AUTOMATIC IMAGE RESTORATION TECHNIQUE FOR UNDER/OVER EXPOSED REGION

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AUTOMATIC IMAGE RESTORATION TECHNIQUE FOR UNDER/OVER EXPOSED REGION

by

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In The Name Of The Almighty Allah, The Most Merciful God.

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LIST OF ABBREVIATIONS

ACE	Automatic Colour Equalization
AHE	Adaptive Histogram Equalization
BHE	Block-based Histogram Equalization
CCTV	Closed Circuit Television
CYMK	Cyan, Magenta, Yellow, Key Black
FMSR	Fast Multi Scale Retinex
FPGA	Field Programmable Gate Array
GHE	Global Histogram Equalization
GIMP	GNU Image Manipulation Program
HDR	High Dynamic Range
HE	Histogram Equalization
HSI	Hue, Saturation, Intensity
HSL	Hue, Saturation, Lightness
HSV	Hue, Saturation, Value
HVS	Human Vision System
MSR	Multi Scale Retinex
MSRIP	Multi Scale Retinex with Initial Approximation
MSRWDR	Multi Scale Retinex with Wide Dynamic Range

OM	Orientation Map
RAF	Retinex-based Adaptive Filter
RGB	Red, Green, Blue
SDR	Standard Dynamic Range
SSR	Single Scale Retinex
YCbCr	Luminance, Chrominance Blue, Chrominance Red

TEKNIK PEMULIHAN IMEJ SECARA AUTOMATIK UNTUK KAWASAN KURANG/LEBIH DEDAHAN

ABSTRAK

Pelbagai kaedah telah dicadangkan untuk meningkatkan kejelasan, kualiti, dan memulihkan imej yang berada dalam keadaan kurang atau lebih dedahan. Dalam pemulihan imej, tujuan utamanya adalah untuk meningkatkan kejelasan imej. Imej dengan tahap kejelasan tinggi mengandungi banyak maklumat. Kejelasan ini sangat mudah dipengaruhi oleh pencahayaan, cuaca atau peralatan yang digunakan untuk merekod gambar. Beberapa keadaan seperti pencahayaan yang tidak tetap, menyebabkan berlakunya kawasan kurang dedahan atau lebih dedahan dan dengan itu imej mungkin mengalami kehilangan maklumat. Oleh yang demikian, projek ini mencadangkan satu algoritma pemulihan imej yang baru untuk mengembalikan semula maklumat dalam imej. Teknik yang dicadangkan ini hanya melakukan pemulihan pada kawasan kurang dedahan atau lebih dedahan tanpa menjejaskan kawasan yang mempunyai pencahayaan yang sesuai. Fungsi pemetaan nada yang digunakan dalam kaedah ini diinspirasi oleh ciri-ciri di sekitar sel-sel pusat pertembungan daripada keluaran penapisan ruang. Fungsi ini dimodulasi secara berbeza untuk setiap elemen gambar, mengikut keadaan sekelilingnya, dan dengan itu mengurangkan kesan 'lingkaran cahaya'. Teknik baru ini juga mempunyai fungsi untuk mengenalpasti kawasan kurang atau lebih dedahan secara automatik dan melaksanakan pembetulan yang bersesuaian untuk mengimbangi kawasan tersebut. Keputusan ujikaji yang diambil daripada beberapa siri ujikaji menunjukkan bahawa kaedah yang dicadangkan berjaya meningkatkan kualiti dan kejelasan imej. Kaedah yang dicadangkan ini memberikan hasil yang baik untuk nilai entropi dan meningkatkan kadar pengesanan dalam sistem pengesanan wajah. Algoritma ini juga hanya memerlukan sekitar 0.43 saat untuk memproses imej bersaiz 704×576 menggunakan komputer peribadi.

AUTOMATIC IMAGE RESTORATION TECHNIQUE FOR UNDER/OVER EXPOSED REGION

ABSTRACT

Many methods have been proposed to improve the clarity, quality and to compensate the under-exposed or over-exposed regions of an image. In image restoration, the main goal is to improve the clarity in the image. Images with high clarity level contain a lot of information. The clarity is very easily affected by lighting, weather or equipments that have been used to capture the image. Some of these conditions such as inconsistent lighting lead to under-exposed or over-exposed conditions where the image may suffer information loss. Thus, this thesis puts forward an improved restoration method in order to retain the information in the image. This proposed method only performs image restoration on the under-exposed and over-exposed regions without degrading the correctly exposed ones. The tone mapping functions used in this method is inspired by a shunting characteristic of the centre surround cells of the spatial filtering output. This function is modulated differently for every pixel, according to its surround, thus minimizes the halo effect. It also has automatic functions to recognize the under-exposed or over-exposed regions, in which suitable correction is applied to restore these particular regions. The empirical results from series of experiments demonstrate that the proposed method successfully improves the image quality and clarity. The proposed method gives good results for entropy value and increases the detection rate in face detection system. This algorithm only requires around 0.43 seconds to process an image of size 704×576 using conventional personal computer.

