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A Study on Retinex Theory and Illumination Effects –I

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Abstract— Retinex Theory was initially developed by Edwin H. Land in 1964 and further evolution of "reset Retinex" formulated by Land and McCann. It was the first attempt to simulate and explain the human visual system how to perceive color based on experiments using Mondrian patterns. Gradually, several Retinex algorithms have been evolved ever since and applied to many imaging field. Retinex algorithm is actually an image enhancement algorithm based on illumination compensation method. It explains the phenomena of colour constancy and contrast in which it is consider that perceived colors of objects are largely independent of the chromaticity of the light incident upon them. we tried to discuss here a review on basics of retinex agorithms and briefly show how there is change in improvement of traditional retinex algorithm which modify the entropy its average gradient, standard variance which indicates that the images contain more details and information of the source image. In these series,

KeyWords—Retinex theory, color perception, classification, SSR, MSR

I. INTRODUCTION

Retinex Theory was formulated by Edwin H. Land In 1964. His theory and an extension, the "reset Retinex" were further formalized by Land and Mc Cann[1]. It was the first attempt to simulate and explain the human visual system how to perceives color based on experiments using Mondrian patterns.[3] . Several Retinex algorithms have been developed ever since and applied to many imaging field .Retinex algorithm is actually an image enhancement algorithm based on illumination compensation method. It explains the phenomena of colour constancy and contrast in which it is consider that perceived colors of objects are largely independent of the chromaticity of the light incident upon them. These color constancy algorithms modify the RGB values at each pixel to give an estimate of the color sensation without a basic priori information on the illumination which is low-frequency component.[2] Hence Retinex improves visual rendering of an image when lighting conditions are not good. While our eye can see colors correctly when light is low, cameras and video cams can't manage this well. The retinex is aimed at obtaining the balance between the human vision and machine vision system along with color constancy.[4] Retinex model is based on the assumption that the HVS operates with three retinal-cortical systems, each processing independently the low, middle and high frequencies of the visible electromagnetic spectrum. Besides digital photography, this algorithm is used to make the information in astronomical photos visible and detect, in medicine, poorly visible structures in X-rays or scanners. In brief it helps to achieve many features such as sharpening, color constancy processing and dynamic range compression[5] The Retinex Image Enhancement Algorithm is an automatic image enhancement method that enhances a digital image in terms of dynamic range compression, color independence from the
spectral distribution of the scene illuminant, and color/ lightness rendition. The digital image enhanced by the Retinex Image Enhancement Algorithm is much closer to the scene perceived by the human visual system, under all kinds and levels of lighting variations, than the digital image enhanced by any other method.[6] Image enhancement technology has permeated in many areas of science, engineering and civilian, such as biomedicine images, astrophotography, satellite pictures, computer vision, surveillance systems, civilian cameras, etc. Color constancy failures and simultaneous contrast are two major phenomena which severely degrade the usefulness of colored (RGB) image. The color images have two major drawbacks due to scene lighting conditions. First is the dynamic range problem [7] 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 [8] occurring due to loss of color distortions when spectral distribution of illuminant varies. So various algorithms based on histogram equalization[9] , algorithms based on retinex method[10],some on haze removal method[11] and gamma correction etc are applied. Retinex theory[12,13] considers how brightness and reflectance behave and investigates a computational model of color constancy human perception of color is largely independent of illumination conditions. It shows that a captured 2D image can be decomposing into two sub images-one depends on their reflectance properties of the surface of the imaged object while other depends on the illumination conditions. So among these algorithms, retinex based algorithms have received more and more attentions. The retinex theory is first proposed by Land [2][3] to model the imaging process of the human visual system. This theory assumes that the scene in human's eyes is the product of reflectance and illumination [14][15]. Most retinex based enhancement algorithms use different ways to estimate the illumination and remove it to obtain the reflectance as the enhanced image. The details and textures can be enhanced by illumination removal. While the enhanced results look over-enhanced and unnatural since the result does not meet with human vision system. It is well-known that human eye perception is a combined effect of

