DEVELOPMENT OF CONTRAST ENHANCEMENT METHOD FOR DIGITAL IMAGES

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2017

DEVELOPMENT OF CONTRAST ENHANCEMENT METHOD FOR DIGITAL IMAGES

by

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Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Engineering (Electronic Engineering)

JUNE 2017

ACKNOWLEGMENTS

With the completion of this thesis, I would like to express my deepest gratitude to all people who assisted and guided me in this research project.

First and foremost, I would wish to convey my sincere gratitude to my final year project supervisor, Dr. Haidi Ibrahim for his guidance, support and encouragement until the completion of this project. He has been a great source of knowledge and inspiration to me. He also willing to sacrifice his valuable time to guide me in image enhancement and C++ programming. I am extremely grateful to him for proofreading my thesis. His guidance and patience made this work possible. Besides that, I would like to extend my appreciation to my thesis examiner, Mr Ahmad Nazri Ali for his valuable feedback and helpful comments on my thesis.

Next, I would like to thank all my friends who willing to give me suggestions and advice on my project. I also take this opportunity to thank all respondents who help to answer the visual assessment survey.

Last but not least, I wish to thank my family for their support and encouragement during the four years of studying engineering at School of Electrical and Electronic Engineering, Engineering campus, Universiti Sains Malaysia.

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LIST OF ABBREVIATIONS

ACMHE	Adapted Contrast enhancement using Modified Histogram Equalization
AHE	Adaptive Histogram Equalization
BBHE	Brightness preserving Bi-Histogram Equalization
BOHE	Block Overlapped Histogram Equalization
BPNMBHE	Brightness Preserving and Non-parametric Modified Bi-Histogram Equalization
BR	Border Region
CDF	Cumulative Distribution Function
CegaHE	Contrast enhancement algorithm based on gap adjustment for Histogram Equalization
CLAHE	Contrast Limited Adaptive Histogram Equalization
CPP	Contrast per Pixel
CR	Corner Region
DOTHE	Dominant Orientation based Texture Histogram Equalization
DRE	Dark Region Enhancement
DSIHE	Dualistic Sub-Image Histogram Equalization
ESIHE	Exposure based Sub-Image Histogram Equalization
ETHE	Edge based Texture Histogram Equalization
GHE	Global Histogram Equalization
HE	Histogram Equalization
IR	Inner Region
IV	Image Variance
LHE	Local Histogram Equalization

MLBOHE	Multiple Layers Block Overlapped Histogram Equalization
NOBHE	Non-Overlapped Block Histogram Equalization
NSD	Noise Standard Deviation
OPENCV	Open Source Computer Vision
PDF	Probability Density Function
R-ESIHE	Recursive Exposure based Sub-Image Histogram Equalization
RS-ESIHE	Recursively Separated Exposure based Sub-Image Histogram Equalization
RWMPHE	Recursive Weighted Multi-Plateau Histogram Equalization
SI	Speckle Index

LIST OF SYMBOLS

a, b	parameters used to control enhancement rate
c	constant
$C(k)$	CDF of image for k-th intensity level
$C_L(k)$	CDF of lower sub-histogram for k-th intensity level
$C_U(k)$	CDF of upper sub-histogram for k-th intensity level
d	gap between new value and old value of intensity level
$f(x, y)$	two-dimensional function of image at spatial coordinates (x, y)
h_c	clipped histogram
$H(k)$	number of pixels for k-th intensity level
$i(x, y)$	illumination at spatial coordinates (x, y)
j	input intensity level
j'	normalized input intensity level
k	output intensity level
L	intensity level of image
L_l^r	lower intensity value for r-th sub-histogram
L_u^r	upper intensity value for r-th sub-histogram
$L(G)$	limiting gap of each gray value
n	number of sub-histograms
N	total number of pixels
N_L	total number of pixels for lower sub-histogram
N_U	total number of pixels for upper sub-histogram
$p(x)$	gradient probability of x

$P(k)$	PDF of image for k-th intensity level
$P_L(k)$	PDF of lower sub-histogram for k-th intensity level
$P_U(k)$	PDF of upper sub-histogram for k-th intensity level
$r(x, y)$	reflectance at spatial coordinates (x, y)
T_c	clipped threshold value
$T(k)$	transform function for HE at input intensity, k
$T_L(k)$	transform function of lower sub-histogram for HE at input intensity, k
$T_U(k)$	transform function of upper sub-histogram for HE at input intensity, k
w	non-negative weight
x, y	spatial coordinate on the images
X_a	exposure threshold parameter
$\nabla I(x, y)$	gradient of image at spatial coordinates (x, y)
γ	constant (gamma)
$\mu(x, y)$	local mean at spatial coordinates (x, y)
$\sigma(x, y)$	local standard deviation at spatial coordinates (x, y)
τ	variance threshold

PEMBANGUNAN KAEDAH PENINGKATAN BEZA JELAS BAGI IMEJ DIGITAL

ABSTRAK

Gambar yang ditangkap dalam persekitaran gelap, yang keadaan pencahayaannya tidak mencukupi atau tidak sekata, mungkin membawa kepada imej dengan beza jelas yang rendah. Imej malam kelihatan gelap dan tidak jelas berbanding dengan imej siang. Keadah peningkatan imej boleh digunakan untuk meningkatkan kualiti imej. Kaedah penyeragaman histogram (HE) adalah kaedah peningkatan imej yang biasa. Walaupun penyelidik telah mencadangkan pelbagai kaedah peningkatan imej termasuk penyeragaman histogram sejagat dan setempat, namun masih terdapat beberapa masalah yang dihadapi termasuk lebih peningkatan, peralihan kecerahan purata, dan kehilangan butiran. Oleh itu, dua kaedah peningkatan imej telah dibangunkan dengan melata penyeragaman histogram sub-imej dedahan (ESIHE) dan penyeragaman histogram penyesuaian kontras terhad (CLAHE). ESIHE adalah kaedah berdasarkan penyeragaman histogram sejagat, manakala CLAHE adalah kaedah berdasarkan penyeragaman histogram setempat. Kemudian, kedua-dua keadah yang dicadangkan dibandingkan dengan kaedah sedia ada yang berdasarkan HE secara kualitatif dan kuantitatif. Penilaian kualitatif merupakan kaji selidik penilaian visual, manakala penilaian kuantitatif adalah sisihan piawai hingar (NSD), varians imej (IV) indeks rintik (SI) dan beza jelas setiap piksel (CPP). Berdasarkan penilaian, kaedah yang digunakan ESIHE kemudian diikuti oleh CLAHE mampu meningkatkan imej lebih baik daripada kaedah digunakan CLAHE dan diikuti dengan ESIHE. Imej keluaran mempunyai penampilan semula jadi, beza jelas tinggi dan butir-butir imej adalah jelas.

