Color Image Enhancement Techniques: A Critical Review

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Abstract

Image enhancement is one of the key issues in high quality pictures such as digital camera and HDTV. Since Image clarity is very easily affected by lighting, weather, or equipment that has been used to capture the image. These conditions lead to image may suffer from loss of information. As a result, many techniques have developed known as image Enhancement techniques to recover the information in an image. This paper presents a literature review on some of the image Enhancement techniques for color image enhancement like, Contrast Stretching, Histogram Equalization and its improvement versions, Homomorphic Filtering, Retinex, and Wavelet Multiscale Transform. Comparison of all the techniques concludes the better approach for its future research.

Keywords: Image enhancement; Homomorphic Filtering; Retinex

1. Introduction

Color images provide more and richer information for visual perception than that of the gray images. 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. During poor illumination conditions, the images appear darker or with low contrast. Such low contrast images needs to be enhanced. In the literature many image enhancement techniques such as gamma correction, contrast stretching, histogram equalization, and Contrast-limited adaptive histogram equalization (CLAHE) have been discussed. These are all old techniques which will not provide exact enhanced images and gives poor performance in terms of Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR) and Mean Absolute Error (MAE) [5]. Use of the old enhancement technique will not recover exact true color of the images. Recently, Retinex, Homomorphic and Wavelet Multi-Scale techniques have been popular for enhancing images. These methods are shown to perform much better than those listed earlier [7]. This report is organized as follows: Section II presents brief description of image Enhancement techniques, Section III gives comparison between various enhancement techniques in tabular form, Section IV presents performance comparison of those techniques and finally, conclusion is presented in Section V.

2. Image Enhancement Techniques

Image enhancement is basically improving the Interpretability or perception of information in images for human viewers and providing better input for other automated image processing techniques [1]. There exist many techniques that can enhance a digital image without spoiling it. The enhancement methods can broadly be divided in to the following two categories:
1. Spatial Domain Methods 2. Frequency Domain Methods

In spatial domain techniques, we directly deal with the image pixels. The pixel values are manipulated to achieve desired enhancement. In frequency domain methods, the image is first transferred in to frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image. Image enhancement is applied in every field where images are ought to be understood and analyzed. For example, medical image analysis, analysis of images from satellites etc. In this section we briefly describe the various image enhancement techniques.

2.1. Contrast Stretching

Contrast stretching technique is used to stretch the dynamic range of an image. Dynamic range is the range between the minimum intensity value and the maximum intensity value of an image. Mathematically, Contrast Stretching is given by [3],

$$I^{'}(x,y) = \frac{d}{I_{max}-I_{min}} \times (I(x,y) - I_{min}) + I_0 \quad (1)$$

Where, $I^{'}(x,y)$ is the new dynamic range image, d is the new dynamic range value, $I(x,y)$ is the input image, I_{min} is the minimum intensity value of the input image, I_{max} is the maximum intensity value of the input image, and I_0 is the offset point of the new dynamic range for $I^{'}(x,y)$. This transformation will provide good visual representation of the original scene but some of the detail maybe loss due to saturation and clipping as well as due to poor visibility in under-exposure regions of the image.

2.2. Histogram Equalization

Histogram Equalization (HE) [1], is a technique that made contrast adjustment using image's histogram. This technique is based on the idea of remapping the histogram of the scene to a histogram that has a near-uniform probability density function. Histogram Equalization redistributes intensity distribution. If the histogram of any image has many peaks and valleys, it will have peaks and valleys after equalization but the peaks and valleys will be shifted. This technique improves contrast and the goal of Histogram Equalization is to obtain a uniform histogram. In general, Histogram Equalization can be divided into three types, Global Histogram Equalization (GHE), Adaptive Histogram Equalization (AHE), and Block-based Histogram Equalization (BHE) [4].

