A Review: Image Compensation Techniques

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Abstract—**Image clarity is very easily affected by lighting, weather, or equipment that has been used to capture the image. Some of these conditions lead to over-exposure of under-exposure condition where an image may suffer from loss of information. As a result, many researchers have developed several techniques known as image compensation techniques to bring back the information in an image. This paper presents a review on some of the image compensation techniques that have been proposed by the past researchers including Manual Tuning, Contrast Stretching, Non-Linear Point Transform, Histogram Equalization, Homomorphic Filtering, and Retinex.**

Keywords-image compensation; manual tuning; contrast stretching; non-linear point transform; histogram equalization; homomorphic filtering; retinex

I. INTRODUCTION

Image compensation is widely used to restore the information in an image. This technique is normally employed in recognition system, surveillance, and etc. For example, surveillance system, especially for outside environment monitoring such as auto teller machine (ATM), parking lot, sidewalk, and traffic light is usually being exposed with too many kinds of lighting condition (i.e. day and night, lamps, and weather). This condition affects the output of the surveillance camera. Some of these conditions lead to over-exposure or under-exposure condition and make the information in the image loss. This is where the image compensation technique becomes one of the methods to restore the loss information. The rest of the paper is organized as follows: Section II presents detail description of image compensation techniques and finally, summary is presented in Section III.

II. IMAGE COMPENSATION TECHNIQUES

A. Manual Tuning

Manual Tuning is the technique where no computer-aid involved. Example of the manual tuning technique is dodging and burning. Dodging and burning [1] are the technique used by photographers during the printing process to manipulate the exposure of a selected region on photographic print. Burning is the process to increase the exposure of the regions. To burn-in-print, the print is first given normal exposure. Next, extra exposure is given to the area or areas that need to be darkened. A card or other opaque object is held between the enlarger lens and the photographic paper in such a way as to allow light to fall only on the portion of the scene to be darkened. Dodging is the process to decrease the exposure of the regions. To do this, a card or other opaque object is held between the enlarger lens and the photographic paper is such a way as to block light from the portion of the scene to be lightened. Since the techniques is used with a negative-to-positive process, reducing the amount of light results in a lighter image.

B. Contrast Stretching

Contrast Stretching [2] 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,

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

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.

C. Non-Linear Point Transform

Other method used for dynamic range modification is the Non-Linear Transform such as Gamma Intensity Correction (GIC) [2], and Logarithmic Function [2].

Mathematically, GIC is given by,

$$I'(x,y) = c \times I(x,y)^{\gamma} \tag{2}$$

where γ and c are the positive constants, $I'(x,y)$ is the GIC output image and $I(x,y)$ is the input image. GIC is often used in the field of computer graphic. By controlling the value of

γ, we control the overall brightness in the image. If the value of γ is not properly selected, the image will become either bleached out or too dark.

Logarithmic Function has an important characteristic that is it compresses the dynamic range with large variation in pixel values. Mathematically, Logarithmic Function is given by,

$$I'(x,y) = c \times \log\left[1 + I(x,y)\right] \tag{3}$$

where c is the positive constant, $I'(x,y)$ is the output image and $I(x,y)$ is the input image.

D. Histogram Equalization

Histogram Equalization (HE) [2], 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. The types are Global Histogram Equalization (GHE), Adaptive Histogram Equalization (AHE), and Block-based Histogram Equalization (BHE).

In Global Histogram Equalization (GHE) [2], 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 greyscale 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;

$$I'(x) = \frac{d}{C_{\max} - C_{\min}} \times \left(C(x) - I_{\min}\right) + I_0 \tag{4}$$

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.

To solve the lighting problem that occurs in Global Histogram Equalization (GHE), Adaptive Histogram Equalization (AHE) [3] has been proposed. The steps used in this method almost the same as the one in Global Histogram Equalization (GHE). The difference is; Global Histogram Equalization (GHE) is applied on the whole image but Adaptive Histogram Equalization (AHE) applies the Histogram Equalization technique on the small block in the image. The input image will be separated into small blocks first then the Histogram Equalization technique will be applied in each block. As a result, uneven lighting problem is solved. However, discontinuities between blocks and noise amplification in flat regions and ring artefact at strong edges occurred.