DEVELOPMENT OF CONTRAST ENHANCEMENT METHOD FOR DIGITAL IMAGES

ABSTRACT

Photos captured in the dark environments, which have insufficient or uneven lighting conditions, might lead to low contrast images. The night images are looked dark and not clear as compared to day images. Image enhancement methods can be applied to improve the image quality. Histogram equalization (HE) method is a common image enhancement method. Although researchers had proposed many enhancement methods which including global and local histogram equalization, there are still some problems faced which include over enhancement, shift of mean brightness and loss of details. Hence, two image enhancement methods were developed by cascading exposure sub-image histogram equalization (ESIHE) and contrast limited adaptive histogram equalization (CLAHE) in different sequences. ESIHE is a global histogram equalization based method, while CLAHE is a local histogram equalization based method. Then, these two proposed methods were compared with existing HE based methods qualitatively and quantitatively. The qualitative assessment is visual assessment survey, while quantitative assessments are. noise standard deviation (NSD), image variance (IV), speckle index (SI) and contrast per pixel (CPP). Based on the assessments, the method that applied ESIHE then followed by CLAHE is able to enhance images better than the method applied CLAHE first and followed by ESIHE. The output image have a natural appearance, high contrast, and the details of image are clear.

CHAPTER 1

INTRODUCTION

1.1 Overview

Over the past few years, the average number of photos been uploaded to a famous social media website, Facebook, were 350 million per day, while the total number of photos are more than 250 billion (Kit, 2016; Zephoria, 2017). However, it is worth noting that the number of the photos taken are definitely greater than this because not every photo taken is uploaded to Facebook. It is estimated that up to 1.2 trillion photos will be taken in 2017 and 85% of them are taken by using mobile phones (Eric, 2016). According to Eric (2016), the number of photos taken is increasing exponentially and the people are changing from using digital camera to mobile phone cameras when capturing photos.

With this high amount of photos taken, it can be sure that the chances of taking low quality images are also increased. Photos captured in low light conditions such as during night and inside a dark room might lead to the low contrast images (Khan, Khan, & Abbasi, 2015a). This will result in a low quality image as the details of image cannot be seen clearly. Therefore, night images typically have low quality and loss of information due to the insufficient or uneven light during the night (Zhang & Wan, 2016). Therefore, night image requires longer exposure time, but this causes it to be more prone to noise. Figure 1.1 shows the grayscale day and night images taken from the same place. Day images details can be seen clearly as it has sufficient amount of light, while night image is looked darker.

To improve the image, image enhancement can be applied. Image enhancement can be used to manipulate the image so that the output image will appear better, subjectively, than the original image for a specific application. The application is not limited to night image only, it can be extended to enhance video quality. For example, surveillance cameras are widely used as for crime prevention, image enhancement method can be the fundamental way to improve the low quality video taken during night.

Image enhancement can be carried out in spatial domain, and also in frequency domain. Spatial domain methods operate directly on the image pixels. The examples of spatial domain techniques include image negative, log transformations, power-law (Gamma) transformations, piecewise-linear transformation function, and histogram equalization (Gonzalez & Woods, 2008; Janani, Premaladha, & Ravichandran, 2015).

(a)

(b)

Figure 1.1: Grayscale digital images (a) day view (b) night view

On the other hand, frequency domain methods require transformation to other domains, which can be achieved by using transformations such as Fourier transform and wavelet transform. The frequency domain methods include Butterworth lowpass and highpass filter, Gaussian lowpass and highpass filter, and Notch filter (Agrawal, Chourasia, Kapoor, & Agrawal, 2014; Gonzalez & Woods, 2008; Janani et al., 2015).

Histogram equalization (HE) is one of the popular spatial domain image enhancement methods (Gonzalez & Woods, 2008). HE uses the histogram to construct its transfer function. The histogram of an image represents the number of pixels in that image at each intensity level. Figure 1.2 shows the histogram of an image, where the x-axis represents the grayscale intensity range whereas the y-axis represents the number of pixels. The brightness of image can be observed from the histogram. If the image is dark, the histogram bins are skewed toward the left side of the histogram. On the other hand, most of the intensity bins are located on the right side of the histogram for bright image.

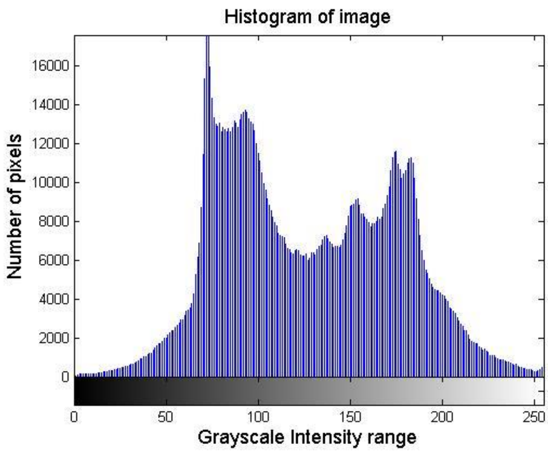
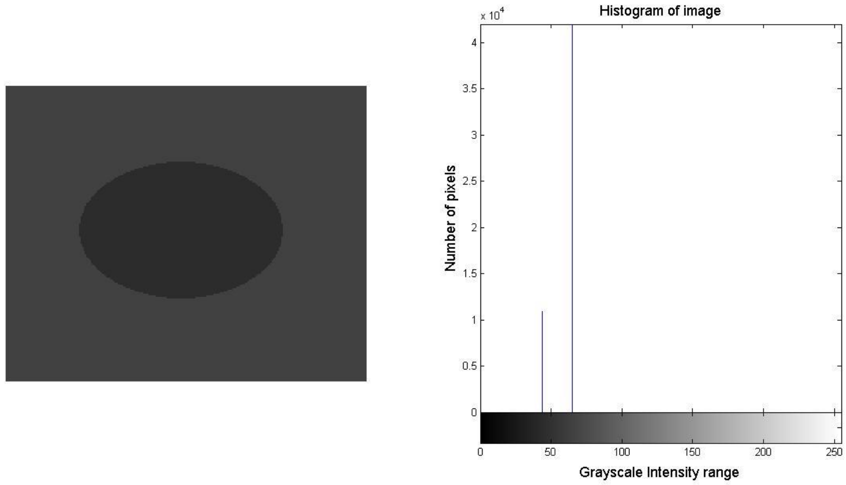