In Global Histogram Equalization (GHE), each pixel is assigned a new intensity value based on previous cumulative distribution function. To perform Global Histogram Equalization (GHE), the original histogram of the grayscale image needs to be equalized. The cumulative histogram from the input image needs to be equalized to 255 by creating the new intensity value by applying [4];

$$I^{'}(x) = \frac{d}{C_{max}-C_{min}} \times (C(x) - I_{min}) + I_0 \quad (2)$$

Where, $I^{'}(x)$ is the new intensity level, d is the new dynamic range value, I_0 is the offset point of new dynamic range for $I^{'}(x)$, $C(x)$ is the normalized cumulative value, C_{max} is the maximum value in normalized cumulative value, and C_{min} is the minimum value in normalized cumulative value. Lastly, the normalized cumulative histogram is used as the mapping functions of the original image. This technique increased the contrast of the image but lighting condition under uneven illumination may sometimes turn to be more uneven.

2.3. Homomorphic Filter

Homomorphic Filtering [3], is sometimes used for image enhancement. It simultaneously normalized the brightness across an image and increases the contrast. Here, Homomorphic Filtering is used to remove multiplicative noise. Illumination and reflectance are not separable, but their approximate locations in the frequency domain may be located. Since illumination and reflectance are combined multiplicatively, the component are made additive by taking the logarithm of the image intensity, so that these linearly in the frequency domain. Illumination variations can be thought of as a multiplicative noise, and can be reduced by filtering in the log domain.

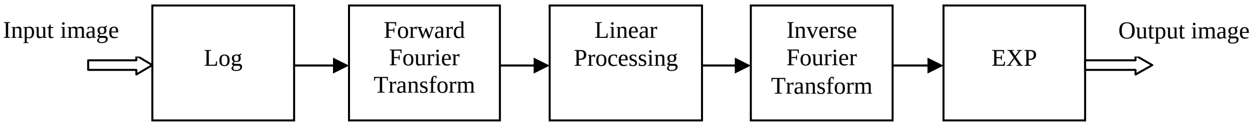

Fig. 1. Block Diagram of Homomorphic Filtering[3]

2.4. Retinex

Retinex theory was first proposed by Edwin Land in 1964 [6]. There are many algorithms based on Retinex theory such as Multi Scale Retinex (MSR) [8], Multi Scale Retinex with modified color restoration (MSRCR)

[7], Fast Multi Scale Retinex (FMSR) [10] etc. According to Land [6], image is composed by two parts namely the incident light and the reflectance of the object. This can be represented by,

$$L = R/E \tag{3}$$

Where, *L* represents value of incident light, *R* represents the value of object's reflection, and *E* represents the value of reflected light.

Single Scale Retinex, is the most basic technique for Retinex based algorithm. In Single Scale Retinex method proposed by Jobson et al. [9], 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 (4):

$$R_i(x, y) = \log I_i(x, y) - \log[F(x, y) \otimes I_i(x, y)] \tag{4}$$

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 (5).

$$F(x, y) = K \times F_n(x, y) \tag{5}$$

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

K is selected such that;

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

Where *x* & *y* are spatial coordinates, c is the standard deviation of Gaussian distribution that determines the scale.

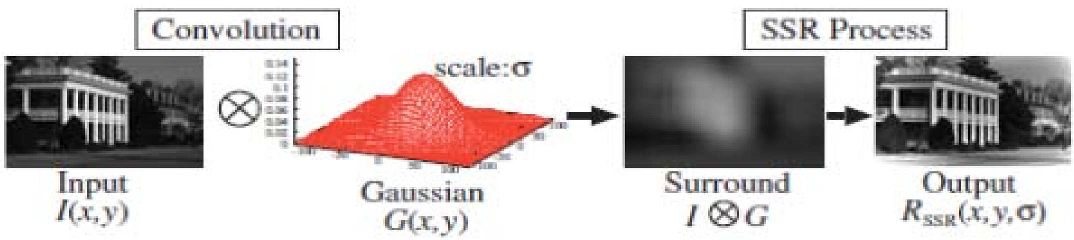

Fig. 2. Image processing by single-scale Retinex [6]

The Multiscale retinex is given by Equation (6):

$$F_{MSR_i}(x, y) = \sum_{n=1}^{N} W_n R_{n_i}(x, y) \tag{6}$$

W_n is the weighting factor. The Multiscale retinex with color restoration is given by Equation (7):

$$F_{MSRCR_i}(x, y) = C_i(x, y) F_{MSR_i}(x, y) \qquad i \in \{R, G, B\} \tag{7}$$

