}{(\overline{S_i(x,y)r_i(x,y)})} \quad (8)$$

Normally illumination has slow spatial variation, which means

$$S_i(x, y) \approx \overline{S_i(x, y)} \quad (9)$$

So it is obvious that color constancy is obtained.

$$R_i(x, y) \approx log\frac{r_i(x,y)}{\overline{r_i(x,y)}} \quad (10)$$

Here various surround functions could be used. The inverse square spatial surround function is given by

$$F(x, y) = 1/r^2 \quad (11)$$

The exponential formula with absolute parameter is given by:

$$F(x, y) = Kexp^{(-r/c)} \quad (12)$$

Gaussian function is given by

$$F(x, y) = Kexp^{(-r^2/c^2)} \quad (13)$$

In our work we used Gaussian function because experiments revealed that Gaussian has the characteristics of being more regional and showed good dynamic range compression over a large range of space constant. Selection of space constant is connected with visual angel in the direct observation. Literature survey shows that there is a trade-off between dynamic compression and color rendition. The middle of the range from 50 to 100 pixels has acceptable compromise.

B. *Multi Scale Retinex(MSR)*

Because of the trade-off between the dynamic range compression and color rendition, an appropriate value of scale 'c' in equation (13) must be chosen. For a compromise between dynamic range compression and color rendition, a combination of weighted different scale of SSR which is actually MSR is found to be a good choice. Mathematically MSR is given by:

$$R\ MSRi = \sum_{n=1}^{N} \omega_n R_{ni} \quad (14)$$

Where N is the number of the scales and R_{ni} is *i-th* component of the *n*th scale. The first query about MSR is that what should be number of scales required, scale values and weight values (ω_n). Our experiments showed that three scales are sufficient and weights can be equal. We used scales of 15, 85 and 255 because in real life we do not know the scale of images. The weights can be changed to adjust compression in dynamic range and color rendition. The MSR based images have significant dynamic range compression in the boundary between the lighted parts and dark parts, and reasonable color rendition in the whole image scale.

IV. Proposed Method

Firstly, using PCA we transformed the input colored (RGB) image into luminance and chrominance. Applying PCA provided orthogonality among the channels. Furthermore, colors also remain stable despite the change in luminance. Performing PCA on an input image, we obtain an image with first channel having luminance information and the other two having chrominance information. Table 1 shows the general pseudocode of this PCA based procedure. On the average PCA consumed 1.10 seconds on input RGB image.

The luminance channel is enhanced using MSR. We obtain the ratio of enhanced luminance to original luminance and then multiply it with each R, G, and B signal of input. Finally, contrast stretching is performed on each plane to get the output image.

Table.1 General pseudocodo of the PCA based procedure

1. Get the initial Red, Green and Blue components of colored RGB image.
2. Peform matrix-to-vector representation.
3. Calculate eigenvectors and eigenvalues.
4. Normalize luminance.
5. Choose components and form a feature vector.
6. Derive the new data set and later get the old data back.

A. *Applying MSR*

MSR is a type of retinex algorithm which integrates different SSR outputs to generate a final output colored image having good dynamic range compression along with color constancy. In our work we use weight values (ω_n) = 1/3 with three weight scales in equation 14. To reduce the processing time of MSR and to strengthen our technique, the convolution theorem of the Fourier transform is applied. Mathematical expression for Discrete Fourier Transform (DFT) and its inverse transform for a two-dimensional signal at size M by N is given below:

$$F(u, v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x, y) \exp\left[-j2\pi\left(\frac{ux}{M} + \frac{vy}{N}\right)\right] \quad (15)$$

$$f(x,y)=\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}F(u,v)\exp\left[j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right] \quad (16)$$

Where $F(u,v)$ is the frequency domain expression of signal $f(x,y)$. Combining the DFT term in eq. 15 and eq. 16 with MSR given in Eq. 14, the new form of MSR is:

$$R(x,y)=\sum_{n=1}^{N}\omega_n\ \{\log I(x,y) - \log[F^{-1}(I'(u,v)F'_n(u,v))]\} \quad (17)$$

Where $I'(u,v)$ and $F'_n(u,v)$ are the DFT solutions of original image $I(x,y)$ and the *nth* surround function $F_n(x,y)$ respectively.

Two dimensional DFT can also be performed through the Fast Fourier Transform on the cast of increased computational time. Since luminance component is two dimensional signal, so the one dimensional Fast Fourier Transform (FFT) is applied separately into its rows and columns. Hence, FFT significantly improves the processing time of MSR. On the average applying MSR consumed about 0.90 seconds during its execution.