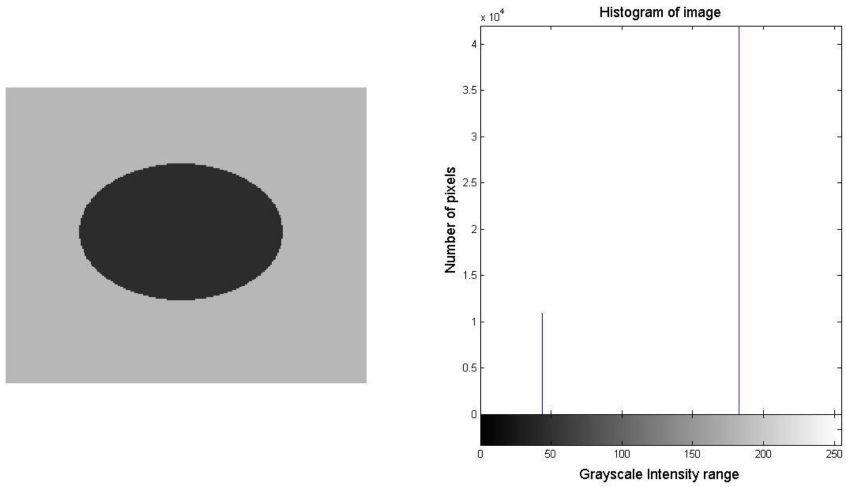
Figure 1.2: Histogram of a digital image

The range of intensity levels used by an image is defined as dynamic range. An image with low contrast usually has a narrow dynamic range. Therefore, an image needs to fully utilize the wide range of intensity levels in order to obtain a high contrast image. HE can be used to stretch the narrow range of intensity level to wider dynamic range. An image can have L intensity levels, which are 0, 1, 2,… , $L-1$ and for an 8-bit-per-pixel grayscale image, the value of L is equal to 2^8 or 256.

Figure 1.3 shows the examples of low contrast and high contrast images. The grayscale intensity inside the oval shape is the same for both Figure 1.3 (a) and (b). The difference is that the grayscale intensity outside the oval shape. Figure 1.3 (a) shows low contrast image where the intensity of the oval is similar to its background. This can be proved by using the image histogram which shows the two intensity levels are close to each other’s. On the other hand, Figure 1.3 (b) shows higher contrast image. From the histogram, it is shown that the intensity of the oval is well separated from its background.



(a)



(b)

Figure 1.3: Images and their histograms showing (a) low contrast (b) high contrast

1.2 Problem Statements

Image enhancement is an active research in digital image processing field. Night image is one of the applications of image enhancement methods. This types of images usually have poor quality and their details cannot be seen clearly as the foreground and the background has similar intensity levels. Thus, many methods, including global and local image enhancement methods have been proposed to solve the mentioned problems.

However, these two different approaches have their own limitations. Global image processing methods normally cause over enhancement, mean-brightness shift problem, and loss of information (Khan, 2015a; Qadar, Zhaowen, Rehman, & Alvi, 2015). While local image processing methods generally are time consuming (Liu, Guo, & Lai, 2016). In addition, when researchers tried to solve the mentioned drawbacks faced by many methods, the natural appearance of images are overlooked in some cases. This situation might be caused by intensity saturation of images (Chiu & Ting, 2016).

1.3 Objectives

The objectives to be achieved in this project are as follow:

1. To develop image contrast enhancement methods, which is suitable for images suffer from low illumination by cascading global histogram equalization based method and local histogram equalization based method in different sequences.
2. To evaluate the proposed methods and select the best method based on their performance.

1.4 Scopes of Project

This project is about developing an image enhancement method and focuses only on the implementation of 8-bit-per-pixel grayscale digital images. The digital images should be taken by digital cameras, mobile phone cameras, and tablet cameras. Satellite images and cephalometric images are not included in this project.

Furthermore, only low illumination images are used as input images. Usually, the low illumination images are captured in a low light condition such as in a closed dark room and during night. The overexposed images are not considered in this project.

This project is carried out in spatial domain only, therefore spatial domain image enhancement method is used. The method operates directly on the image pixels rather than transform the images into other domain. The spatial domain image enhancement methods used including global image enhancement method and local image enhancement method. Global image enhancement method operates on the entire image, while local image enhancement method operates on the image patches or blocks.

1.5 Thesis Organization

There are five chapters in this thesis. Chapter 1 gives a brief introduction to the project which includes the overview of image enhancement, problem statement, objectives, the scope of project, and organization of thesis.

Chapter 2 reviews about the past researches and the algorithms developed to enhance the images. Knowledge on the basic image enhancement techniques are included. The global and local image processing methods are further discussed in this chapter.

Chapter 3 shows the project development flow. The details of the procedures are explained throughout this chapter. The details of algorithms developed used to solve the underexposed night image is also explained throughout this chapter.

Chapter 4 presents and discusses the experimental results and the performances of the proposed method. The performance of algorithms is examined and assessed qualitatively and quantitatively.

Chapter 5 concludes the findings from the project and give a few constructive suggestions for the future works.

CHAPTER 2

LITERATURE REVIEW

This chapter is started by describing the formation of images and the reason of formation of low contrast image. Some image enhancement methods are explained. Then, the common way to enhance image, which is histogram equalization, is discussed section 2.2. Its variations are also included. Local histogram equalization is explained in the next section. Lastly, chapter remarks conclude this chapter by giving a summary table.

2.1 Introduction

Image is defined as a two-dimensional function, $f(x, y)$, where x and y are spatial coordinates. The function, $f(x, y)$, is defined by equation (2.1) (Gonzalez & Woods, 2008):

$$f(x, y) = i(x, y) \times r(x, y) \tag{2.1}$$

where $i(x, y)$ is illumination and $r(x, y)$ is reflectance. These components are defined as source illumination incident on the scene being viewed and illumination reflected by the objects in the scene respectively (Gonzalez & Woods, 2008). Hence, image is formed by manipulation of illumination and reflectance. If image is taken at night or low light condition, the illumination value, $i(x, y)$ will become low. This phenomena will result in production of low contrast image.

Image enhancement methods can be used to increase the value of reflectance, $r(x, y)$ in order to improve the contrast of image, so that the images quality will look better than that of original images. Four types of image enhancement methods are explained in the following sub-sections. They are image negative, log transformation, power-law transformation, and piecewise-linear transformation.