reflectance and illumination. It is unreasonable to remove the illumination and only regard the reflectance as an improved result [10]. Other retinex based algorithms firstly use logarithmic transformation to transform product into sum to reduce the computational cost [22], and then employ a variational model for enhancement. Note that the logarithmic transformation stretches low values and compresses high values, increasing the contrast of low intensities and decreasing the contrast of high intensities. The resulting reflectance is usually smoothed and loses some details which can be manageable. [16] In many papers, some novel retinex based image enhancement approach using illumination adjustment is proposed in which some new variational model is established that is different from conventional models [16][17], where the model does not need the logarithmic transformation and is more appropriate for the decomposition because reflectance is constrained in image domain. So a fast alternating direction optimization method was adopted to solve the proposed old model, where the reflectance and illumination can be computed and decomposed. Then a simple and effective post-processing method of the decomposed illumination is used to make an adjustment for image enhancement. The enhanced image is obtained by combining the reflectance and the adjusted illumination. The naturalness of enhanced images can be preserved while details enhanced. Meanwhile, reflectance and illumination can be obtained as a by-product of the enhanced Image and this method has good clarity on naturalness preservation and detail enhancement due to the illumination adjustment and precise computed reflectance. Hence their common principle is to assign a new value to each pixel in an image based on spatial comparisons of light intensities. So with increase in better performance of retinex algorithm it is developed into many forms according to its application in grey images, color images and mostly in real time image processing in field of medical images and texture feature parameters.

- Single Scale Retinex (SSR)
- Multi-Scale Retinex (MSR)
- Multi-Scale Retinex With Color Restoration (MSRCR)

II. RETINX THEORY

Retinex is defined as a process which images are automatically provided with visual realism. It is formed from "retina" and "cortex", suggesting that both the eye and the brain are involved in the processing. The Retinex theory motivated by Land [1] is based on the physical imaging model, in which an image $I(x,y)$ is regarded as the product $I(x,y) = R(x, y) \cdot L(x,y)$ where $R(x, y)$ is the reflectance and $L(x, y)$ is the illumination at each pixel (x,y). Here, the nature of $L(x, y)$ is determined by the illumination source, whereas $R(x,y)$ is determined by the characteristics of the imaged objects. Therefore, the illumination normalization can be achieved by estimating the illumination L and then dividing the image I by it. However, it is impossible to estimate L from I, unless something else is known about either L or R. Hence, various assumptions and simplifications about L, or R, or both are proposed to solve this problem [10]. A common assumption is that edges in the scene are edges in the reflectance, while illumination spatially changes slowly in the scene. Thus, in most Retinex methods, the reflectance R is estimated as the ratio of the image I and its smooth version which serves as the estimate of the illumination L, and many smoothing filters to estimate the illumination have been proposed. Retinex theory mainly compensate for the impact of images affected by illumination.[18] Based on Retinex image formation model:

S(x,y) = R(x, y) · L(x, y)-------------(1)

The formula of retinex is $S = RL$, where $S \in [0, 255]$ is the observed image, $R \in [0, 1]$ is the reflectance and $L \in [0, 255]$ is illumination. It is an ill-posed problem to solve R and L by using one observed image S, so other assumptions should be used to constrain this problem. The following known information is used as the constraint of the proposed model: 1) illumination is spatially smooth; 2) the value of R is from 0 to 1, which means $L \geq S$; 3) the reflection contains high frequency part, i.e., edge and texture information. Retinx Algorithms is the conversion of the given image into Logarithmic domain. As shown in formula 2:

Log S = logR + log L--------------(2)

Therefore, as shown in formula 3, the logarithm of the reflectance can be obtained by the logarithm of the image subtract the logarithm of the illumination.

LogR = log S - log L---------------(3)

Then the reflectance can be obtained by taken its index form, as shown in formula 4. The reflectance is inherent properties of object itself.

