Enhancement of Low Light Images via IIlumination Map Estimation using Variational Optimization-based Retinex Model

Priyanka B. Waghmode[1] Nilesh Vani[2]
[1,2]GF's Godavari College of Engineering, Jalgaon, India

Abstract— Retinex is a method of bridging the gap between images and the human observation of scenes. Retinex theory is a model of lightness and color perception of human vision proposed by Edwin Land in 1986. While the retinex theory was actually aimed at providing explanation of human color perception, it has led to various image enhancement algorithms called as retinex algorithms, which are usually used to enhance local image contrast. Single-scale Retinex (SSR) is defined as an implementation of center/surround Retinex. Superposition of weighted different scale SSR balances both dynamic range compression and tonal rendition, which is Multiscale Retinex (MSR). For color images, spatial averages of the three color bands are far from equal, thus the output appears grey. To address this issue, a weight factor for different channels is introduced which is Multiscale Retinex with color restoration (MSRCR). In this paper, SSR, MSR and MSRCR systems for image enhancement are implemented and their performances are compared using MATLAB as the software tool.

Key words: Retinex, image enhancement, single-scale, multi-scale, illumination estimation, Color Restoration

I. INTRODUCTION

Retinex is the theory of human color vision proposed by Edwin Land to account for color sensations in real scenes. Color constancy experiments showed that color does not correlate with receptor responses. In real scenes, the content of the entire image controls appearances[2]. A triplet of L, M, S cone responses can appear any color. Land coined the word "Retinex" (the contraction of retina and cortex) to identify the spatial image processing responsible for color constancy. Further, he showed that color sensations are predicted by three lightness observed in long-, middle-, and short-wave illumination[2]. Retinex is also used as the name of computer algorithms that mimic vision's spatial interactions to calculate the lightness observed in complex scenes[2].

Edwin H. Land, the inventor of hundreds of film patents, was struck by experiments showing that color sensations in real complex images depend on scene content. Film responds to the light falling on each tiny local region. Land realized that vision's mechanisms were very different from film. His early experiments studied the colors observed in red and white projections. He realized color appearance required both the cone responses to a local region and the neural spatial processing of the rest of the scene. He proposed the Retinex Theory[2].

Land coined the word Retinex to describe three independent spatial channels. In 1964 he wrote: "We would propose that all of the receptors with maximum sensitivity to the long-waves in the spectrum, for example, operate as a unit to form a complete record of long-wave stimuli from objects being observed. (For convenience of reference, let us call this suggested retinal-cerebral system a "retinex."). It is the word that describes the mechanism that performs the comparison of scene information to create the array of sensations of lightness in three channels[2].

II. RETINEX IN IMAGE PROCESSING

Land described that the fundamental challenge of color vision shifted to the ability to predict lightness; that is, the spatial interactions found in post-receptor neural processes. The important feature of real complex scenes is that the illumination is rarely uniform. Shadows and multiple reflections increase the dynamic range of light coming to our eyes and to cameras [2]. The application of Retinex algorithms to high dynamic range (HDR) scenes has become a major topic of research and engineering applications. The limits of HDR scene capture and reproduction are controlled by optics, namely, optical veiling glare. Camera glare limits the range of light on the sensor, just as intraocular glare limits the range of light on the retina. The scene content controls the range of light in images. Vision's post-receptor neural processes compensate for veiling glare. That explains humans' high dynamic range of appearances from low-dynamic-range retinal images. The spatial mechanisms modeled by Retinex algorithms play a major role in compensating for glare and generating our range of color and lightness sensations[1][3].

Over the years many variations of spatial processing mimicking human vision have been called Retinex algorithms [1].

The different types of retinex algorithms are:

A. Single Scale Retinex algorithm (SSR)
B. Multiscale Retinex algorithm (MSR)
C. Multiscale retinex with Color Restoration algorithm (MSRCR)

A. *Single Scale Retinex Algorithm (SSR)*

Single Scale Retinex, is the most basic method for Retinex algorithm. A low pass filter is applied on Ii (x, y) which is the input color image to estimate the illumination. This illuminations log signal is subtracted to get the output color image Ri(x,y).It is a 2D convolution of Gaussian surround function and ith component of the original image[1].