CHAPTER 1

INTRODUCTION

In this chapter, the importance of the surveillance system and how the system can improve the security in our life are discussed. In addition, the problems of the conventional surveillance system, the main objectives of this research and the scope of the thesis are highlighted at the end of this chapter.

1.1 Overview

Nowadays, the importance of surveillance system continues to rise. The level of the surveillance system ranges from house security up to the national security. This system is mainly located at places where crimes normally took place such as residence, shopping mall, bank, airport, parking lot, and sidewalk. This is because the usage of the surveillance system can help in improving the safety standard. For example, the implementation of surveillance system in Britain shows 71 percent drop in the number of crimes (416,000 in 2003-04 to 121,770 in 2008-09) and 49 percent drop in the number of traffic violation (47,000 to 23,000) (Razaq, 2010). The effectiveness of surveillance system can also be seen in Scotland Yard cases where 65 cases over 86 cases have been solved by using Closed Circuit Television (CCTV) footage as the evident (Edwards, 2010). Instances in (Razaq, 2010; Edwards, 2010) show that surveillance system has many advantages such as:

- This system is very effective for preventing crime and solving criminal cases.
- This system is capable to record the criminal or the victim themselves or track the move-

ment of the criminal before or after the attack.

- This system is suitable to be used for traffic monitoring and helps reducing traffic violation.
- This system is capable to be functional every time for 24/7, nonstop.
- A single person can manage to monitor multiple surveillance cameras as shown in Figure 1.1.

There are several criteria need to be fulfilled for surveillance system to be fully functional. First of all, capturing device must be able to record high quality images; where the subject in the image can be recognized. Secondly, the capturing device must be installed in a proper placement such as the device pointed to the entrance. Lastly, the system must be robust to avoid crashing while operating.

(a) Scotland Yard Control Room (Razaq, 2010). (b) Merseyside Police Control Room (Down, 2008).

Figure 1.1: Surveillance system control room.

In Malaysia, the surveillance system serves the same purpose but most of the systems are using low quality capturing device due to the cost factor. Therefore, the performance of this surveillance systems is not really impressive because there are limitations in the systems. Figure 1.2 shows some footage taken from conventional surveillance system. From this figure, it can be seen that the surveillance systems are usually exposed to uncontrolled lighting condition which can affect the illumination. Hence, the information in the input data might be lost. In the surveillance system, illumination is one of the crucial factors that determine the successfulness of the system. There are conditions where the illuminations become uncontrolled such as day to night condition, weather, and illumination from other lighting sources.

(a) Subjects faces are hidden due to improper camera placement (Penrose, 2009).

(b) Subject is in under-exposed condition (Rossington, 2010).

Figure 1.2: Example of CCTV footages.

During day to night conditions, the lighting from the sun always changes from time to time. The lighting conditions can be divided into four groups, such as morning, afternoon, evening, and night. All these four time frames have different lighting conditions. For a normal situation without interference from other lighting sources, night produces under-exposed conditions, afternoon creates over-exposed conditions while morning and evening produce ideal lighting conditions. Weather also has the influence in the illumination problems. Unpleasant weather condition such as cloudy weather, raining days, storm and lightning will greatly reduce the functionality of outdoor surveillance system where the visibility of the event will be limited due to the dark environment. For outdoor surveillance, other lighting sources such as vehicle headlight also disturbs the surveillance system. These uncontrolled lighting problems need to be solved as soon as possible for the surveillance system to function properly.

There are numbers of solutions that can be implemented to overcome these inconsistent lighting problems. First of all, a controlled lighting environment can be created where the lighting in the situation cannot be interrupted by other lighting sources. As an example, for indoor surveillance system, a light-proof environment can be built where it is able to control the illumination in the facility but this solution is very difficult to be applied in outdoor environment. Another solution is to upgrade the surveillance system hardware by using High Dynamic Range (HDR) capturing device instead of using Standard Dynamic Range (SDR) ones (Castorina et al., 2003; Krawczyk et al., 2005; Wang and Bi, 2010; Lee et al., 2010; Kokufuta and Maruyama, 2009) but this method increases the processing time and not suitable for real time processing. To reduce the time required to process HDR image, Field Programmable Gate Array (FPGA) can be implemented in the system (Iakovidou et al., 2008; Lu et al., 2009; Tsutsui et al., 2010) but, however, this solution is costly and increase the system complexity.

In view of the aforementioned problems, this research puts forward a simple and inexpensive solution for under-exposed and over-exposed problems where the user neither required to create controlled lighting environment nor replace their SDR surveillance camera to HDR surveillance camera. This research proposes a new method for image restoration where it can be deployed in the surveillance system and able to improve the output of the capturing device. It is based on spatial modulated tone mapping in the SDR image and performs image compensation on the under-exposed and over-exposed regions without affecting the correctly exposed ones. It also has automatic functions to recognize the under-exposed or over-exposed regions and implement suitable correction to restore those regions.

1.2 Problem Statements

This research is conducted to deal with the following problems:

1. Conventional surveillance system is very sensitive towards illuminations which brings to under-exposed or over-exposed regions. It normally produces low quality images that lead to unusable data for machine vision application especially face recognition or verification system.

2. For the users to upgrade their conventional surveillance system for better quality purpose is not practical due to cost factor since they normally need to replace the whole existing surveillance system.