R = exp(log S - log L) ---------------------(4)

As the illumination compared with the reflectance is low frequency component, so the Retinex Algorithm uses the low-pass filter to estimate the illumination component. [19]

The Retinex algorithms can be classified into three classes: path-based algorithms, recursive algorithms, and center/surround algorithms. Single Scale Retinex (SSR) [2] algorithm is the first proposed center/ surround algorithm that can either achieve dynamic range compression or color/lightness rendition, but not both simultaneously. The dynamic range compression and color/lightness rendition were combined by the Multi-Scale Retinex (MSR) and Multi-Scale Retinex with Color Restoration (MSRCR) [3] algorithms with a universally applied color restoration.

III. CLASSIFICATION

Single Scale Retinex (SSR) Algorithm:-

The basics of SSR include a logarithmic photoreceptor function that approximates the vision system based on a center/surround [6] function. The SSR is given by:-

$$R_i(x,y) = \log_i(x,y) \log[F(x,y) * I_i(x,y)] \text{——(5)}$$

The purpose of the logarithmic manipulation is to transform a ratio at the pixel level to a mean value for a larger region. The general form of the center/surround retinex is similar to the Difference-of-Gaussian (DOG) function widely used in natural vision science to model both the receptive fields of individual neurons and perceptual processes. The only extensions required are i) to greatly enlarge and waken the surround Gaussian (as determined by its space and amplitude constants) and ii) to include a logarithmic function to make subtractive inhibition function to make subtractive inhibition into a shunting inhibition into a (i.e., arithmetic division). The surround space function computes the average of the surrounding pixel values and assigns it to the center pixel.

Land [3] proposed an inverse square spatial surround function:

$$\mathbf{F(x,y) = K * exp(-\frac{r^2}{c^2})} \text{-------------- } \mathbf{(7)}$$

Moore suggested the exponential formula with absolute parameter:

$$\mathbf{F(x,y) = K * exp(-\frac{r}{c})} \text{-------------- } \mathbf{(8)}$$

Hurlbert [8] suggested:

$$\mathbf{F(x,y) = K * exp(-\frac{r^2}{c^2})} \text{-------------- } \mathbf{(9)}$$

For a given space constant, the inverse-square surround function accounted for a greater response from the neighboring pixels than the exponential and Gaussian functions. The spatial response of the exponential surround function was larger than that of the Gaussian function at distant pixels. Therefore, the inverse-square surround function was more commonly used in global dynamic range compression and the Gaussian surround function was generally used in regional dynamic range compression [20].The exponential and Gaussian surround functions were able to produce good dynamic range compression over neighboring pixels. The selection of space constant is related with visual angle in the direct observation. But the value cannot be theoretically modeled and determined. Basically there is a trade-off between dynamic compression, (for example, details in the shadow) and color rendition. SSR is incapable of simultaneously providing sufficient dynamic range compression and tonal rendition. It also introduces halos around the objects. The function returns the "illumination invariant" reflectance R and the estimated luminance function L (both in the log domain). Here the luminance function is returned only for visualization purposes, as it is usually only of little value from the perspective of illumination invariant face recognition.

A. Characteristics of SSR

SSR has been defined to have the following characteristics and properties-

- The functional form of the surround is a Gaussian.
- The placement of the log function is after surround formation.
- The post retinex signal processing is a canonical gain offset rather than an automatic gain offset.
- There is a tradeoff between dynamic range
  Compression and tonal rendition which is governed by the Gaussian surround space constant. A space constant of 80 pixel is a reasonable compromise between dynamic range compression and rendition.
- A single scale seems incapable of simultaneously providing sufficient dynamic range compression and tonal rendition.
- Violations of the gray world assumptions has led to retinex images which were either greyed out locally or globally or more rarely suffered from colour distortion.