2.1.1 Image Negative

Image negative method is suitable to be applied on the image that dark region is dominant in size (Janani et al., 2015). The negative image is obtained by using negative transformation that reverses the intensity levels of image. The negative transformation function is defined as (Gonzalez & Woods, 2008):

$$k = L - 1 - j \tag{2.2}$$

where L is the intensity levels of image, and k and j are the output intensity level and input intensity level, respectively.

The mapping function for the negative transformation is shown in Figure 2.2. In this figure, the image used is an 8-bit-per-pixel image, where the intensity level, L in the range of $0 - 255$. For example, the pixel with input intensity level of 255 will obtain output intensity level of 0 after this negative transformation.

Image negative enhancement method is normally used to enhance white or gray details in a dark region of image. This method were used to enhance the vein pattern in hand image (Deepak, Neelamegam, Sriram, & Nagarajan, 2012).

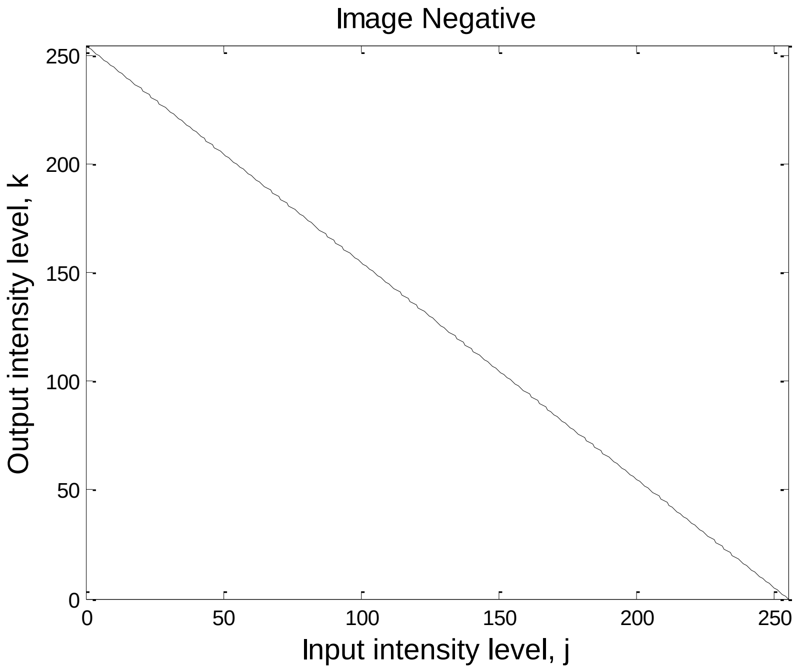


Figure 2.1: Image negative transformation function (Gonzalez & Woods, 2008)

2.1.2 Log Transformation

The log transformation can be defined, generally by equation (2.3) (Gonzalez & Woods, 2008):

$$k = c\log(1 + j) \tag{2.3}$$

where c is a constant, and k and j are the output intensity level and input intensity level, respectively.

The log transformation maps the narrow range of low intensity level input into a wide range of high intensity level output, while the wide range of high intensity level input is mapped into narrow range of high intensity level (Gonzalez & Woods, 2008; Janani et al., 2015). Therefore, the image contains intensity level that bias toward high intensity level which is a brighter part. The processed image becomes brighter than the original image. On the other hand, inverse log function converts the image into a darker image. Figure 2.2 shows the curves of log and inverse log functions.

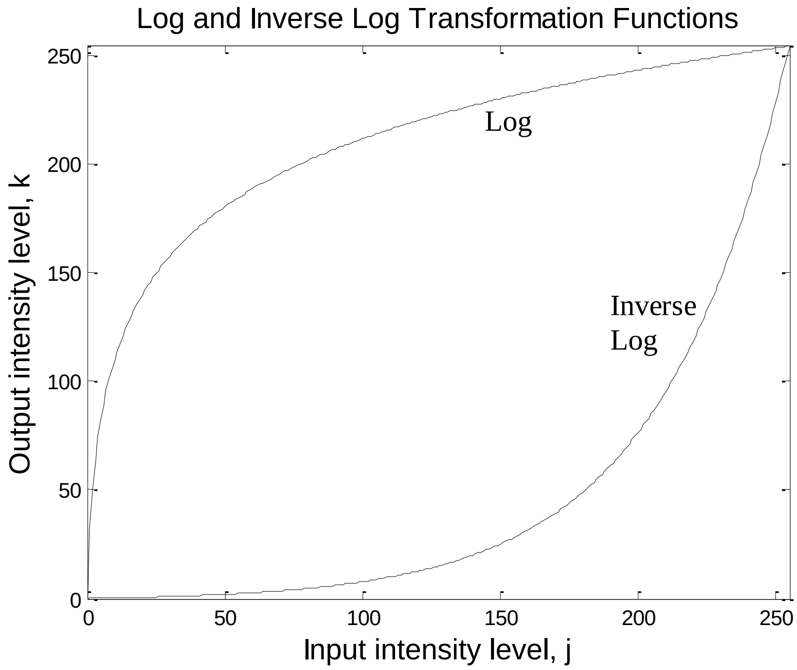


Figure 2.2: Log and inverse log transformations functions (Gonzalez & Woods, 2008)

2.1.3 Power-law Transformation

Power-law transformation is expressed by equation (2.4) (Gonzalez & Woods, 2008):

$$k = cj^{\gamma} \tag{2.4}$$

where the c and γ are constant. Power-law transformation is used to transform the input intensity level by using the curve that similar to log transformation, but power-law transformation able to adjust the curve by varying the gamma, γ.

Figure 2.3 shows the power-law transformation curve with different gamma, γ. Power-law curve with γ less than 1 maps the narrow range of dark input intensity level to wide range of output intensity level which made the image becomes brighter. While the power-law curve with γ greater than 1 maps the wide range of dark input intensity level to narrow range of dark output intensity level which causes the image becomes darker. Power-law curve with γ equals to 1 has no effect to the image.