3. Existing image restoration algorithms suffer from complex calculation which brings to high computational time and unsuitable to be implemented in real time system.

1.3 Objective

The main objective of this research is as follows:

To design an automatic image restoration technique for under-exposed and over-exposed regions that enhances those regions without requiring any hardware implementation and has low computational time.

1.4 Scope of Thesis

In this thesis, the scopes are:

1. Only spatial domain-based algorithm are considered in the research and for comparison purpose. This is because, most of the frequency domain-based algorithms are time consuming and not suitable for real time system implementation.

2. No standard benchmarking database is available. To deal with this limitation, a database

is created based on actual surveillance system footage. Another database tested in this thesis is taken from the Yale database. Both databases are chosen because they have similarity with the surveillance environment especially for illumination conditions.

3. Kernel size in the centre surround function is fixed to 111×111 as discussed in chapter 4. This kernel size produces good results for image of size 640 by 480 and 704 by 574. Minor tuning is needed for centre surround function when the size of the input image is either too small or too big.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the basic of image processing methods that are implemented in this research are explained. Advantages and disadvantages of the restoration techniques by past researchers are also being reviewed in this chapter. For evaluation purpose, image quality metrics such as entropy value, naturalness and colourfulness, and face detection accuracy are used.

2.2 Under-Expose and Over-Expose

Under-exposed image and over-exposed image are defined as an image which is too dark and too bright condition, respectively. Images having these two conditions are losing some of their details due to insufficient lighting or too much lighting. These conditions hide the actual intensity values that form the details in the image. Figure 2.1 shows the example of under-exposed region (blue circle) and over-exposed region (red circle).

2.3 Colour Space

Colour space is a mathematical model for colour component representation. Examples of colour spaces are Red, Blue, Green (RGB) (Susstrunk et al., 1999), Luminance, Chrominance Blue, Chrominance Red $(YCbCr)$ (Wilson, 2010), Hue, Saturation, Value (HSV) (Agoston, 2005), and Hue, Saturation, Lightness (HSL) (Agoston, 2005). They have their own advantages or disadvantages depending on applications. In image compensation field, these colour spaces play an

Figure 2.1: Example of under-exposed (blue circle) and over-exposed (red circle) region (Taken from (Baril, 2010)).

important role towards the final output quality and the computational time. Some of the image compensation algorithms use all the colour planes available in RGB colour space, such as most of the Retinex based methods. On the other hand, other methods use only one colour plane e.g. luminance for processing purpose such as in (Meylan and Susstrunk, 2004; Vonikakis and Andreadis, 2007; Erkanli and Rahman, 2010). This can decrease the computational time effectively.

Among these colour spaces, the $YCbCr$ and HSV colour spaces were chosen and implemented in this research.. This is because, both colour spaces are the most common colour space used for one channel processing as stated in (Meylan and Susstrunk, 2004). In the $YCbCr$ colour space, Y represents the luminosity while Cb and Cr stand for chrominance or rough colour for blue and red, respectively. Luminance can be described as the amount of light move across or emitted from the certain region. In other words, visibility in particular region can be improved by increasing luminosity value for under-exposed region and decreasing luminosity value for over-exposed region. HSV colour space alternatively represents the RGB colour space in cylindrical coordinate point where HSV stands for hue, saturation, and value of brightness. Brightness is a value for light intensity which has profound impact in image clarity where the clarity of the under-exposed region can be improved by increasing the value of brightness while decreasing the value of brightness for over-exposed region. Equation (2.1) (Poynton, 1996) and Equation (2.2) (Smith, 1978) show the conversion of RGB to $YCbCr$ and RGB to HSV, respectively.

$$\begin{aligned} Y &= 16 + (65.481 \cdot \frac{R}{255} + 128.533 \cdot \frac{G}{255} + 24.966 \cdot \frac{B}{255}) \\ Cb &= 128 + (-37.797 \cdot \frac{R}{255} - 74.203 \cdot \frac{G}{255} + 112 \cdot \frac{B}{255}) \\ Cr &= 128 + (112 \cdot \frac{R}{255} - 93.786 \cdot \frac{G}{255} - 18.214 \cdot \frac{B}{255}) \end{aligned} \tag{2.1}$$

where, Y is luminance for $YCbCr$, Cb is chrominance blue for $YCbCr$, Cr is chrominance red for $YCbCr$, R is red channel in RGB, G is green channel in RGB and B blue channel in RGB.

$$\begin{aligned} H &= \begin{cases} \frac{G-B}{\max(R,G,B)-\min(R,G,B)} & \text{if } R = \max \\ 2 + \frac{B-R}{\max(R,G,B)-\min(R,G,B)} & \text{if } G = \max \\ 4 + \frac{R-G}{\max(R,G,B)-\min(R,G,B)} & \text{if } B = \max \end{cases} \\ S &= \begin{cases} \frac{\max(R,G,B)-\min)R,G,B)}{\max(R,G,B)} & \text{if } \max \neq 0 \\ 0, & \text{otherwise} \end{cases} \\ V &= \max(R,G,B) \end{aligned} \tag{2.2}$$

where, H is hue for HSV, S for saturation in HSV, V is value for HSV, $\max$ is maximum intensity value and $\min$ is minimum intensity value.