Block-based Histogram Equalization (BHE) [4] has been proposed to solve the problems associated with the Global Histogram Equalization (GHE) and Adaptive Histogram Equalization (AHE). Block-based Histogram Equalization (BHE) also use blocks as in Adaptive Histogram Equalization (AHE). The difference between Adaptive Histogram Equalization (AHE) and Block-based Histogram Equalization (BHE) is, Adaptive Histogram Equalization (AHE) used non-overlapped block while Block-based Histogram Equalization (BHE) used overlapped block. To perform the Block-based Histogram Equalization (BHE), an image is divided into a small blocks and the Histogram Equalization technique is performed within each of the block. In order to avoid the block discontinuity problem, the blocks are overlapped half by each other. Weight averaging is then applied to smooth the boundaries. Weight averaging equation is given by,

$$f(x,y) = \sum_{i=1}^{N} w_i(x,y) \times f_i(x,y) \tag{5}$$

where $f_i(x,y)$ and $f(x,y)$ are the intensity value at (x,y) of block i and the smoothed image. N is the number of overlapping blocks involved in computing value at (x,y) and $w_i(x,y)$, where $i=1,\ldots,N$, is a weighting function of block i. The value of N depends on the position of the image block consideration, which is four when the block is not at the border, and two or one when it located at the border or at the one of the four corners of an image. The weighting function $w_i(x,y)$ is simply a product of individual weighting function in the x and y direction is given by,

$$w'(x) = 1 - \left|\frac{x - S_B/2}{S_B/2}\right| \tag{6}$$

where, S_B is the length of block, and x is its relative x-coordinate in the block. Thus we have $w'(0)=0$, $S_B=0$ and $w'(S_B/2)=1$. Using this technique, almost all the problems that occur in previous Histogram Equalization technique has been solved but noises still exist in output image.

E. Homomorphic Filter

Homomorphic Filtering [2], 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 multiplicative components of the image can be separated 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. To perform this method, the input image is first passed through a Logarithmic Function that provides dynamic range compression. It is then Fourier Transformed, and its representation in the frequency domain is modified by applying a filter similar to high pass filter. Next, the modified frequency spectrum is then transformed back into spatial domain by using inverse Fourier Transform and passes through an Exponential Function that 'reverses' the effects of the Logarithmic Function.

F. Retinex

Retinex theory was first put forward by Edwin Land in 1964 [5]. This method relates to the human vision perceiving problem towards brightness and colour. It represents calculating theory, where an object will show different colours on different observing conditions. There are many algorithms based on Retinex theory such as Multi Scale Retinex (MSR), Multi Scale Retinex with Wide Dynamic Range (MSRWDR), Retinex based Adaptive Filter (RAF), Multi Scale Retinex with Initial Approximation (MSRIP), and Fast Multi Scale Retinex (FMSR). According to Land, image is composed by two parts namely the incident light and the reflectance of the object. This can be represented by,

$$L = R / E \tag{7}$$

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 [6], is the most basic technique for Retinex based algorithm. Mathematically, Single Scale Retinex (SSR) is given by,

$$R_i(x,y) = \log I_i(x,y) - \left[\log F(x,y) * \log I_i(x,y)\right] \tag{8}$$

where, * is the convolution operation, $R_i(x,y)$ is the Retinex output, $I_i(x,y)$ is the input image and $F(x,y)$ is the smoothing filter defined by,

$$F(x,y) = Ke^{-(r/c)^2} \tag{9}$$

K is selected such that:

$$\iint F(x,y)\,dxdy = 1 \tag{10}$$

This technique increases the information in the uneven illumination image but does not provide good tonal rendition and the output image suffer from 'washed out' appearance.