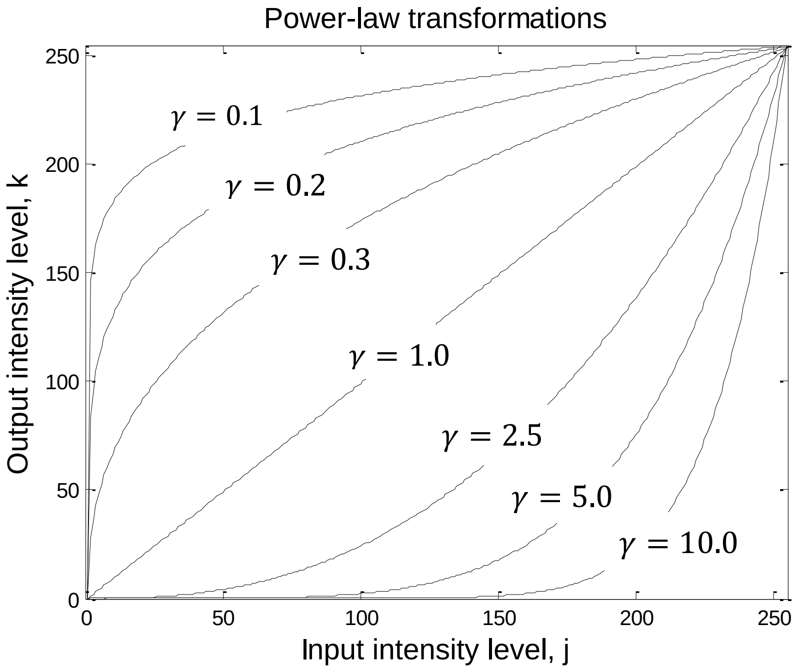


Figure 2.3: Power-law transformations with different values of γ (Gonzalez & Woods, 2008)

Kumar & Ramakrishnan (2012) used power-law transformation to enhance word images. Different type of word images have their own suitable gamma value, γ. Thus, they proposed a method that can choose the optimal gamma value, γ automatically in order to maximize the quality of image.

2.1.4 Piecewise-linear Transformations

Piecewise-linear transformation function is another image enhancement method which is also more complicated compared to the methods discussed previously. This is because the process of forming piecewise functions is complex. There are few types of piecewise-linear transformation function, for example, contrast stretching, intensity-level slicing, and bit-plane slicing (Gonzalez & Woods, 2008).

Contrast stretching is the simplest technique among piecewise-linear transformation functions. It expands the narrow dynamic range of low contrast image to full range intensity level, so that the appearance of image becomes better (Gonzalez &

Woods, 2008; Janani et al., 2015). Figure 2.4 shows the piecewise linear transformation graph. The input intensity levels are mapped into output intensity levels by the using piecewise functions. The application of contrast stretching includes X-ray image (Yang, 2006).

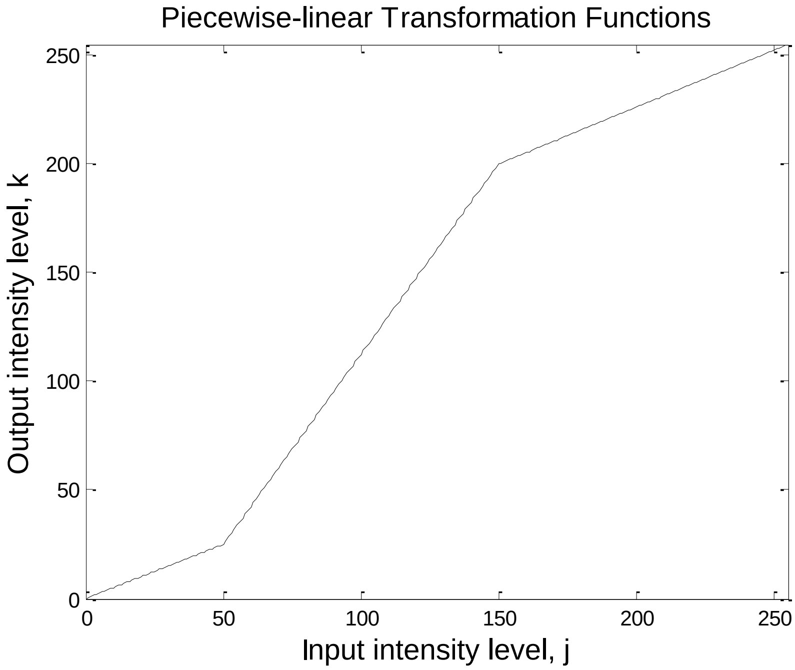


Figure 2.4: Piecewise-linear transformation function (Gonzalez & Woods, 2008)

Intensity-level slicing is another type of piecewise-linear transformation functions. It is used when only a specific intensity level range of image is required to be highlighted. It can be used to increase the quality of images. The applications of this method include satellite images, X-ray images and hand vein image (Deepak et al., 2012; Gonzalez & Woods, 2008).

Bit-plane slicing method operates on the bit-plane of image pixels. Images with 256 intensity level grayscale are composed of 8 bits or 1 bytes (Janani et al., 2015). This method highlighted the specific bit-plane instead specific intensity level. Images are decomposed into 8 bit-plane, then manipulation is done on the bit-plane. After the bit-plane slicing process, the bit-planes are compressed back to an image (Gonzalez & Woods, 2008).

2.2 Histogram Equalization and Its Variations

Histogram equalization (HE) is a simple and common image enhancement technique used to solve low contrast image which has narrow dynamic range (Gonzalez & Woods, 2008). The basic idea of histogram equalization is to use cumulative distribution function (CDF) as a transformation function to allocate the input intensity level to new intensity level. Basically, it stretches the narrow range of intensity level to a wider range of intensity level.

The aim of HE is to obtain a uniform histogram which is able to increase the entropy of an image. Entropy measures the information content of an image. The image might have narrow range before HE, so that the intensity bins are not fully occupied. When the image is equalized, the intensity almost occupied all intensity bins. As the result, the entropy increases (Qadar et al., 2015).

The histogram of an image refers to the probability density function (PDF). The PDF of an image for k-th intensity level, $P(k)$ is defined as (Gonzalez & Woods, 2008):

$$P(k) = \frac{h(k)}{N}, 0 \leq k \leq L-1 \qquad \text{for } k = 0, 1, 2, \dots, L-1 \tag{2.5}$$

where L is the intensity levels, N is the total number of pixels and $h(k)$ is the number of pixels for k-th intensity level. Then, the CDF for k-th intensity level, $C(k)$ is defined as (Gonzalez & Woods, 2008):

$$C(k) = \sum_{i=0}^{k} P(i) \qquad \text{for } k = 0, 1, 2, \dots, L-1 \tag{2.6}$$

where $P(i)$ is the PDF for i-th intensity level. After that, CDF is used to map the input intensity level to output intensity level and the transform function, $T(k)$ is defined as (Gonzalez & Woods, 2008):

$$T(k) = X_o + (X_{L-1} - X_o)[C(k)] \quad \text{for } k = 0, 1, 2, \ldots, L-1 \qquad (2.7)$$

Therefore, histogram equalization maps the input histogram into entire dynamic range of image, $[X_o - X_{L-1}]$.