2.4 Spatial Domain

Spatial domain for an image is a space where the intensity of a pixel can be referred by its coordinate. Operation in spatial domain normally involved the neighbouring pixels by using filtering method. The kernel can be shape of circle, rectangular, and diamond (Gonzales et al., 2004).Most usual shape used is rectangular (Polesel et al., 1997). On the other hand, frequency domain processes involved transforming data from spatial domain to frequency domain via discrete time Fourier transform (DTFT), discrete Fourier transforms (DFT) or fast Fourier transform (FFT). In comparison for processing time, frequency domain method is usually neglected due it is time consuming (Gonzales et al., 2004). In this research, the spatial filtering technique is studied to perform the edge enhancement and mean kernel is implemented as centre surround function.

2.4.1 Edge Enhancement

Example of the spatial filtering for edge enhancement is given in Figure 2.2.

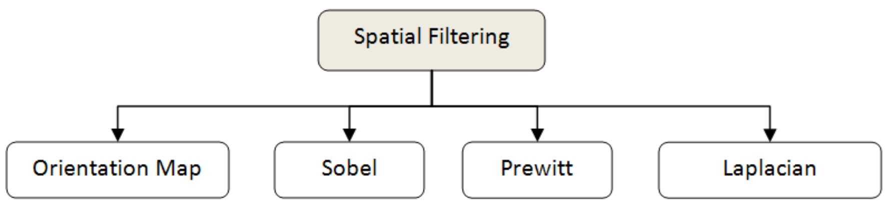


Figure 2.2: Example of spatial filtering method.

2.4.1(a) Orientation Map

Orientation map is an output of an image in orientation form built from 10×10 pixels kernel which has similarity to the human visual system (HSV). The orientation kernel is built from 60 binary kernels which contains two parts (A_K and B_K) and the sets of the kernel has 12 different orientations (every $15°$) and in all possible phases within the 10×10 kernel. They are applied to non-overlapping region of the Y component. The illustration of the 60 kernels and the magnification of 44th kernel are shown in Figure 2.3.

The orientation map is calculated as in Equation (2.3), which i and j are the coordinate of the upper left pixel of the Y component.

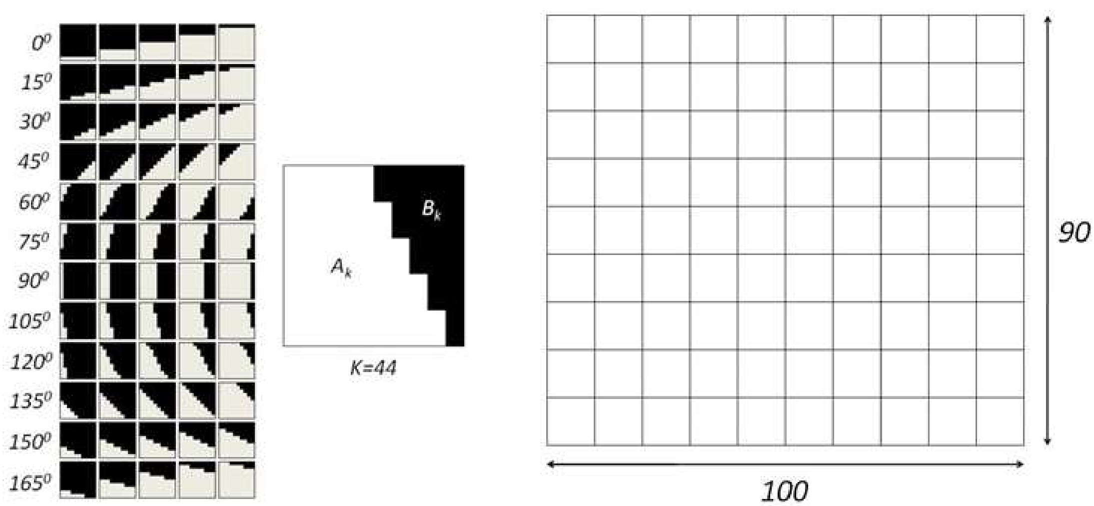
$$out^K_{u,v} = \left|M^{A,K}_{u,v} - M^{B,K}_{u,v}\right|, \;\; u = \frac{i}{10}, v = \frac{j}{10}, \; u,v \in Z \tag{2.3}$$

where, u and v are the coordinate of orientation map while $M^{A,K}_{u,v}$ and $M^{B,K}_{u,v}$ is defined by Equation (2.4);

$$M^{A,K}_{u,v} = \frac{1}{N_{A,K}} \sum_{y=i}^{i+9} \sum_{x=j}^{j+9} Y_{y,x} \; \forall \, Y_{y,x} \in A_K, \quad M^{B,K}_{u,v} = \frac{1}{N_{B,K}} \sum_{y=i}^{i+9} \sum_{x=j}^{j+9} Y_{y,x} \; \forall \, Y_{y,x} \in B_K \tag{2.4}$$

$$OM^A_{u,v} = M^{A,K'}_{u,v}, \;\; OM^B_{u,v} = M^{B,K'}_{u,v}, \;\; K' : max[out^K_{u,v}]^{60}_{K=1} = out^{K'}_{u,v} \tag{2.5}$$

where, $M^{A,K}_{u,v}$ is the mean intensity of A_K, $M^{B,K}_{u,v}$ is the mean intensity of B_K, $N_{A,K}$ is the number of pixels of A_K, $N_{B,K}$ is the number of pixels of B_K, and K is the number of kernel. Equation (2.5) selects the most suitable output kernel which matches the phase and orientation of the input image.