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

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

The comparison of the enhanced color images obtained from different techniques is of done by taking parameters Mean Square Error (MSE), and Peak Signal to Noise Ratio (PSNR). These parameters for color images are given by equation (8) and (9).

$$MSE = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left[\left(r(i,j) - r'(i,j)\right)^2 + \left(g(i,j) - g'(i,j)\right)^2 + \left(b(i,j) - b'(i,j)\right)^2\right] \tag{8}$$

$$PSNR = 10\log_{10} \frac{255^2}{(MSE_R + MSE_G + MSE_B)/3} \quad (9)$$

Where $r(i,j)$, $g(i,j)$,$b(i,j)$, $r'(i,j)$, $g'(i,j)$, $b'(i,j)$ are image pixels of original and enhanced image of image size of $M \times N$ and MSE_R, MSE_G, MSE_B are the MSE between the R component, G component and B component of the original and the enhanced image.

2.5. Wavelet Multi-scale Transform

Wavelet analysis [12] has proven to be a powerful image processing tools in recent years. When images are to be viewed or processed at multiple resolutions, the wavelet transform (WT) is the mathematical tool of choice. In addition to being an efficient, highly intuitive framework for the representation and storage of multi-resolution images, the WT provides powerful insight into an images spatial and frequency characteristics. The image detail parts are stored in the high-frequency parts of image transformed by wavelet and the imagery constant part is stored in low-frequency part. Because the imagery constant part determines the dynamic range of image, the low-frequency part determines the dynamic range of image. We attenuate the low-frequency part in order to compress the dynamic range.

But the details must be loss when the low-frequency part is attenuated [11]. As some details are stored in the high-frequency parts very well, the image reconstructed by inverse wavelet transform (IWT) has more detail.

3. Performance Comparison

- In [4] simulation results of different histogram equalization techniques were compared, for comparison three quality measurements were used: flatness (σ), Contrast-per-pixel (C), and average absolute mean brightness error (AAMBE).Observed data from [4] is compared as given in Table-1.

Table 1. Comparison of different histogram equalization techniques

Method	Flatness Value	Contrast per pixel	AAMBE	Average Execution Time (ms)
GHE	2079.2001	4.6450	35.9358	30.93
BBHE	1226.1185	4.2699	22.1924	32.19
DSIHE	1217.9784	4.5453	16.7719	36.77
MMBEBHE	1217.7566	4.2225	18.5597	65.55
BHENM	**115.9456**	**5.1296**	**16.6760**	**90.67**

This paper concludes that histogram equalization extension BHENM technique shows the improved image contrast, flatness, and simultaneously preserved the image brightness as compared to previous version of Histogram equalization techniques, but it requires 90.67 ms (Table 1) average execution time which is three times higher than the GHE.

- In [5] different color image enhancement techniques were compared by taking parameters Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR), and Mean Absolute Error (MAE), which is presented in Table 2. In this paper Retinex model with different surround function such as Gaussian, Laplacian, and Gamma distribution as the illumination estimation function were used and there results were also presented in Table 2. This paper conclude that Use of the Laplacian distributed surround function gives some better results compared to Gaussian distribution function. And also the use of the Gamma distributed surround function gives still better results compared to both Gaussian and Laplacian distribution function. Compared to Histogram Equalization, Gamma Correction and Homomorphic filtering techniques, the Retinex method of image enhancement is giving us more contrast enhanced results without destroying any parts of the image that does not require enhancement.

Table 2. [5]

Errors	Measurment Between Original & Noisy	Homom-orphic Method	Homomorphic Method with Thresholding	Gaussian Surround	Laplacian Distribution	Gamma Distribution	Gamma Correction	Histogram Equalization	CLAHE
RMSE	128.93	125.44	105.38	75.16	75.47	71.99	124.54	53.17	102.05
PSNR	13.56	14.10	17.59	24.35	24.27	25.21	14.25	31.27	18.23
MAE	113.89	111.39	91.02	65.04	65.15	62.77	110.61	39.55	85.31

- The papers [6],[7],[8] describe performance of Retinex model with different color correction and color restoration techniques. An efficient color correction technique with single scale Retinex (SSR) is shown in figure 3 which was used in [6].