There are two types of histogram equalization, which are global histogram equalization (GHE) and local histogram equalization (LHE). The method discussed above is global histogram equalization. GHE can be implemented easily and offer a short processing time. However, it is weak in brightness preservation and causing intensity saturation artifacts (Ibrahim & Hoo, 2014; Liu et al., 2016). The saturation of intensity occurs because GHE extremely shifts the intensities towards the right or left side of the histogram. This saturation effect also leads to information loss of the image (Kong, Ibrahim, & Hoo, 2013).

HE has a wide range of applications which include medical images, night images, underwater images, and hand vein images (Azadeh, Jumaily, & Hoshyar, 2014; Deepak et al., 2012; Kaur & Singh, 2017; Khan et al., 2015a; Singh, Kapoor, & Sinha, 2015). However, improvement works of GHE are still carried out by many researchers. Various methods have been proposed as the extension of GHE such as brightness preserving HE, histogram clipping, dynamic HE, and histogram weighting to overcome the drawbacks of GHE. These extension methods are discussed in the following subsections.

2.2.1 Brightness Preserving Histogram Equalization

Kim (1997) explained that it is rarely a direct application of HE in consumer electronics such as TV due to the brightness of image might be shifted. Therefore, he proposed a method named as Brightness preserving Bi-Histogram Equalization (BBHE), which decomposes the histogram of input image into two sub-histograms based on the mean of the input image. Figure 2.5 shows the histogram partition by mean value. The sub-histograms are equalized independently. He explained that BBHE is able to preserve the mean brightness of image and at the same time, the contrast can be enhanced.

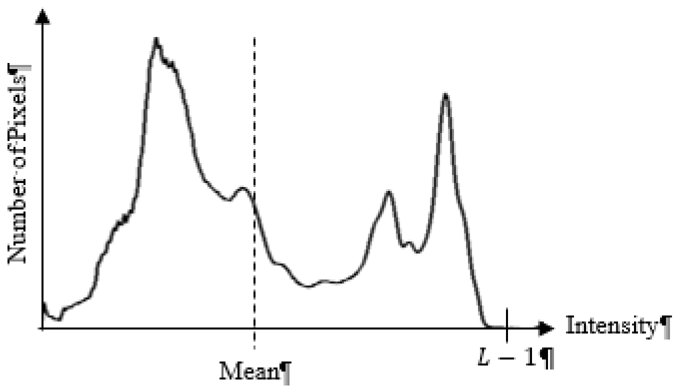


Figure 2.5: Histogram partition of BBHE method

However, Wang, Chen, & Zhang (1999) claimed that partition based on median value is better than mean value in term of image brightness and entropy, which known as information content . The method named as Dualistic Sub-Image Histogram Equalization (DSIHE) was proposed by Wang et al. (1999). DSIHE divides the histogram based on the median value of histogram. Then, two sub-histograms are equalized independently.

Singh & Kapoor (2014) proposed a method named as Exposure based Sub-Image Histogram Equalization (ESIHE). This method divides the histogram into under-exposed sub histogram and over-exposed sub histogram based on its intensity exposure. The cutting point of the histogram is based on exposure value and it normalizes the intensity level to range of [0-1]. If the image contains majority of low exposed regions, then the exposure value is less than 0.5, while the exposure value is greater than 0.5 if the image contains majority of high exposed regions. They claimed that this method is better than BBHE and DSIHE because it able to maximize the entropy of images (Singh & Kapoor, 2014).

Yao, Lai, & Wang (2016) proposed Brightness Preserving and Non-parametric Modified Bi-Histogram Equalization (BPNMBHE) method which uses the similar partition technique as BBHE. BPNMBHE partitions the histogram of image into two sub-histograms based on the mean brightness. This method is able to preserve the image brightness, but it might not able to maximize the contrast. Thus, this method was combined with other techniques which are intensity normalization and histogram weighting (Yao et al., 2016).

Two contrast enhancement methods based on fuzzy logic are proposed, namely, image contrast enhancement method based on fuzzy logic and histogram equalization, and semi dynamic histogram equalization. Both of them partition the fuzzy histogram based on the median value of fuzzy histogram[1]. The sub-histograms are combined after they are equalized (Khan, Ren, & Khan. 2015b; Kaur & Kaur 2016).

Furthermore, many researchers suggested to partition the histogram into more than two sub-histograms in order to further preserve the brightness and natural appearance of image (Khan et al. 2015a; Santhi & Wahida Banu 2015; Singh et al. 2015; Qadar et al. 2015). Singh et al. (2015) proposed a method named as Recursively Separated Exposure based Sub-Image Histogram Equalization (RS-ESIHE) which modify ESIHE method to partition the input histogram into four sub-histograms using exposure threshold value. RS-ESIHE is extension of ESIHE method.

[1] Fuzzy histogram will be further discussed in section 2.2.6 on page 21.

Recursive Weighted Multi-Plateau Histogram Equalization (RWMPHE) method also partitions histogram into four parts, but it is using mean or median value namely RWMPHE-M and RWMPHE-D respectively (Qadar et al., 2015). Santhi & Wahida Banu (2015) proposed Adapted Contrast enhancement using Modified Histogram Equalization (ACMHE) which uses similar partition method as RWMPHE-D. ACMHE uses median as cutting points to partition the histogram into four parts. Khan et al. (2015a) proposed to divide the histogram using optimal threshold that minimizes the variance of the histogram. However, the intensity range of sub-histograms become very narrow resulting in saturation of intensity in the sub-histograms (Khan et al., 2015a).

2.2.2 Histogram Equalization by Clipping

The purpose of histogram clipping is to prevent over enhancement that leads to unnatural appearance of images. Among the methods mentioned in last subsection, RWMPHE, ACMHE, and ESIHE methods clip the histogram before histogram partition takes place (Qadar et al., 2015; Santhi & Wahida Banu, 2015; Singh & Kapoor, 2014). The image enhancement by HE is depending on the cumulative density function (CDF), $C(k)$, hence the enhancement rate is proportional to the rate of CDF. The rate of CDF is defined in Equation (2.8):

$$\frac{d}{dk}C(k) = P(k) = \frac{h(k)}{N} \tag{2.8}$$

where the PDF, $P(k)$ is defined by Equation (2.5). Therefore, clipped histogram is able to limit the enhancement rate by controlling the value of $h(k)$.