(a) 44^{th} kernel zoomed in. (b) Non-overlapping kernel implementation.

Figure 2.3: Orientation map.

2.4.1(b) Sobel

The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in the horizontal and vertical direction and is therefore, relatively inexpensive in terms of computations. On the other hand, the gradient approximation which has been produced is reasonably crude, in particular for high frequency variations in the image. Mathematically, equation for Sobel is given by Equation (2.6);

$$G_x = f(x,y) * S_x \text{ and } G_y = f(x,y) * S_y \tag{2.6}$$

where, $*$ is the convolution operation, $f(x,y)$ is the input image, S_x is the Sobel vertical edge kernel as shown in Figure 2.4(a), S_y is the Sobel horizontal edge kernel as in Figure 2.4(b), G_x is the output for vertical derivative approximations, and G_y is the output for horizontal derivative approximations.

1	2	1
0	0	0
−1	−2	−1

(a) Kernel defined by S_x.

1	0	−1
2	0	−2
1	0	−1

(b) Kernel defined by S_y.

Figure 2.4: Sobel kernel.

2.4.1(c) Prewitt

Prewitt is used in image processing for edge detection. Technically, it is a discrete differentiation operator, where it computes an approximation of the gradient of the image intensity function. Prewitt is also a method that calculates the maximum response of a set of convolution kernels to find the local edge orientation for each pixel. Mathematically, equation for Prewitt is given by Equation (2.7);

$$G_x = f(x,y) * P_x \text{ and } G_y = f(x,y) * P_y \tag{2.7}$$

where, $*$ is the convolution operation, $f(x,y)$ is the input image, P_x is the Prewitt vertical edge kernel as shown in Figure 2.5(a), P_y is the Prewitt horizontal edge kernel as shown in Figure 2.5(b), G_x is the output for vertical derivative approximations, and G_y is the output for horizontal derivative approximations.

1	1	1
0	0	0
−1	−1	−1

(a) Kernel defined by P_x.

1	0	−1
1	0	−1
1	0	−1

(b) Kernel defined by P_y.

Figure 2.5: Prewitt kernel.

2.4.1(d) Laplacian

Laplacian is one of the operators for edge enhancement. Mathematically, Laplacian edge enhancement is shown by Equation (2.8);

$$G_x \ = \ G_y = f(x,y) * L \tag{2.8}$$

where, $*$ is the convolution operation, $f(x,y)$ is the input image, L is the Laplacian kernel defined in Figure 2.6.

0	−1	0
−1	4	−1
0	−1	0

Figure 2.6: Kernel defined by L.

2.4.1(e) Unsharp Masking Filter

Unsharp masking filter is a simple sharpening operator. Its name is derived from the fact that it enhances edges (and other high frequency components in an image) by subtracting an unsharp or smoothed version of an image from the original image. The unsharp masking filter is implemented by a window based operation. The filter relies on a convolution kernel to perform spatial filtering. It can be implemented by using an appropriately defined low pass filter to produce the smoothed version of an image, which is then subtracted from the original image, pixel by pixel, in order to give a description on high pass region i.e. edges. In other words, this filter only affects the edge in the image while maintaining the intensity in non-edge region. Mathematically, the unsharp masking filter is given by Equation (2.9);

$$f_{unsharp} = f(x,y) * a - f(x,y) * esp \tag{2.9}$$

where, $f_{unsharp}$ is the output image, $f(x,y)$ is the input image, a is the kernel shown in Figure 2.7(a), and esp is the edge enhancement kernel i.e. Sobel, Prewitt or Laplacian.

For Sobel and Prewitt, the kernels are same as in Figure 2.4 and Figure 2.5 but for Laplacian, the negative Laplacian filter is used as shown in Figure 2.7(b).

1	1	1
0	0	0
−1	−1	−1

(a) Kernel defined by a.

1	0	−1
1	0	−1
1	0	−1

(b) Negative Laplacian filter.

Figure 2.7: Unsharp masking filter based on Laplacian.

2.4.2 Centre Surround

Centre surround is a normal average function derived from the mean kernel. This method is applied in order to eliminate the unwanted halo effect and to reduce the uneven intensity in particular regions. The centre surround function is given by Equation (2.10);

$$S_{n,m} = \frac{1}{\gamma^2} \sum_{y=n-\frac{\gamma-1}{2}}^{n+\frac{\gamma-1}{2}} \sum_{x=m-\frac{\gamma-1}{2}}^{m+\frac{\gamma-1}{2}} f_{unsharp}(x,y) \tag{2.10}$$

where, $S_{n,m}$ is the centre surround output, $f_{unsharp}(x,y)$ is the output from the Laplacian unsharp filter, γ is the centre surround factor and n,m is the centre surround point.

