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Frequency Domain Based MSRCR Method for Color Image Enhancement

Siddesha K, Kavitha Narayan B M
Assistant Professor, ECE Dept., Dr.AIT, Bangalore, India, Assistant Professor, TCE Dept., Dr.AIT, Bangalore, India,

Abstract--*There are often serious discrepancy existing between the recorded image and the direct observation of the same scene. Human visual system is able to distinguish details and vivid colors in shadows and in scenes that contain illuminant shifts. In this paper it is presented an image enhancement algorithm called Multiscale Retinex with Color Restoration (MSRCR). The MSRCR algorithm tries to imitate human visual "computation" while observing scenes that contains lighting variations. MSRCR is an extension of a former algorithm called Single Scale center/surround Retinex (SSR) and its extension Multi Scale center/surround Retinex (MSR).MSRCR achieves simultaneous dynamic range compression, color consistency and lightness rendition.*

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.

Keywords—Retinex, Single Scale Retinex, Multi Scale Retinex, Multi Scale Retinex with Color Restoration, dynamic range compression, surrounding function.

Introduction:

Image enhancement improves the quality (clarity) of images for human viewing. Removing blurring and noise, increasing contrast, and revealing details are examples of image enhancement operations. Reducing the noise and blurring and increasing the contrast range could enhance the image. Image processing technology is used by planetary scientists to enhance images of Mars, Venus, or other planets. Doctors use this technology to manipulate CAT scans and MRI images.

There are often serious discrepancy existing between the images and the direct observation of the real scenes. The human perception has natures of dynamic range compression and color rendition on the scenes. It can compute the details across a large range of spectral and lightness variations. So it is color constant. By comparison, the recorded films and other electric cameras, have no such computations before the scenes are recorded in the dynamic range limited media. Even with wide dynamic range imaging systems, the recorded images will not be seen same as real observation. This is because the dynamic range compression for perception of the recorded images is weaker than that for the scene itself. This could be explained as that in the real world, the wider angular extent helps to improve the dynamic range compression.

The idea of Retinex was proposed as a model of lightness and color perception of the human vision. Obviously it is not only a model, but also could be developed to algorithms of image enhancement. Later single-scale Retinex (SSR) was defined as an implementation of center/surround Retinex. But depending on the special scale, it can either provide dynamic range compression (small scale) or tonal rendition (large scale). Superposition of weighted different scale SSR is obvious a choice to balance these two effects. This is multiscale Retinex (MSR). For color images, if the content is out of "gray world", which means the spatial averages of three color bands are far from equal, the output will be forced to be gray by MSR. This problem could be solved by introducing weight factor for different channels in multiscale Retinex with color restoration (MSRCR).

Image Enhancement using Retinex Algorithms:

Land [1] first proposed the idea of Retinex as a model of lightness and color perception of the human vision. Obviously it is not only a model, but also could be developed to algorithms of image enhancement. Land gave more contributions on Retinex algorithm, evolving the concept from a random walk computation, to his latest version of a center/surround spatially opponent operation. The center/surround opponent operation is related to the neurophysiological functions of neurons in the primate retina, lateral geniculate nucleus, and cerebral cortex. Hurlbert [2] studied the lightness theories and found that they have a common mathematical foundation. Also the leaning problems for artificial neural networks suggested a solution with center/surround form. But that is not enough. The human vision does not determine the relative reflectances, but rather content dependent relative reflectances for arbitrary illumination conditions.

Researchers defined a single-scale Retinex (SSR), which is an implementation of center/surround Retinex. But depending on the special scale, it can either provide dynamic range compression (small scale) or tonal rendition (large scale). Superposition of weighted different scale SSR is obvious choice to balance these two effects. This is multiscale Retinex (MSR). For color images, if the content is out of "gray world", which means the spatial averages of three color bands are far from equal, the output will be forced to be gray by MSR. This problem could be solved by introducing weight factor for different channels in multiscale Retinex with color restoration (MSRCR). After MSRCR, generally the outputs will be out of the range of display. Auto gain/offset can be used to shift and compressed the histogram of MSRCR outputs to the display domain. But the histograms of MSRCR outputs show typical shapes and the gain/offset parameters could be "canonical".

Retinex Algorithm: In general, the human visual system is better than machines when processing images. Observed images of a real scene are processed based on brightness variations. The images captured by machines are easily affected by environmental lightening conditions, which tend to reduce its dynamic range. On the contrary, the human visual system can automatically compensate the image information by psychological mechanism of color constancy. Color constancy, an approximation process of human perception system, makes the perceived color of a scene or objects remain relatively constant even with varying illumination conditions. Land proposed a concept of the Retinex, formed from "retina" and "cortex", suggesting that both the eye and the brain are involved, to explain the color constancy processing of human visual systems. After the human visual system obtain the approximate of the illuminating light, the illumination is then discounted such that the "true color" or reflectance can be determined. Hurlbert and Poggio applied the Retinex properties and luminosity principles to derive a general mathematical function. Differences arose when images from various center/surround functions in three scales of gray-level variations were shown. Hurlbert applied a center/surround function to solve the brightness problem, using the learning mechanism of neural networks and a general solution to evaluate the relative brightness in arbitrary environments.