It is given by,

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

Where $i = 1 \dots . S$

Here,

$$F(x,y) = K\exp[-(x2 + y2)/c2$$

is Surround Function, S is the number of spectral bands, c is surround constant or scale value and selection of K is such that $\iint F(x,y)dxdy = 1$. The log function in SSR is placed after the Gaussian surround function. A canonical gain offset is used as a post retinex signal processing. A space constant of 80 pixel is a good compromise between dynamic range compression and tonal rendition[1].

A single scale cannot simultaneously provide dynamic range compression and tonal rendition. The images are either locally or globally grayed out or suffered from color distortion due to violations of the gray world assumptions. These are the drawbacks of SSR[1][4].

B. *Multi Scale Retinex Algorithm (MSR)*

Single-scale Retinex cannot provide both the dynamic range compression and tonal rendition. Multi Scale Retinex (MSR) [4] is developed to combine the strength of different surround spaces. The Gaussian filters of different sizes are used to process input image several times [1]. The resulting images are weighted and summed to get output of MSR.
It is given by

$$R_i(x,y) = W_n \log\ I_i(x,y) - \log[F_n(x,y) * I_i(x,y)]$$

Where $i = 1,..S$

Here, Wn represents the weight for the net scale, N is number of scales.

MSR provide color enhancement. It also provides dynamic range compression and tonal rendition.

But MSR output images violate gray world assumptions. So it suffers from greying out of the image, either globally or locally. This gives a washed out appearance. This is the main drawback of MSR algorithm [5]

C. *Multi Scale Retinex with Color Restoration Algorithm (MSRCR)*

To restore color, MSR is modified by adding a color restoration function. The color restoration factor is given by:

$$\alpha_i(x,y) = f\left[\frac{I_i(x,y)}{\sum_{n=1}^{N} I_n(x,y)}\right]$$

It is the color restoration coefficient in the i^{th} spectral band. The number of spectral bands is given by K MSRCR algorithm is given by,

$$R_i(x,y) = \propto_i (x,y) \sum_{k=1}^{K} W_K \log I_i(x,y) - \log[F_K(x,y) * I_i(x,y)]$$

The block diagram of MSRCR algorithm is shown in fig.1 MSR algorithm fails to meet Grey World Assumption. This problem can be removed by using color restoration method. Thus a color restoration factor (CRF) block is added with the MSR block to obtain the MSRCR algorithm [6].

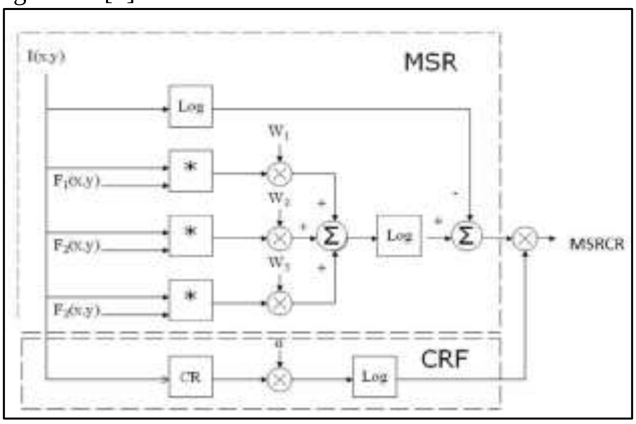


Fig. 1: Block Diagram for MSRCR Algorithm

III. NATURALNESS PRESERVATION IN RETINEX

Since Retinex-based algorithms regard illumination removal as a default preference and fail to limit the range of reflectance, the naturalness of non-uniform illumination images cannot be effectively preserved[8]. However, naturalness is essential for image enhancement to achieve pleasing perceptual quality. In order to preserve naturalness while enhancing details, instead of removing the illumination, its transformation is useful. The following section shows the naturalness preserved Retinex based algorithm for non-uniform illumination[7].