2.5 Previous Work on Image Compensation Techniques

Numerous researchers have shown their interest in image processing field, especially in image compensation technique where the main objective of this technique is to improve the image quality and to restore under-exposed or over-exposed regions. They have carried out various studies to improve the effectiveness of the technique and countless experiments to solve the problems that occur in this field. Some of their findings and suggestions are reviewed in this section.

Apart from this, brief explanations about common techniques in image compensation such as Manual Tuning, Contrast Stretching, Non Linear Point Transform, Histogram Equalization, Homomorphic Filtering, and last but not least the Retinex method is also given. Figure 2.8 shows the common methods for image compensation techniques. From this figure, only Homomorphic Filtering is the frequency domain technique while other methods are spatial domain techniques. This method is chosen for comparison purpose between spatial domain technique with frequency domain technique.

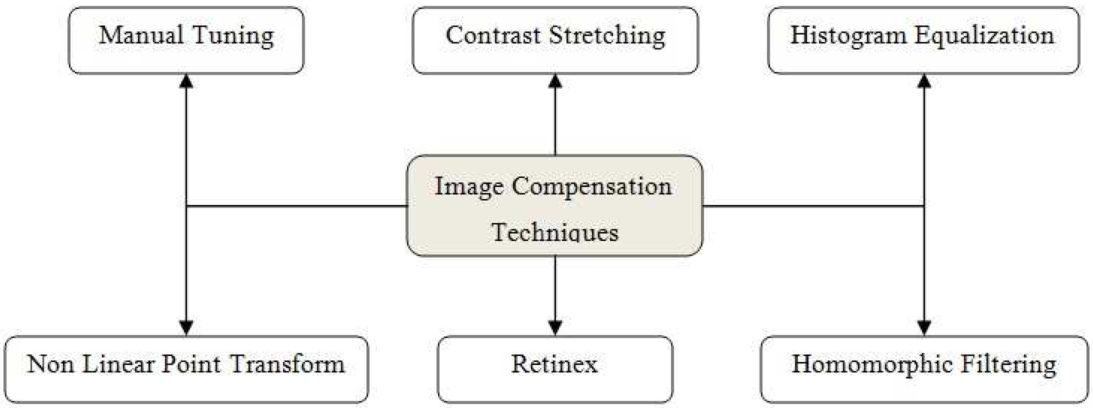


Figure 2.8: Examples of Image Compensation Techniques.

2.5.1 Manual Tuning

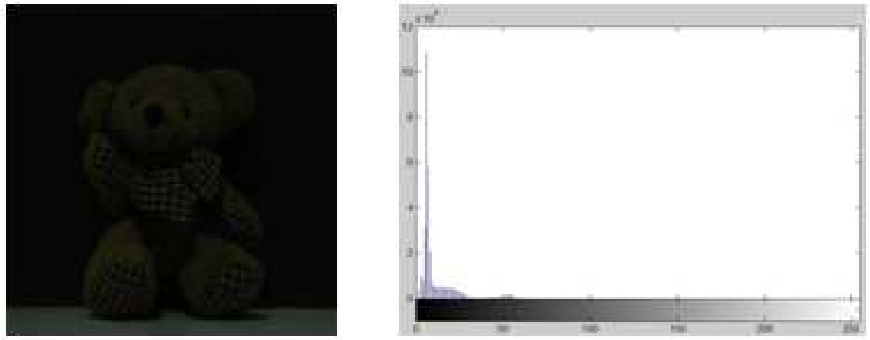
Manual Tuning is the technique where no computer-aid involved. One of the most used manual tuning techniques is dodging and burning. Dodging and burning (Adams, 1995) is the technique used by photographers during the printing process to manipulate the exposure of a selected region on photographic print. 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 in such a way as to block light from the portion of the scene to be lightened. Since the technique is used with a negative-to-positive process, reducing the amount of light results in a lighter image. Burning is the process to increases 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. Nowadays, a lot of modern digital imaging software such as Adobe Photoshop, Aperture, and GIMP (GNU Image Manipulation Program) has 'burning and dodging' tools that mimic the effect on digital images.

2.5.2 Contrast Stretching

One of the common methods utilized in image compensation is contrast stretching (Gonzales et al., 2004). This algorithm's function is to stretch the dynamic range of an image where dynamic range is the range between the minimum and the maximum intensity value of an image. In Equation (2.11), it is decided that the range of the contrast by changing the d value and that value is dependent on the image to be processed. Usually, dynamic range in the image is equal to 256 $[0,255]$. However, by using this method, loss of the detail occurs due to saturation and clipping as well as due to poor visibility in darker regions of the image. Mathematically, contrast stretching algorithm is given by Equation (2.11);

$$I' = \frac{d}{I_{max} - I_{min}} \cdot (I - I_{min}) + I_0 \tag{2.11}$$

where, I' is the output image, d is the new dynamic range value, I is the input image, I_{max} is the maximum intensity value in the input image, I_{min} is the minimum intensity value in the input image, and I_0 is the offset point for the output image. In Figure 2.9, the input image dynamic range is $[0,62]$ as shown in the histogram in Figure 2.9(b). As a result of contrast stretching algorithm, the output image dynamic range becomes $[0,255]$ as depicted in Figure 2.10(b). In this example, parameter for d is set to 255 while I_0 is equal to 0.