Multi Scale Retinex Algorithm:-

In order to preserve both the dynamic range compression and color rendition, Multi-scale retinex, which is represented in combination of weighted different scales of SSR [21], is a good solution. The novel multiscale retinex algorithm for medical image enhancement based on multi-rate sampling has been also used. The speed of the proposed multiscale retinex algorithm has significantly improved, since the different sampled versions of value channel are processed in parallel. The main practical consequence of this is that MSR is not appropriate for applications which are sensitive to color. In the image processing/image enhancement context, MSR serves a subset of the following four image processing goals, depending on the circumstances:

(i) Compensating for uncalibrated devices (gamma correction)
(ii) Color constancy processing
(iii) Dynamic range compression
(iv) Color enhancement

Hence MSR is expressed in form of weight functions such as in below equation

$$\mathbf{R_{MSR} = \sum_{n=1}^{N} WnRni} \text{------------ } \mathbf{(10)}$$

Or $R_{MSRi} = \sum_{n=1}^{N} \omega_n \{\log I_i(x,y) - \log[F_n(x,y) * I_i(x,y)]\}$ where N is the number of the scales, R_{ni} is the i_{th} component of the nth scale, W_n is the weight of the nth scale. For MSR, the number of scales needed, scale values and weight values are important. Experiments showed that three scales are enough for most of the images and the weights can be equal. Generally fixed scales of 15, 80 and 250 can be used, or scales of fixed portion of image size can be used. The weights can be adjusted to weight more on dynamic range compression or color rendition [11]. The MSR based images have significant dynamic range compression in the boundary between the light parts and dark parts and reasonable color rendition in the whole image scale.MSR combined various SSR weightings, selecting the number of scales used for the application and evaluating the number of scales that can be merged. Important issues to be concerned were the number of scales and scaling values in the surround function, and the weights in the MSR. The best weights had to be chosen in order to obtain suitable dynamic-range compression at the boundary between light and dark parts of the image, and to maximize the brightness rendition [12] over the entire image. MSR worked by compensating for lighting variations to approximate the human perception of a real scene. There were two methods to achieve this: (1) compare the psychophysical mechanisms between the human visual perceptions of a real scene and a captured image, and (2) compare the captured image with the measured reflectance values of the real scene. Thus the method involved combining specific features of MSR with processes of SSR, in which the center/surround operation was a Gaussian function. The logarithm was then applied after surround function processing (i.e., two-dimensional spatial convolution). Next, appropriate gain and offset values were determined according to the retinex output and the characteristics of the histogram. These values were constant for all the images. This procedure yielded the MSR function. However, it is difficult to predict whether the color of the reproduction will be accurate; and it has issues of color sensitivity [13]. This is also not true for other adaptive techniques since variations in lighting conditions imply variations in the control parameters. To overcome the error in MSR in color processing MSRCR is followed.

Multi-Scale Retinex With Color Restoration (MSRCR)

To reduce the computational effort the two dimensional filtering between surround function and the image function is performed in the frequency domain by finding the product of spectra of both the functions.[23]

The drawback of MSR with regard to color restoration, where weights are introduced for three color channels depending on the relative intensity of the three channels in the original images. In images which violate the gray-world assumption, that is, images where a certain color may dominate, the MSR retinex procedure produces grayish images by decreasing the color saturation. To solve this problem, Jobson et al. [7] proposed to complete the algorithm with a color restoration step. They proposed to modify the MSR output by multiplying it by a color restoration function of the chromaticity. The first move is to compute the chromaticity coordinates Individual the relative intensity of three channels is given. As **Color fidelity** in image reproduction is a complex and active research topic so it is assume that changing the intensity does not change the perceived non-intensity aspects of color. but only an approximation. Even for isolated colors, color appearance does change with intensity. It is also found that the original MSR also does not address these problems, and the modified version of MSR is the MSRCR which is more suited to adding corrections for deviations from all of the assumption and to include more complex color appearance models, including ones for simultaneous contrast effect. MSRCR algorithm is widely used in illumination compensation. This problem could be solved by introducing weight factor for different channels in multiscale retinex with color restoration (MSRCR). It helps to overcome the color constancy problem to some extend. Color constancy which refers to computational approaches to recover the actual color of surface objects independent of the color of light source. Color is important in many applications such as human computer interaction, color feature extraction and color appearance models. The color of light source significantly affect on the color of object in the scene. As a result, the same object, taken by the same camera but under different illumination, may vary in its measured color values. This color variation may introduce undesirable effects in digital images. Human has the ability to recognize the actual color of object despite variations in the color of the light source. The solution to this problem is to introduce weights for three color channels depending on the relative intensity of the three channels in the original images[24]