B. Luminance ratio and New Red, Green, Blue values

New Red, Green and Blue values for the colored image are obtained using the following equations:

Luminance ratio = Enhanced luminance / Original luminance

R_{new} values = (Luminance ratio) ($R_{original}$ values)

G_{new} values= (Luminance ratio) ($G_{original}$ values)

B_{new} values= (Luminance ratio) ($B_{original}$ values)

Luminance ratio calculation took 0.03 seconds to give new RGB values for colored image.

C. Contrast Stretching (CS)

In the last step of the algorithm, contrast stretching is performed. Two common types of contrast stretching algorithms are the basic contrast stretching and the ends-in-search. In the histogram of a low contrast image, the pixels are concentrated on the right, left, or in the middle. Images which have high contrast contain regions of both dark as well as light.

Contrast stretching is performed on an image to stretch a histogram to fill the whole dynamic range of the image. For Gaussian or near-Gaussian distributions best results are obtained. The mathematical form of contrast stretching is:

$$new\ pixel=\frac{old\ pixel-low}{high-low}\ \text{x}\ 255 \quad (18)$$

In the proposed technique, basic contrast stretching was applied on each red, green and blue channel separately. Low and high values of pixels were calculated according to the following expression.

$$\text{low}\ =\ 5\le low\le 26$$
$$\text{high}=\ 255-low$$

On the average contrast stretching technique consumed 0.10 seconds before giving the final output image.

V. Experimental Results

Detailed experiments were performed on 81 colored images having variation in luminance and contrast. Sizes of all the images are set to 256 by 256. For two example test images, fig. 2 and 3 show the results of conventional image enhancement methods along with the proposed technique. It can be seen that our proposed technique is better in terms of visual appearance than conventional techniques. It can be noted that histogram of the input test image mostly lies on the left side while for enhanced images it is towards the right side. For the proposed method histogram of the output image covers full range of pixels, i.e., whole region on x-axis.

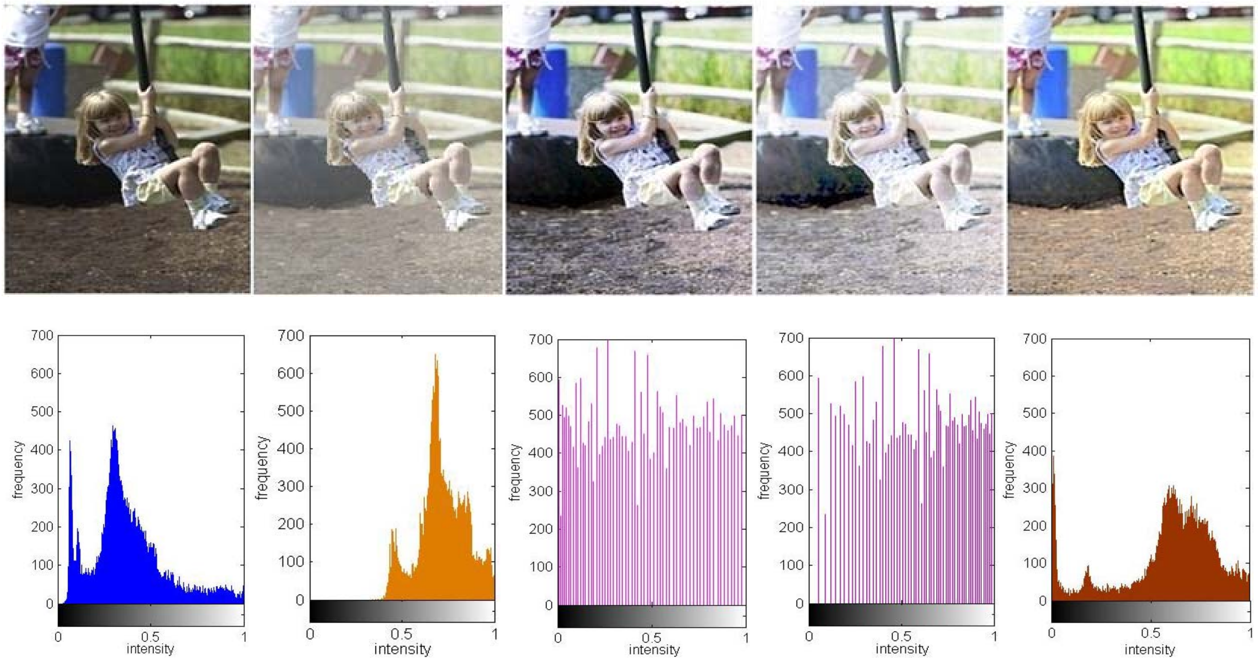
Table 2 shows the execution time of each technique. Simulation results were observed using Matlab 7.5.0 (R2007b) on a Pentium-IV machine. For gamma correction method, execution time is less however, as can be seen in the figure 2 and 3, the quality of enhancement is worst compared to other techniques.