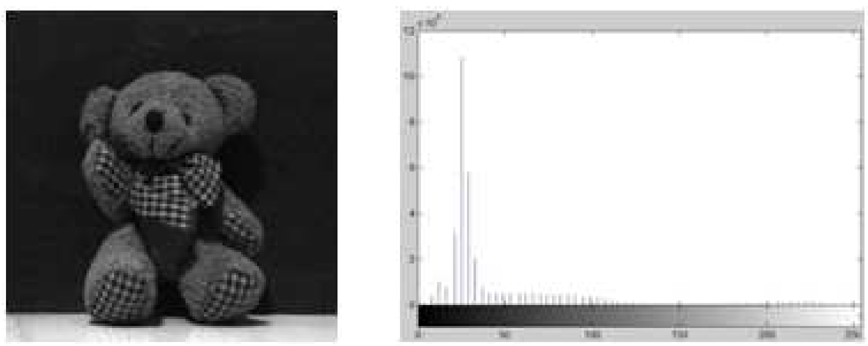


(a) Input image (Taken from (Paul, 2009)).

(b) Input histogram.

Figure 2.9: Contrast stretching input image.

The result from Figure 2.10(a) shows the effect of the algorithm where the output image has wide dynamic range hence provides more information in the image.



(a) Output image.

(b) Output histogram.

Figure 2.10: Contrast stretching output image.

2.5.3 Non Linear Point Transform

Another well known method used for image compensation is Non Linear Point Transforms. Gamma Intensity Correction (Gonzales et al., 2004) and Logarithmic Function (Gonzales et al., 2004) are the examples of the algorithm that implement non linear point transforms as represented in Figure 2.11.

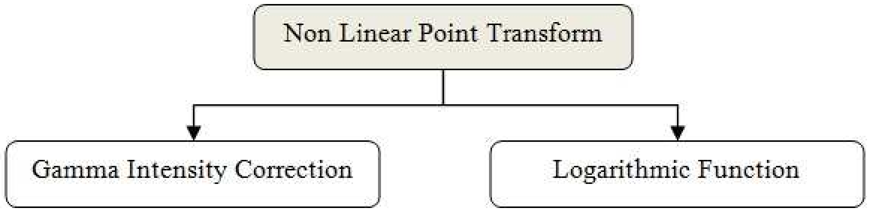


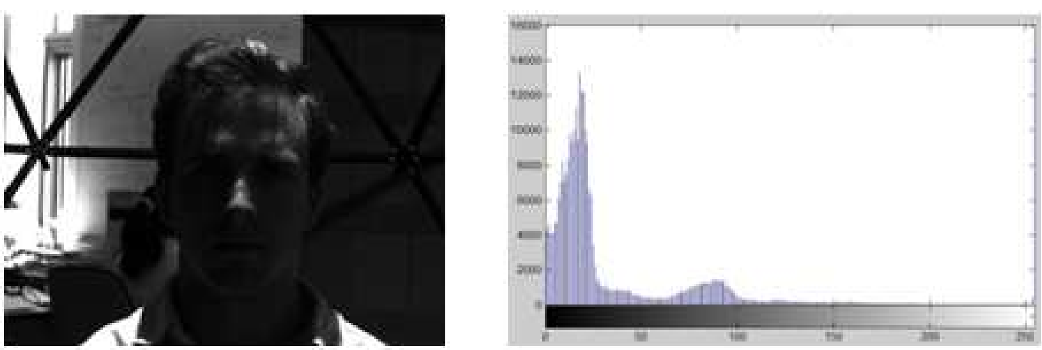
Figure 2.11: Examples of Non Linear Point Transform method.

2.5.3(a) Gamma Intensity Correction

Gamma Intensity Correction is often used in the field of computer graphic. Gamma parameter, γ in Equation (2.12) functions as brightness controller of the output image. When the value of γ is not properly selected, the output image will become either too dark or bleached out as shown is Figure 2.13(a) and Figure 2.13(c), respectively. Figure 2.13 shows the output for gamma intensity correction when the value of γ is properly selected. Mathematically, gamma intensity correction algorithm is given by Equation (2.12);

$$I' = c \cdot I^{\gamma} \tag{2.12}$$

where, I' is the output image, I is the input image, γ and c are the positive constant. For further discussion, an input image as in Figure 2.12 is used for reference purpose.

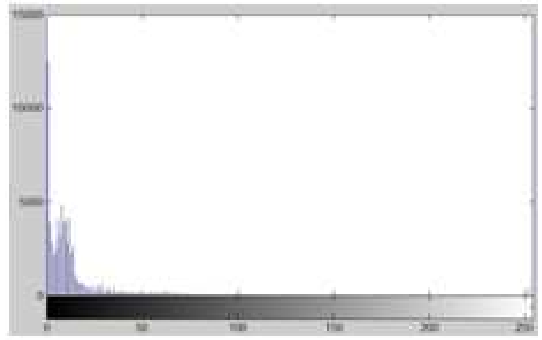


(a) Input image.