Although Jobson et al. proposed a single-scale Retinex (SSR) algorithm that could support different dynamic-range compressions, the multi-scale Retinex (MSR) can better approximates human visual processing, verified by experiments, by transforming recorded images into a rendering which is much closer to the human perception of the original scene.

1) Single-Scale Retinex (SSR)

The basics of an SSR were briefly described as follows. A logarithmic photoreceptor function that approximates the vision system was applied, based on a center/surround organization [2]. The SSR was given by

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

Where Ii(x,y) is image distribution in the ith color band, F(x,y) is the normalized surround function.

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

The purpose of the logarithmic manipulation was 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 weaken the surround Gaussian (as determined by its space and amplitude constants), and ii) to include a logarithmic function to make subtractive inhibition into a shunting inhibition (i.e., arithmetic division).

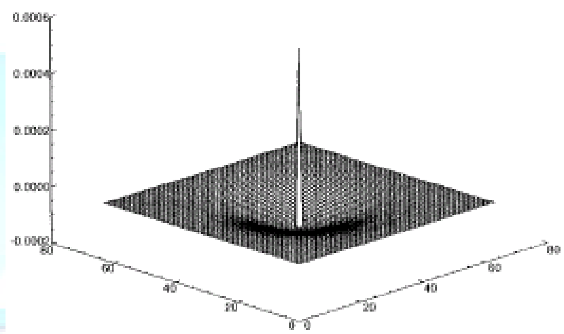

Figure: Spatial form of the center/surround Retinex operator, 3-D representation.

Surround Space Constant: While Land proposed the center/surround Retinex with a 2–4 pixel diameter for the center (perhaps in keeping with the widely known coarser spatial resolution of purely chromatic vision), a center of only 1 pixel is clearly demanded for general-purpose image processing. Only after segmentation into lightness and chromatic images can the purely chromatic images be made coarser. In contrast, the surround space constant cannot be so clearly defined. Land proposed an inverse square surround with a full width-half maximum (FWHM) of 40 of visual angle. This corresponds to FWHM of about 270 visual pixels (assuming a visual pixel is 0.015).

We can the performance of the Gaussian surround over a wide range of space constants. Since previous research found variations in the space constant with the spatial variation in shadow profiles, a particular concern is the question of an optimum space constant that gives good performance for diverse scenes and lighting conditions. The image sequence established a trade-off that has not been previously studied. In varying the space constant from small to large values, dynamic range compression is sacrificed for improved rendition. The middle of this range (50 - 100 pixels) represents a reasonable compromise, where shadows are fairly compensated and rendition achieves acceptable levels of image quality. This is qualitatively compatible with human visual perception in that the treatment of shadows is influenced by their spatial extent. Larger shadows tend to be more compensated (less dark) while smaller shadows appear less compensated (blacker and with less visible internal detail).

2) Multi-Scale Retinex (MSR)
Because of the tradeoff between dynamic range compression and color rendition, we have to choose a good scale c in the formula of F(x,y) in SSR. If we do not want to sacrifice either dynamic range compression or color rendition, multiscale Retinex, which is a combination of weighted different scale of SSR, is a good solution,

$$R_{MSRi} = \sum_{n=1}^{N} \omega_n R_{ni}$$

Where N is the number of the scales, Rni is the ith component of the nth scale [3]. The obvious question about MSR is the number of scales needed, scale values, and weight values. 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. But these are more experimental than theoretical, because we do not know the scale of image to the real scenes. The weights can be adjusted to weight more on dynamic range compression or 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.

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. MSR was implemented by a series of MR images, based on a trade-off between dynamic-range compression and brightness rendition. Also, we needed to choose the best weights 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 over the entire image.

We verified the MSR performances on visual rendition with a series of MR images scanned by MR systems. Furthermore, we compared the efficacy of the MSR technique in enhancing the contrast of these MR images with other image processing techniques.

An algorithm for MSR as applied to human vision has been described in past literature. The 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. To summarize, our method involved combining specific features of MSR with processes of SSR, in which the center/surround operation was a Gaussian function. A narrow Gaussian distribution was used for the neighboring areas of a pixel (which was regarded as the center). Space constants for Gaussian functions with scales of 15, 80, and 250 pixels in the surrounding area, as proposed by Jobson et al, were adopted in this study. 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 [4].