Multi Scale Retinex (MSR) [8] is a combination of a weighted sum of the output of different Single Scale Retinex (SSR). According to [7], this technique can solve the uneven illumination produced by the Single Scale Retinex (SSR). This is because some of the region only can be enhance by using certain value of scale. It is impossible to find only one scale that suitable for all regions. Mathematically, the Multi Scale Retinex (MSR) is given by,

$$R_{MSR_i} = \sum_{n=1}^{N} w_n R_{ni} \tag{11}$$

where, N is the number of scales, R_{ni} is the i-th component of the n-th scale, R_{MSRi} is i-th spectral component of the MSR output and w_n is weight associated with the n-th scale. By using this technique, clarity in certain region is increased but it still suffers from the 'washed out' appearance.

Multi Scale Retinex for Wide Dynamic Range (MSRWDR) has been proposed by Marius et al. [9] to overcome the 'washed out' appearance problem. Two modifications have been made to enhance the result obtained with the original Multi Scale Retinex (MSR) technique. The first modification is obtained by recombination of the resulting image with the original image in certain weight. The second modification is achieved by adjusting histogram of the resulting picture. These modifications improve the results of the original Multi Scale Retinex (MSR) technique and retain global contrast of brightness and natural impression of the resulting image. The equation for this technique is same as in [8]. The difference between these two methods is the size of scale used in the technique. For the first modification, three types of scale have been chosen. Two small sized kernels and one middle sized kernel. The small sized kernel function is to suppress the 'halo' effect and middle sized kernel function is to give natural impression to the image. By using the three types of scale, the output image becomes too bright and the global contrast is lost. To restore the information that has been loss, recombining with original pictures is needed. Mathematically, Multi Scale Retinex for Wide Dynamic Range (MSRWDR) is given by,

$$R_{MSR_i} = \sum_{n=1}^{N} w_n R_{ni} + w_{oripic} \log I_i(x,y) \tag{12}$$

where, N is the number of scales, R_{ni} is i-th component of the n-th scale, R_{MSRi} is i-th spectral component of the MSR output and w_n is weight associated with the n-th scale, w_{oripic} is weight function associated to original image, and $I_i(x,y)$ is the original image. For the second modification, to enhance the global contrast, pixels that have value above or below these limits [15,200] would be clipped. Lastly, contrast adjustment is made so that all 256 levels [0,255] are displayed between the lower and upper limits.

Retinex-based Adaptive Filter (RAF) has been proposed by Laurance Meyland and Sabine Susstrunk [10]. The first step of this technique is to apply global tone mapping on the input image. Input image then converted to *YCbCr* colour space when only *Y* (luminance) is treated. The new output of *Y* component and the two chrominance (*CbCr*) are combined back to *RGB* colour space. Finally, the *RGB* image is scaled to the output device dynamic range using histogram scaling. The difference between this technique and other Retinex technique is, this technique only applied on *Y* component while other Retinex techniques apply the Retinex algorithm on all colours. Mathematically, Retinex-based Adaptive Filter (RAF) is given by,

$$R_i(x,y) = \log I_i(x,y) - \log[mask] \tag{13}$$

where, $R_i(x,y)$ is the output image of *Y* component, $I_i(x,y)$ is the *Y* component of the input image and *mask* is given by,

$$mask = I_y * F \tag{14}$$

where * is the convolution operation, I_y is the *Y* component of the input image and *F* is the low pass filter that is circularly symmetric. *F* is entirely defined by a 1-dimensional function that is rotated around the *z* axis. The 1-dimentional curve is usually defined by a simple Gaussian or a composition of Gaussian function.

$$mask = \int_{\theta=0^\circ}^{360^\circ} \int_{r=0}^{r_{\max}} I_y(x+\cos\theta, y+\sin\theta).e^{-\left(\frac{r}{c}\right)^2}\, dr d\theta \tag{15}$$

$$r_{\max} = \max\bigl(size(I)\bigr) \tag{16}$$

By using the surround function that is not circularly symmetric but its shape follows the image high contrast image, artefact and black halos around light source have been reduce.