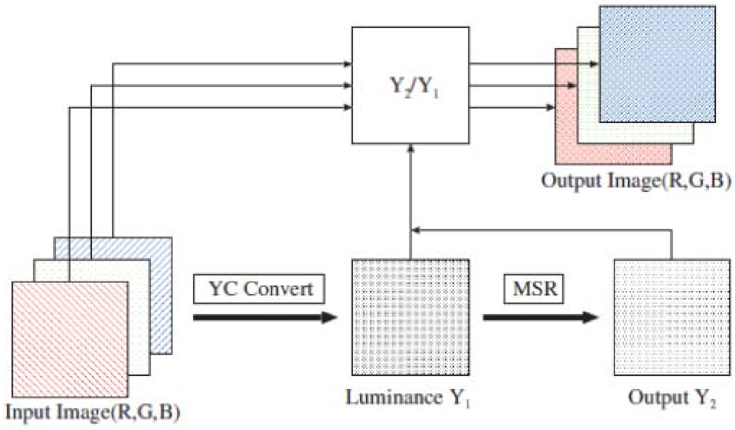

Fig. 3. Luminance signal processing [6]

This method shows good contrast improvement compare to Gamma correction, Histogram equalization, and its improved methods denoted by BBHE, DSIHE, RMSHE and RSIHE, but this method has still large computation time because of large scale Gaussian filter.

In [8] Adaptive Multi Scale Retinex with Gaussian filter of various sizes were used. A visual contrast measure (VCM) and halo artifact measure were used to evaluate the image produced using various Gaussian filters and weights. Figure 4 shows VCM results corresponding to different test images and figure 5 shows the averaged maximum color differences using an SSR (single Scale Retinex) model. In the case of a Gaussian filter less than 80, the color difference was greater than three, resulting in halo artifacts. Therefore, when considering the VCM and halo artifacts, the size of the large Gaussian filter must be greater than 200.

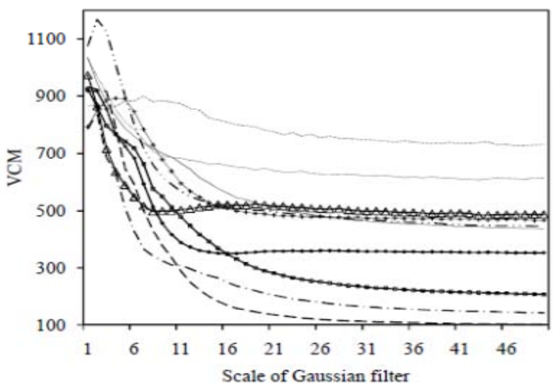

Fig. 4. VCM values for test images varying scale of Gaussian filter [8]

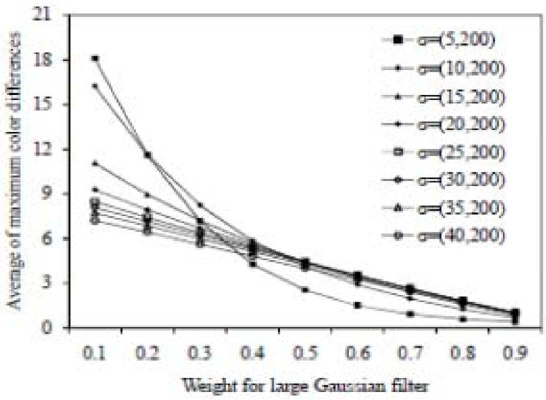

Fig. 5. Halo artifacts for varying the weight of large Gaussian filter [8]

This paper conclude that proposed color correction method based on MSR (Multi Scale Retinex) takes into account the dominant chromaticity in an image to improve local contrast and color rendition.

In [7] a new technique for the enhancement of color image using Multi scale Retinex with modified color restoration was proposed. The operational sequence of the proposed algorithm for Multi Scale Retinex method based on modified color restoration technique is shown in figure 6. Table 3 shows that proposed method in this paper has nearly the same contrast performance and PSNR values compared to NASA’s Multi Scale Retinex method of Jobson’s et al.