(b) Input histogram.

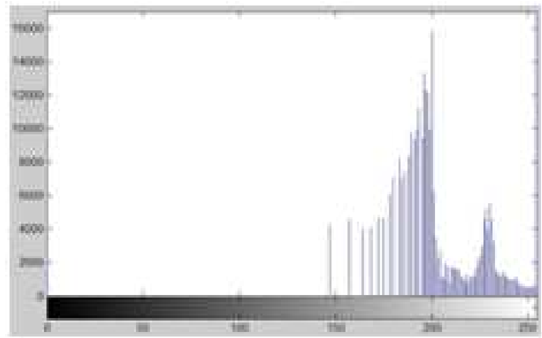
Figure 2.12: Input Image.

(a) γ value is set too high.



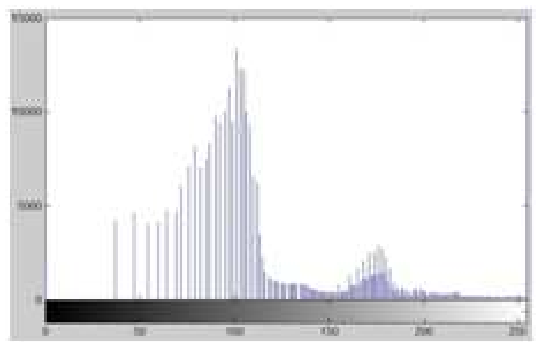
(b) Histogram of the output image.

(c) γ value is set too low.



(d) Histogram of the output image.

(e) γ value is properly selected.



(f) Histogram of the output image

Figure 2.13: Gamma intensity correction.

2.5.3(b) Logarithmic Function

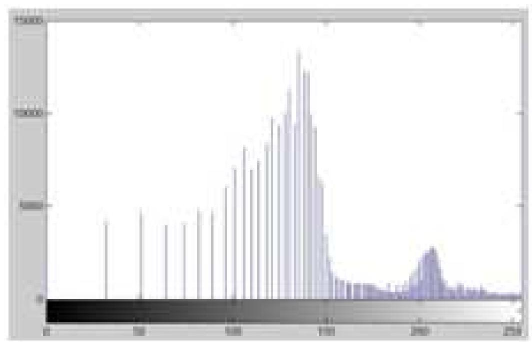
Logarithmic Function is one of the non linear transformations where its important characteristic is to compress the dynamic range with large variation in pixel values. Logarithmic Function equation is as described in Equation (2.13);

$$I' = c \cdot \log[1 + I] \quad (2.13)$$

where, I' is the output image, I is the input image and c is the positive constant.

Figure 2.14 shows the effect of implementing the Logarithmic Function on the image. From the observation of the output histogram as shown in Figure 2.14(b), it can seen that Logarithmic Function modifies the input image by compressing the displayed brightness at the bright end of scale, while expanding those dark pixels at the dark end. As a conclusion, Logarithmic Function manages to improve the information in the image.

(a) Output image.



(b) Output histogram.

Figure 2.14: Logarithmic Function output image.

2.5.4 Histogram Equalization

Histogram Equalization (HE) (Gonzales et al., 2004) is a technique that makes 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 distributions. If the histogram of any image has many peaks and valleys, it will have peaks and valleys after equalization but 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) as shown in Figure 2.15.

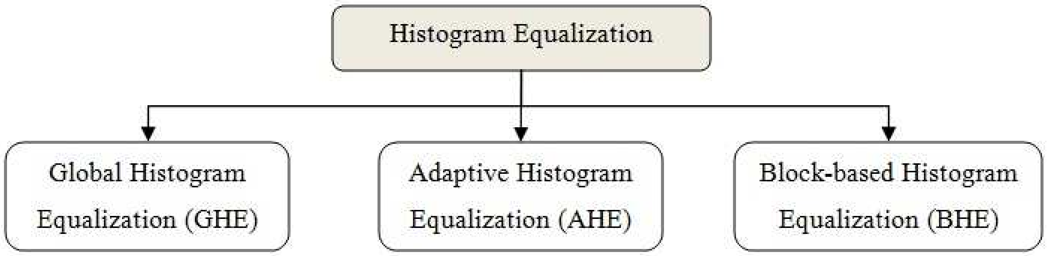


Figure 2.15: Types of Histogram Equalization.

2.5.4(a) Global Histogram Equalization

In Global Histogram Equalization (GHE) (Gonzales et al., 2004), 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 gray scale 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 Equation (2.14);

$$I' = \frac{d}{C_{max} - C_{min}} \cdot (C - C_{min}) + I_0 \tag{2.14}$$

where, I' is the output image, d is the new dynamic range value, C is the normalized cumulative value, C_{min} is the minimum value of C, C_{max} is the maximum value of C and I_0 is the offset point of dynamic range of I'.

Implementation of GHE is described as follows where Figure 2.16 shows the intensity of input image. First, cumulative value, C, is calculated and applied into Equation (2.14). In this example,