3) Multi-Scale Retinex with Color Restoration (MSRCR)
MSR is good for gray images. But it could be a problem for the color images because it does not consider the relative intensity of color bands. This can be seen from formula of MSR, whose output is the relative reflectances in the special domain. Considering the images "out of gray world", whose average intensity for three color band are far from equal, the output of MSR for three channels will be more close, which make it looks more gray. 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 [5].

$$C_i(x,y) = f[I_i'(x,y)]$$

Where the relative intensity of three channels

$$I_i'(x,y) = I_i(x,y) / \sum_{i=1}^{S} I_i(x,y)$$

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

$$C_i(x,y) = \beta \log[\alpha I_i'(x,y)]$$

This color restoration method can be described as,

$$R_{MSRCRi}(x,y) = C_i(x,y) R_{MSRi}(x,y)$$

Where R_{MSRCRi} is the *i*th band of the MSRCR output.

4) Proposed MSRCR in Frequency Domain
In the proposed method, the surround (filter) function is choosen as a zero matrix of size same as image dimension. At the center of the zero matrix a 21 x 21 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 21 x 21 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.

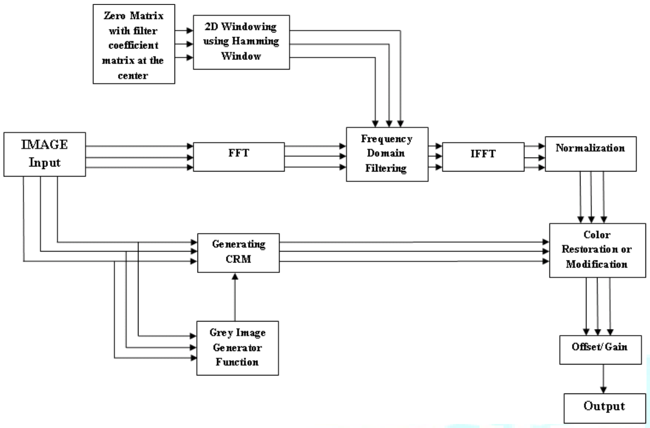

Figure: MSRCR processing in frequency domain.

I. IMPLEMENTATION

The SSR, MSR and MSRCR based image enhancement systems are implemented using MATLAB.

The surrounding function constants for MSR are considered as 250, 120 and 80 respectively.

The corresponding MATLAB statement is given below.
Scales = [250, 120, 80];

The 3 MSR weights are taken as 1/3 each. The corresponding MATLAB statement is given below.
Weight = [1/3, 1/3, 1/3];

The color restoration constant is taken as 125.

Crc = 125;

The gain and offset values for the implementation of MSRCR is 0.35 and 0.65 respectively.

gainoff = [0.35, 0.65];

The cut-off values in histtruncate() function are take 0.2 and 0.2 each.

II. RESULTS

The results of the image enhancement implementation employing MSRCR along with the original image are shown below.

Figure1a: Original Image

Figure 1b: MSRCR Output

Figure 2a: Original Image

Figure 2b: MSRCR Output

As the results of the performance of this implementation indicate, the MSRCR algorithm achieves graceful dynamic range compression together with tonal and color rendition. The MSRCR algorithm was also tested on some images with familiar colors and no strong lighting defects and the results showed that the MSRCR does not introduce significant distortions into images without lighting variations.

III. CONCLUSIONS

The SSR provides a good mechanism for enhancing certain aspects of images and providing dynamic range compression. However its is limited in its use because it can either provide good tonal rendition or dynamic range compression. The MSR comprised of three scales – small, intermediate and large-overcomes this limitation and was found to synthesize dynamic range compression, color constancy and tonal rendition and produce results which compare favorably with human visual perception except for scenes which contain violations of the gray-world assumption. Even when the gray world violations were not dramatic, some desaturation of color was found to occur. The MSRCR adds a color restoration scheme which produced good color rendition even for severe gray-world violations, but at the expense of a slight sacrifice in color constancy. While there is no theoretical or mathematical basis for providing the generality of MSRCR, this method can be applied to restore diverse color images, including some known to contain severe gray-world violations. Multiscale Retinex is an effective algorithm of Retinex. It can have dynamic range compression and color rendition effects at the same time

As compared with other image enhancement techniques, the Retinex enhancement has the following advantages:

1. "Canonical" constant – once it is defined, image enhancement is an automatic process independent of inputs;

2. Has general application on all pictures;

3. Good dynamic range compression and color rendition effect.

Gamma correction and histogram equalization indicate that the performance of the Multiscale Retinex is consistently good, while the performance of the others is quite variable. Gamma correction produces unsharp masking that damages the color rendition and blurs the details and the Histogram Equalization may produce artifacts.

This paper proposes a novel method of implementing MSRCR in frequency domain for color image enhancement using MATLAB.

This new method resembles of segmenting the image into several small sized blocks of specified size and the Retinex Surround function of same dimension is considered for two dimensional filtering in the frequency domain for each block of data to enhance the resolution in the spatial domain.

The filtered blocks of image are considered for the calculation of Color Restoration Factor for each channel in each block. Comparatively this new method of MSRCR based on frequency domain yielded an enhanced performance.

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