Ci(x,y) □ □f[Ii'(x,y)]------------(11)

Where the relative intensity of three channels

$$\mathbf{I_i'(x,y) = I_i(x,y) / \sum_{i=1}^{s} I_i(x,y)|}\text{----}\mathbf{(12)}$$

The color restoration function should be monotonic. Where s is the total number of color bands i.e. 3. Several linear and nonlinear functions were tried; Jobson found the best overall color restoration was

Ci(x, y) □ □ □ □ log[□Ii□' (x, y)]----(13)

This color restoration method can be described as,

RMSRCRi (x, y) □ □Ci(x, y)RMSRi (x, y)---(14)

Where RMSRCRi is the *i*th band of the MSRCR output.The above equation gives idea about a general approach for the MSRCR algorithm. For improvement of this method some change in algorithm is done. In some case FFT is also applied. From the study it is found that the original MSR also does not address these problems, and that our modified version of MSR is the MSRCR is more suited to adding corrections for deviations from the above assumption. We thus acknowledge that an important area for future work is to include more complex color appearance models, including ones for simultaneous contrast as already discussed. In some cases it is assumed that a approximation of faithful color reproduction is used to preserve the chromaticity factor, as defined by equation (15).

$$X = \frac{X}{X+Y+Z} \quad (15)$$

If we assume that the region's reproduced chromaticity *X*', *Y*', matches the region's scene chromaticity *XY*, then it follows immediately that, equation (16).

X' = KX, Y' = KY, Z' = KZ------(16)

Where

$$K = \frac{X' + Y' + Z'}{X+Y+Z} \quad (17)$$

Similarly, scaling the reproduction *X*', *Y*', *Z*' by a constant *K* preserves chromaticity. Thus to preserve chromaticity we can manipulate *K* on a region-by-region basis, Normally it is deal with intermediate variables such as camera *RGB*. In order to be confident that a good approximation of scene chromaticity is being reproduced. MSRCR is represented in form of frequency domain to have better performance.

IV. MSRCR IN FREQUENCY DOMAIN

In this method, the surround (filter) function is chosen as a zero matrix of size same as image dimension. At the center of the zero matrix a N x N Gaussian (frequency domain) filter is created and placed surrounded by zeros of the zero matrix, two dimensional windowing is done for the filter matrix to smoothen the edges of the N x N sub matrix at the center of filter matrix. Through FFT the frequency domain function of the image is obtained and frequency domain filtering is done through element by element multiplication of filter FFT matrix with the FFT matrix of the image.

Discussion:

Medical images, such as magnetic resonance (MR) images are crucial in clinical diagnosis. So it is necessary to improve the visible quality. As many cases, MR images always suffer from poor contrast due to imaging techniques. Therefore, an image enhancement approach based on multi-scale Retinex is used. A set of MR images which show coronal slices are employed as testing samples where gains good performance and more simple and efficient is increased. It is also helpful in the improvement for X-Ray medical images. Of global and local image enhancement by Retinex algorithm. This is applied by conducting elaborate experiments on over a dozen varieties of spinal cord medical images. When the raw images we obtain from optical and electronic devices are sometimes requiring a further processing to be fully appreciated and properly interpreted by human eye and mind. Say for example the typical figure 1 below. The appearance of the room and the objects drastically changed due to illuminatination with cool white lamps and warm white one.