The histogram clipping process begins with determine the clipping threshold value. ESIHE defines the threshold value, T_c as (Singh & Kapoor, 2014):

$$T_c = \frac{1}{L}\sum_{k=0}^{L-1} h(k) = \frac{N}{L} \tag{2.9}$$

where the L is the intensity level from $0 - 256$. The clipped histogram, $h_c(k)$ is defined as (Singh & Kapoor, 2014):

$$h_c(k) = \begin{cases} h(k), & h(k) < T_c \\ T_c \quad , & h(k) \geq T_c \end{cases} \tag{2.10}$$

Then, the histogram partition and HE are computed using clipped histogram. Singh & Kapoor (2014) claimed that this method of clipping is very fast and efficient.

On the other hand, RWMPHE uses multi-plateau clipping which means there are multiple of clipping threshold values or also named as plateau limits. There are six plateau limits need to be defined for RWMPHE method. Figure 2.6 shows the six plateau limits identified on the histogram. The process of computing clipped histogram removes all values above the plateau limits.

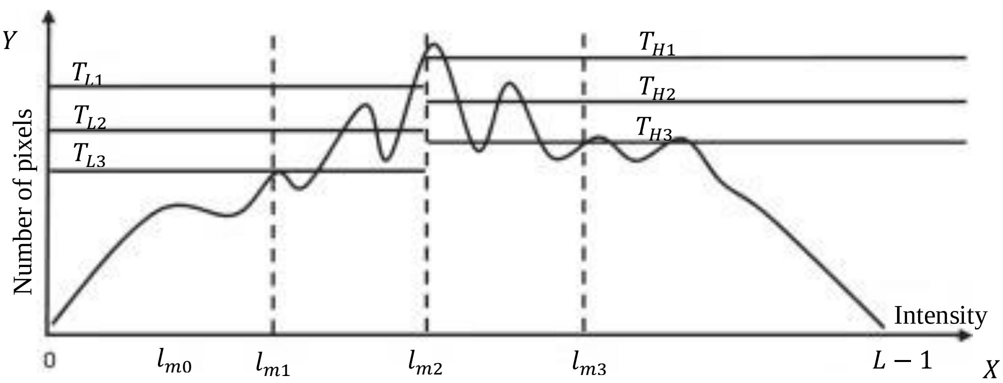


Figure 2.6: Histogram clipping process of RWMPHE (Qadar et al., 2015)

2.2.3 Iterative Histogram Equalization Method

Iterative method means that the proposed method is repeated until the threshold is less than a defined value. Singh et al. (2015) proposed a method as the extension of ESIHE which is recursive exposure based sub image histogram equalization (R-ESIHE). R-

ESIHE performs the ESIHE repeatedly until the difference of exposure value between two successive iterations is less than a predefined threshold. ESIHE partitions the histogram based on exposure values and R-ESIHE uses this value to determine when the computation of histogram should stop. R-ESIHE does not alter the ESIHE method. This method is time consuming as it is repeating the same process for several times.

2.2.4 Dynamic Histogram Equalization

Many HE proposed methods equalize sub-histograms independently within their own intensity level boundaries, but the images results of the contrast enhancement are not significant (Khan et al. 2015a; Khan et al. 2015b; Santhi & Wahida Banu 2015). The drawback includes uneven expansion of intensity which causes intensity saturation artifacts and loss of image contents.

Khan et al. (2015a) proposed to expand the sub-histograms which have narrow dynamic range. Then, full range of intensity level, i.e. $0 - 255$ for an 8 bit grayscale image, is assigned to the sub-histograms with narrow dynamic range. First, the histogram is partitioned into n sub-histograms as mentioned in sub-section 2.2.1. The sub-histogram is considered narrow range if $f(r)$ is less than 1 and $f(r)$ is defined by (Khan et al. 2015a):

$$f(r) = \left(\frac{n}{L-1}\right) \times (L_u^r - L_l^r) \tag{2.11}$$

where $r = 0, 1, 2, \ldots, n$ and n is the total number of sub-histograms. L_u^r and L_l^r are the upper and lower intensity value for r-th sub-histograms respectively.

For semi dynamic fuzzy histogram equalization method, there are only two sub-histograms. Therefore, the two sub-histograms are compared and the full dynamic range is assigned to the narrower sub-histogram (Khan et al. 2015b). The wider sub-histogram range remains the same. The sub-histograms are then equalized independently.

ACMHE proposed by Santhi & Wahida Banu (2015) adjusts all four sub-histograms range in order to balance the enhancement rate for each sub-histogram. Figure 2.7 shows the sub-histograms are expanded to wide intensity range. After obtaining the new intensity range, the sub-histograms are equalized independently.

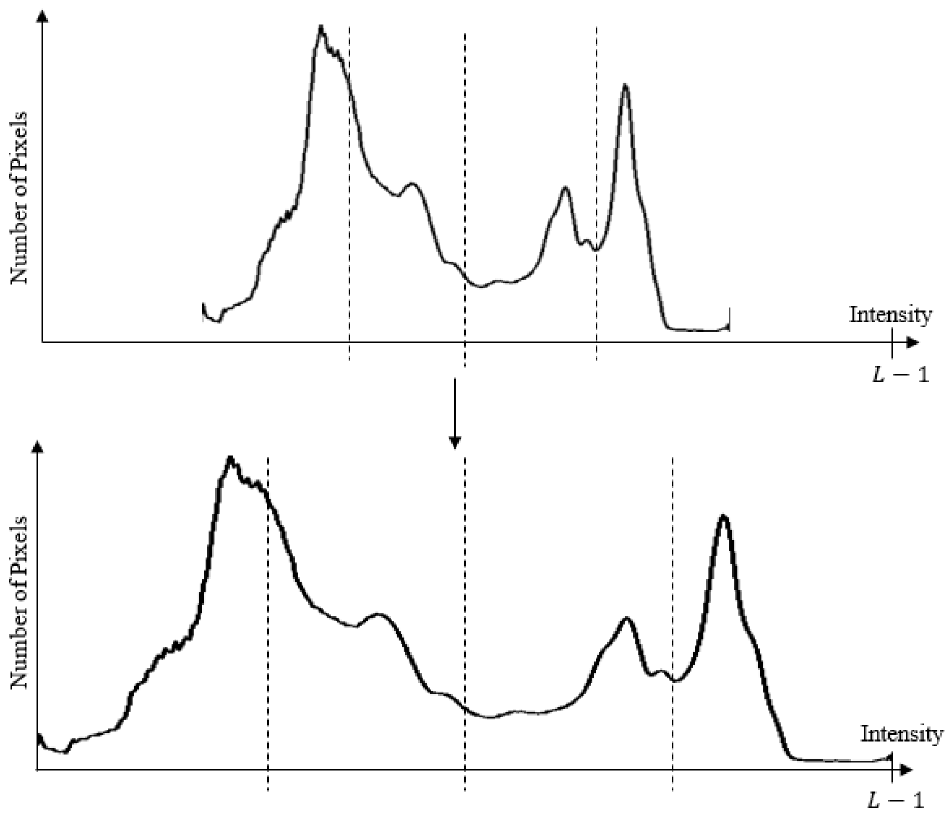


Figure 2.7: Expansion of dynamic range of ACMHE method

2.2.5 Histogram Equalization using Weighting

Histogram weighting is used in RWMPHE and BPNPMBHE (Qadar et al., 2015; Yao et al., 2016). The PDF of histogram is changed by the weight factor applied on histogram. Both methods apply histogram weighting after the histogram is partitioned, therefore the sub-histograms are modified. After that, the modified weighted sub-histograms are equalized independently.