Multi Scale Retinex with Initial Approximation (MSRIA) by Yuehu Liu et al. [11] has two contributions. First, the initial approximation image is computed by both each pixel value and maximum value of original image. Second, discrete wavelet transformation is used to decrease computation complexity. Multi Scale Retinex with Initial Approximation (MSRIA) is given by,

$$g(x,y) = \log[1 + f(x,y)] \tag{17}$$

where, $f(x,y)$ is the input image. Then,

$$R(x,y) = R_1 + R_2 \tag{18}$$

with,

$$R_1 = (0.5 - \sigma(x,y)).g(x,y) \tag{19}$$

$$R_2 = (0.5 - \sigma(x,y)).\log(f_{\max}) \tag{20}$$

With, f_{max} is the maximum intensity of the input image, g_{ave} is the average value of $g(x,y)$ and $\sigma(x,y)$ is defined by,

$$\sigma(x,y) = \begin{cases} \dfrac{g(x,y) - g_{ave}}{g_{ave}}, & g(x,y) < g_{ave} \\ \dfrac{g(x,y) - g_{ave}}{\log f_{\max} - g_{ave}}, & g(x,y) \geq g_{ave} \end{cases} \tag{21}$$

For multi scale decomposition method, the number of decomposition needs only one level. The original image is decomposed into four sub-bands by using wavelet transform: LL, LH, HL, and HH. The Retinex technique is performed to enhance coefficient values of LL sub-band, and obtained enhanced LL sub-band, which denotes as LL'. The inverse discrete wavelet transform then applied using sub-bands LL', LH, HL and HH to obtain the enhance image. The advantage of using this method is that the 'washed out' output image is no longer existed and noises that produced from the Retinex algorithm can be eliminated.

Fast Multi Scale Retinex (FMSR) [12] technique has been proposed to solve the colour distortion and to reduce the time consumed by Multi Scale Retinex technique. As we can see, form the original Retinex equation as in (8), the most time consuming part is the convolution operation in $\log[F(x,y)*I_i(x,y)]$ and to find the centre surround function $F(x,y)$. To overcome this problem, the convolution algorithm in spatial domain can be transformed into multiplication in frequency domain. However, in order to do this conversion, there are certain conditions need to be fulfilled. The image and template must be in the same size and the size of the image must be in the power of two. Lastly, as in [10], only *Y* component will be processed.

III. SUMMARY

The review can be summarized by Table I. The advantages and disadvantages of each method are listed in this table.

TABLE I
ADVANTAGES AND DISADVANTAGES OF EXISTING IMAGE COMPENSATION TECHNIQUE

Method	Advantage(s)	Disadvantage(s)
Single Scale Retinex [6]	Exceptional promise for dynamic range compression	Does not provide good tonal rendition 'Washed out' appearance
Multi Scale Retinex [8]	Provides dynamic range compression Good tonal rendition Preserve most of the detail	'Washed out' appearance but less than SSR
Multi Scale Retinex with Initial Approximation [11]	'Washed out' appearance no longer existed Noises can be reduced	Computational burden increased

TABLE I
CONTINUED

Method	Advantage	Disadvantage
Multi Scale Retinex with Wide Dynamic Range [9]	Detail increased 'Halo' effect are suppressed Increase global contrast Reduce the 'washed out' appearance	'Halo' effect not totally diminished
Retinex-based Adaptive Filter [10]	Reduce artifacts such as black halos around light source	Computational burden increased
Fast Multi Scale Retinex [12]	Fast	Image and template must be in the same size Size of the image must be in the power of two
Global Histogram Equalization [2]	Image has uniform histogram Produce optimal contrast Fast	Lighting condition of an image under uneven illumination may sometimes turn to be more uneven
Adaptive Histogram Equalization [3]	Enhance local contrast Strengthened textures and edges	Noise amplification in flat region and ring artifacts at strong edges Discontinuity between region Computational intensive
Block-based Histogram Equalization [4]	Enhance local contrast Eliminate discontinuity between region Faster than AHE	Noises are not totally eliminated
Gamma Intensity Correction [2]	Fast	
Logarithmic Function [2]	Fast	
Homomorphic Filtering [2]		Computationally intensive

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