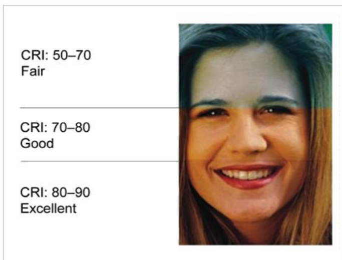
Moreover, a processing for a correct vision of images is fundamental during the analysis of medical data and for their uses in the subsequent diagnoses. In the case of the observation of mental nerve canals, the GIMP Retinex tool was used to improve the efficiency [25]. These canals are in areas of the panoramic image that are usually quite dark, but Retinex allows seeing the details of mandibles in the shadows of the image Of course, GIMP and its tools can be used in general for medical imaging [26] and for x-ray radiography. In fact, a quite interesting use of GIMP Retinex is for images obtained by means of scanning electron microscopes (SEMs The use of GIMP Retinex in biology, had been involved in the analysis of the colony morphology of a mycobacterium [27].In image analysis and visualization were performed using GIMP to merge fluorescent and differential inference contrast (DIC) images and to adjust levels and brightness and to remove out-of-focus background fluorescence [28,29],. It obtained that this filter allows seeing the features of a polypyrrole coating on a textile fibre [22-30], even in the shadow of a deep split of it. Further application also concerns this e -automated detection of vessels in retinal images to improve understanding of the disease mechanism, diagnosis and treatment of retinal and a number of systemic diseases. : Retinex-based image inhomogeneity correction, local phase-based vessel enhancement and graph cut-based active contour segmentation. It is used for the critical challenge in face recognition, researchers have used an extensive manner of illumination variations in the works of pattern recognition and computer vision using retinex algorithm

Experimental Example:

We took 3 sample images; Image 1 (figure 2): one single face with varied illumination with typical residential lamps; Incandescent lamps: 100 Fluorescent, CFL lamps: 60–95 LED lamps: 80–90, source: http://www.yourhome.gov.au/energy/lighting

Image 2 & Image 3 (figure 3):: same face at D65 and TL84 illumination

[Figure 1: Cool white and warm white colour temperature]

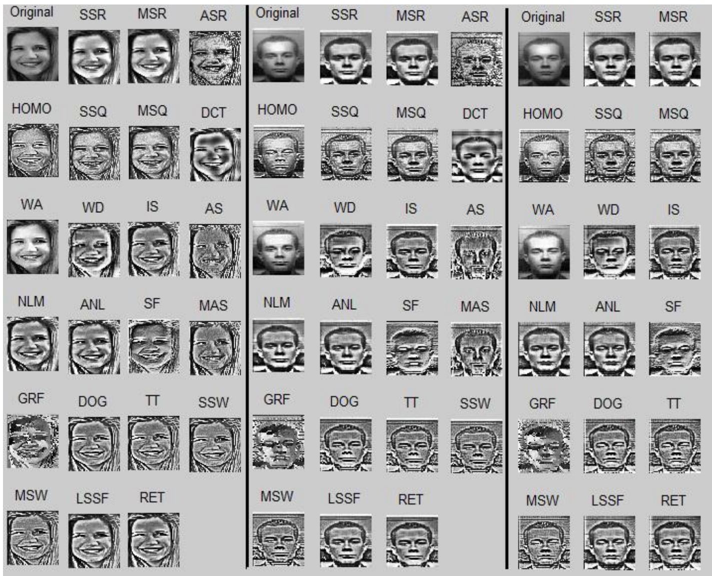


[Figure 2: varied illumination with typical residential lamps]

[Figure 3: same face at D65 and TL84 illumination]

[Figure 4: SSR Input Output]

[Figure 5: MSR Input Output]



[Figure 6: Resulted Images from 23 various algorithms]

V. CONCLUSION

We discuss briefly on concepts of Retinex algorithm which initially developed on image enhancement and evolved to various derived algorithms further based on illumination compensation method with some example. We will further discuss on the issues on Colourspace, ASTM Illuminats and its effect on perception and pattern recognition features

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