Table.2 Average Execution Time of Different Techniques

Gamma Correction (Seconds)	Histogram Equalization (Seconds)	Histogram Specification (Seconds)	Proposed Method (Seconds)
1.52	2.53	3.99	2.12

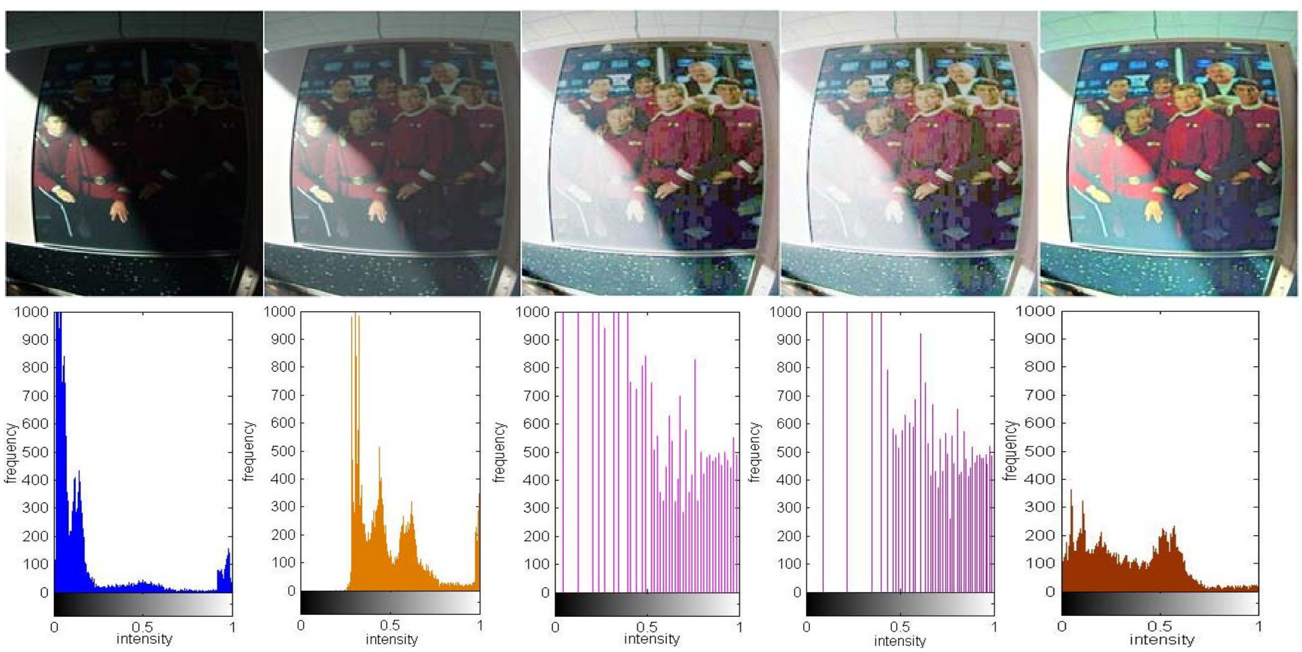
VI. Conclusions

In this paper we have developed a technique for color image enhancement under non-uniform illuminating conditions. Multi Scale Retinex theory was used to enhance the brightness and overall visual appearance of the image. Only the luminance channel was processed which resulted in improved execution time than the conventional techniques. Our proposed method shows good results compared to conventional techniques such as histogram equalization, histogram specification and gamma correction. Gaussian filtering was used in experiments to smooth the edges in the colored image. The developed technique can easily be applied in modern flat panel display control system/monitors to enhance images/videos having non-uniform illumination. Currently we are in the process of developing hardware for proposed technique. Further, to improve the quality of images bilateral filters can be used at the cost of increase in the computation time and complexity of algorithm. Other disadvantage when using bilateral filtering is non-usage of Fast Fourier Transform (FFT). Similarly in order to further improve the performance and quality non local means filtering techniques can be used as well.



Original Image Gamma Corrected Histogram Equalized Histogram Specification Proposed Method

Fig.2 Test Image 1



Original Image Gamma Corrected Histogram Equalized Histogram Specification Proposed Method

Fig.3 Test Image 2

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