A. *Coarse Illumination Estimation using Extension of Max-RGB*

Here, illumination is estimated, assuming that in a local patch it is constant. Thus the Max-RGB algorithm is extended to take into account the local area of a pixel while estimating the maximum response of each colour channel[6]. Formally, for an image I, the coarse illumination is defined as:

$$I^{ie}(x,y) = \max_{c\in\{R,G,B\}}\left(\max_{(x,y)\in\Omega}\left(I^c(x,y)\right)\right)$$

Algorithm for Estimating Illumination
Input: I input color image
Output: Coarse illumination estimation I^{ie}
begin
for each pixel $I(x,y)$:
// Find maximum values of the three channels in a local area
Max_red = Maximum value of red channel among all the pixels in local area
Max_blue = Maximum value of blue channel among all the pixels in local area
Max_green = Maximum value of green channel among all the pixels in local area
// Find maximum among these maximum values of these individual Channels
Max = maximum of Max_red, Max_blue and Max_green

$$I^{ie}(x,y) = \text{Max}$$

endFor
end

B. *Synthesis of Reflectance and Mapped Illumination*

The synthesize $R(x,y)$ and $L_m(x,y)$ together to get the final enhanced image:

$$E\ I^c(x,y) = R^c(x,y) \times L_m(x,y)$$

Algorithm for Synthesis of reflectance and mapped illumination
Input: ReflectanceR^c, mapped illumination L_m
Output: Enhanced image EI^c
begin
For each pixel (x,y) in EI^c :

$$E\ I^c(x,y) = R^c(x,y) \times L_m(x,y)$$

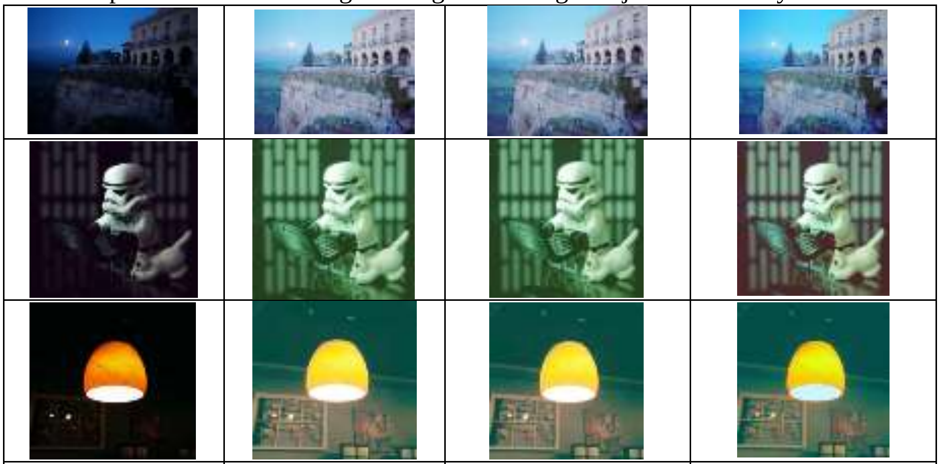
endFor
end

IV. RESULTS & DISCUSSION

In this paper, many low light images tested but only three sample image results kept in this paper along with original images and enhanced images using different Retinex model. Also compared all these results with respect to Absolute

Mean Difference (AMD), Root Mean Square and Entropy. The results are tested using MATLAB tool.

Figure 2 shows the original low light images of lamp, palace, robot and output is enhanced images using Single-Scale Retinex (SSR), Multi-Scale Retinex (MSR) and Multi-Scale Retinex with Color Restoration (MSRCR) model. It is very clear from the enhanced output images, the low light objects are clearly visible.



(a) Input Images	(b) Output of SSR Algorithm	(b) Output of MSR Algorithm	(b) Output of MSRCR Algorithm

Fig. 2: Results of Images using different retinex algorithm

The Absolute Mean Difference (AMD),Root Mean Square(RMSE) and Entropy for Single Scale Retinex(SSR) Model of enhanced image of lamp, palace and robot is shown in table 1.

Input Image/Model	SSR			MSR			MSRCR		
	AMD	RMSE	Entropy	AMD	RMSE	Entropy	AMD	RMSE	Entropy
	103.9633	15.9031	6.8944	104.7167	15.9115	7.1499	92.2710	15.9138	7.7566
	76.3404	15.9245	6.8248	76.3157	15.9242	6.9686	74.7684	15.9179	7.0533
	69.8401	15.7384	4.9043	69.9617	15.7384	5.0033	67.0909	15.7330	6.3657

Table 1: Comparison of different Retinex model with different images

V. CONCLUSION

Retinex theory which was originally developed to explain the human color perception by Edwin Land has inspired many image enhancement algorithms. All these algorithms are collectively called retinex algorithms. This paper provides a brief review of image enhancement techniques based on retinex model. Also, the algorithm for Illumination estimation for image enhancement based on retinex and compared different images with absolute mean difference, Root Mean Square and entropy for different retinex model.

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