The combination of equalized sub-histograms results in saturation of intensity, therefore the output of image suffers from visual artifact (Khan et al., 2015a; Khan et al., 2015b). The solution suggested to solve this problem is by normalizing the histogram intensity. The normalized intensities, j' can be defined by equation (2.12) (Khan et al., 2015b):

$$j' = \frac{(w \times j) + T(j)}{(w+1)} \tag{2.12}$$

where w is non-negative weight, j is the input image intensity and $T(j)$ is the processed image obtained from HE. The value of w is obtained experimentally in order to maximize the information content of the image (Khan et al., 2015b).

2.2.6 Fuzzy Histogram Equalization

The classic logic which known as Boolean logic depends on True (1) or False (0) only. There is a condition where it is partly true and partly false. Different of light condition might lead to the grayscale image that possesses inherent vagueness and ambiguity. Fuzzy logic is also expected to deal impreciseness of intensity level when partitioning the histogram of image. Fuzzy logic is often applied in image processing field such as image enhancement and edge detection and to model vagueness and ambiguity of complex system (Gonzalez & Woods, 2008).

Fuzzy based histogram equalization proposed by many researchers and they claimed that it is able to overcome the problem of over enhancement caused by traditional histogram equalization (Khan et al. 2015b; Kaur & Kaur 2016). Fuzzy logic is expected to handle the imprecision and uncertainties of the intensity level more effectively.

Figure 2.8 shows the block diagram of general structure of fuzzy image enhancement. Fuzzy based image enhancement has three main stages which are image fuzzification, modification of membership values and images defuzzification (Kaur & Kaur, 2016). Spatial grayscale intensities level are converted into fuzzy plane in image fuzzification process by using membership function. Membership function maps the grayscale intensities level which range of 0 to 255 into the elements in fuzzy set which range from 0 to 1 only. The fuzzy set is then intensified to reduce the fuzziness of image by modifying the membership function.

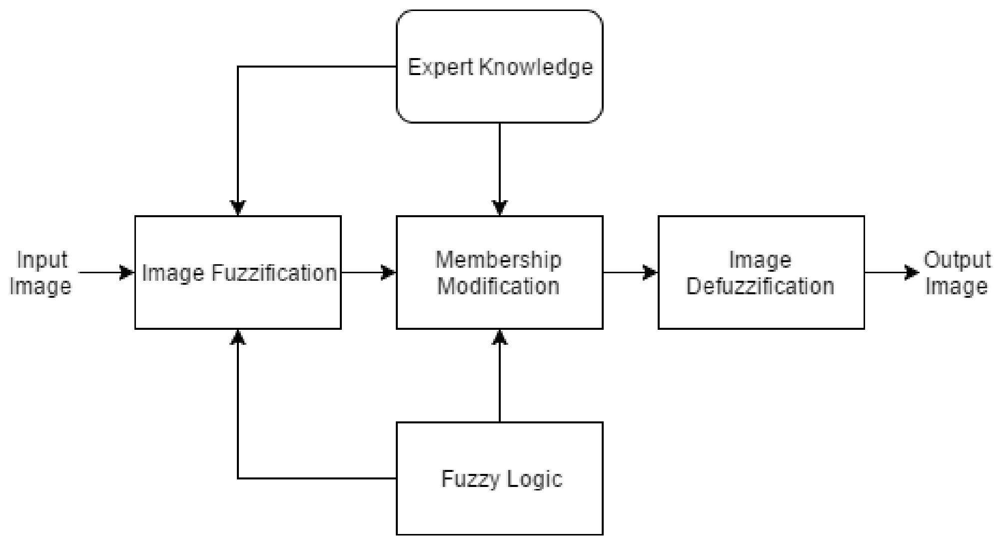


Figure 2.8: Block diagram of general structure of fuzzy image enhancement (Kaur & Kaur, 2016)

After that, fuzzy histogram is computed from modified fuzzy membership function. Then, modification on normal image histogram can be applied on this fuzzy histogram to prevent excessive brightness shift. After applying modifications on the fuzzy histogram such as histogram partition, image defuzzification is applied to the fuzzy histogram to maps the intensity level of fuzzy plan back to the grayscale intensity level.

2.2.7 Texture Region based Histogram Equalization

The limitations of the global histogram equalization such as undesirable artifacts, over enhancement and intensity saturation, are caused by the excessive number of pixels exist in the non-texture region of digital image. These pixels cause the histogram biased to one side. Therefore, two novel methods are proposed based on the idea of texture region, namely Dominant Orientation based Texture Histogram Equalization (DOTHE) and Edge based Texture Histogram Equalization (ETHE) (Singh, Vishwakarma, Walia, & Kapoor, 2016). The idea of these methods is to suppress the pixels in the non-texture region of images. Singh et al. (2016) claimed that methods that consider texture region of image into enhancement technique are able to solve the drawbacks of GHE.

DOTHE method computes the histogram based on the dominant orientation patches of image, then follows by equalized the histogram. First, image patches are extracted from the whole digital image. The size of the image patches are $\sqrt{N} \times \sqrt{N}$ where N is the total number of pixels of image. A variance threshold, τ is applied on every image patch in order to classify the patched into rough or smooth patches. After that, the rough patches are categorized into dominant or non-dominant orientation patches by using local orientation of patch which is estimated based on singular value decomposition of gradient vectors of patch. Then, the histogram of image is constructed based on dominant orientation patches only (Singh et al., 2016).

ETHE method computes the histogram based on the Edge Map of image. The idea of this method is that texture region of an image has high density edges. Then, Sobel operator is applied to determine the edges in the digital image. The gradient of an image, $\nabla I(x, y)$ is determined for every pixel of the image. Edge map is identified by applying threshold on the gradient of image, which is the pixel is considered as a dominant edge if the gradient value greater than threshold. After that, minimum and maximum gray level