Table 3. Multi scale Retinex with color restoration [7]

Parameter	NASA Method	Proposed Method in[7]
Contrast	0.7717	0.7362
Luminance	1.3281	1.8091
PSNR (dB)	37.6	37.8

This method provides balance between contrast and luminance. This method offers better pixel distribution compared to other methods, but performs in unnatural color rendition.

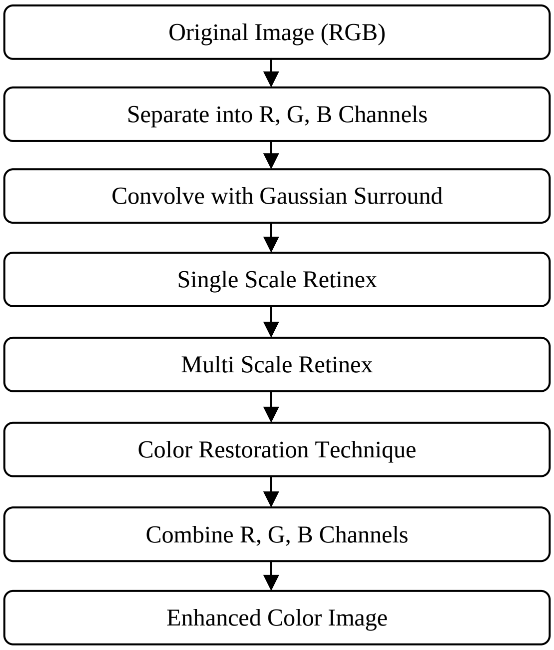

Fig. 6. Flow Sequence of Color Restoration Method [7]

4. Comparison of Different Techniques

Comparison of observations given in all references is discussed here.

Table 4. Comparison between different color image enhancement techniques

S No.	Enhancement Technique/Algorithm	Domain	Measuring Parameters	Advantages	Disadvantages
1.	Contrast Stretching [3]	Spatial	-	Good visual representation of the original scene.	some of the detail maybe loss due to saturation and clipping.
2.	Histogram Equalization [2] [4]	Spatial	RMSE- 53.17 PSNR (dB)- 31.27	Image has uniform histogram Produce optimal contrast Fast	Cannot adapt the local information of the image and preserve the brightness of the original image.
3.	Contrast Limited Adaptive Histogram Equalization [2] [4]	Spatial	RMSE -102.05 PSNR (dB)- 18.23	Enhanced local contrast	Noise amplification in flat region and ring artifacts at strong edges.
4.	Homoporphic Filtering [3] [5]	Frequency	RMSE -125.44 PSNR (dB)- 14.10	Remove multiplicative Noise Simultaneous gray-level range compression and contrast enhancement	Problem of bleaching of the image
5.	Single Scale Retinex [6] [8]	Frequency	-	Exceptional promise for dynamic range compression	Gray level violation problem ‘Washed out’appearance
6.	Multi Scale Retinex [7] [8]	Frequency	PSNR (dB)- 37.8	Provides dynamic range compression Preserve most of the detail	Unnatural color rendition ‘Washed out’appearance but less than SSR

Above table concludes that classical method Contrast stretching losses some of the detail information of the images during enhancement, Histogram Equalization gives better results but it can not preserve the brightness of the original image, so Adaptive histogram Equalization, homomorphic filtering overcome this problem but not for the multiplicative noise. Retinex is the advance technique for the color image enhancement because it is based on color constancy theory and provide dynamic range compression and preserve most of the detail of an image but it still has the problem observed in above table, so it is necessary to use some transform for the remedy of this problem.

5. Conclusion

Critical review concludes that Histogram equalization cannot preserve the brightness and color of the original image and Homomorphic filtering technique has the problem of bleaching of the image. Modern techniques Retinex (SSR & MSR) performs much better than those listed above because it is based on the color constancy theory, but it still suffers from color violation and unnatural color rendition problem, as The Wavelet transforms is the very good technique for the image denoising and input images always faces the noise during image processing so in future work there is scope of applying Wavelet transform with Retinex to improve the image enhancement results such as color rendition problem, PSNR, minimum MSE .

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