Contrast Enhancement in Endoscopic Images Using Fusion Exposure Histogram Equalization

Sim Kok Swee, Lim Choon Chen and Tan Sin Ching

Abstract—**Single illumination source of endoscopy screening can cause recorded images to have low contrast and imbalanced brightness. Low quality of endoscopic images will have difficulties in analyzing endoscopy images. Among contrast enhancement techniques, histogram equalization technique is the most popular image processing technique in improving the contrast of endoscopic images. However, conventional histogram equalization techniques may cause some regions to be over enhanced and some information to be lost due to dominating gray levels. Some existing modified histogram equalization have solved the contrast problem of image but the performance of information preserved still has room for improvement. Therefore, fusion exposure histogram equalization technique (FEHE) is developed to overcome the drawbacks of histogram equalization techniques. There are two stages in FEHE which are low light enhancement technique and the exposure-based histogram equalization with adaptive sigmoid function. In low light enhancement technique, image is converted to principal component analysis and converted into luminance and chrominance component. Each component is enhanced by tone mapping function, adaptive filter and histogram modification respectively. Exposure histogram equalization technique with sigmoid function divides histogram into two sub histograms based on average exposure level. The cumulative distribution function of each sub histogram is manipulated to become two smooth sigmoid functions and equalized the image by referring to the modified cumulative distribution function. The method (FEHE) is tested on endoscopic images. Experimental results have shown that the performance of FEHE is satisfactory in terms of enhancement level and information preserving level.**

Index Terms—**Histogram Equalization, Image Enhancement, Image Processing**

I. Introduction

ENDOSCOPIC screening is the process of detailed inspection and diagnosis of gastrointestinal tract by using endoscopy [1][2]. Acid reflux, ulcer and polyps may occur in upper part of digestive tract while inflammatory bowel disease occurs in lower part of gastrointestinal tract [3]. The worsening of these diseases will induce the formation of cancer such as oesophageal cancer, gastric cancer and colorectal cancer [4] [5]. Among these cancers, oesophageal and stomach cancers are considered more dangerous as these diseases are not easily detected at the early stage. The symptoms of the diseases such as coughing or hoarseness are too common illness. The patients will not know that these are symptoms of these cancers unless endoscopy screening is done. Therefore, they might seek help from a clinic or pharmacist. Different medications will be given by the clinic to same symptoms until the symptoms become severe. As delays in the best time for diagnosis, these diseases only can be treated but cannot be cured. The effective prevention measure is to increase awareness of the public and carry out regular body check-up which includes endoscopic screening [3].

There are two types of endoscopy which are wired endoscope and capsule endoscopy. The deflection of tip of wired endoscope is controlled by the control system while the movement of capsule endoscopy depends on peristalsis action of gastrointestinal tract [6]. Video will be recorded and converted into images for further diagnosis which can be performed by the doctor. The analysis of images normally is analyzed by the eyes of the doctors. Therefore, the quality of endoscopy image is one of the main factor that can affect the accuracy of diagnosis of disease. However, there are some limitations of endoscopy screening which will affect the quality of image. Imaging device in endoscopy screening is depending on a single LED light source. Single illumination source is not able to illuminate all regions that snapped by the imaging system. This causes low contrast occurred in images. The abnormalities that locate at the dark side are not analyzed easily by human eyes [7]. Therefore, some image processing techniques are required to be applied to endoscopy images to enhance the abnormalities contained in image for the ease of analysis. One of the popular image processing techniques is histogram equalization. Histogram equalization is a technique which is used to flatten histogram of image. In other words, histogram equalization is used to balance distributions of gray level in the image so that the range of gray levels is fully occupied by the pixels of image.

However, original histogram equalization induces over enhancement to be occurred in the image [2]. Researchers had developed some new versions of histogram equalization such as dynamic histogram equalization, bi histogram equalization and contrast limited adaptive histogram equalization. These histogram equalization techniques are the extension of the original histogram equalization. Dynamic histogram equalization divides histogram into several parts and specific range of gray levels is assigned to each part so that the pixels

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of image spans over range of gray levels [8]. Each part is equalized respectively so that local content can be maintained when the image is histogram equalized. Bi histogram equalization divides histogram into two sub histograms and equalized respectively [9]. Contrast limited histogram equalization is the most popular contrast enhancement technique in improving the quality of endoscopy images. It operates on each partitioned region and combines all results of the partitioned region. Some information will be lost during the histogram equalization process. Through this method, over enhancement on some regions will not occur and the amplification of the noise contained in the image will be lower than conventional techniques [10]. However, there are some improvements needed to be done in amount of information preserved in the image. The most important information that needs to be preserved in the image is the edges of abnormalities area. Normally, the appearance of abnormalities at the early stages is not significant. The pixels of abnormalities area may occupy in the less dominating gray levels. The conventional histogram equalization technique depends on the dominating gray level. Therefore, fusion exposure histogram equalization (FEHE) is designed to increase the contrast and balance brightness of the image with minimum loss of information content.

In this case, there are existing histogram equalization techniques which can increase the contrast of image. More pixels will be distributed towards both ends of gray levels. However, the abnormalities that lie on dark part of image or background can become darker after the existing histogram equalization technique is applied. The abnormalities area may not be shown clearly and this will increase the difficulties of diagnosis of diseases. Therefore, some algorithms need to apply on dark side to increase the brightness of background before applying histogram equalization. Fusion Exposure Histogram Equalization technique is divided into two stages which are low light enhancement technique and Exposure based Histogram Equalization Technique with adaptive sigmoid function. Low light enhancement technique is used to increase the brightness of background while Exposure based Histogram Equalization Technique is used to increase the contrast, improving the appearance of abnormalities area.

II. METHODOLOGY

A. 1st Stage of FEHE: Low Light Enhancement Technique

Firstly, the image is processed with fusion-based low light enhancement technique so that the brightness of background will be increased. In this technique, image is converted from Red, Green and Blue (RGB) colour model to principal component analysis. Image is converted to one dimension vectors X= []. Luminance and chrominance components are computed from vectors as Equation (2) and Equation (3). The eigenvalues of vector X is computed and is arranged in descending order.

$$\overline{m} = \sum_{i=1} \frac{x_i}{M}, \quad (1)$$

$$b_i = \lambda_i (x_i - \overline{m}), \quad (2)$$

$$R = (c)^{\frac{1}{\alpha}}, \quad (3)$$

Where

M = Total number of elements in vector X
λ = Eigenvalues of vector X
c = Components of image
α = Average luminance value

The first three eigenvalues will be used in forming luminance and chrominance components. Each component of image is enhanced by tone mapping function to increase contrast of the image. This function is implemented by introducing constant value to the power of the component. The constant value is varied by average value of luminance. Then, mask value of each pixel of image is by taking average value on area that surrounds that pixels. Adaptive multiscale retinex is employed to produce output image by referring the difference between logarithmic function of component and logarithmic function of mask.

For luminance components, adaptive filter is applied on the luminance component to increase brightness of the area near edges while maintaining sharpness of edges. Histogram modification is then applied to limit the value of luminance, preventing region is over enhanced. The chrominance components are varied by alpha factor to maintain saturation of colour after combining with luminance components.

Color space of input image that used for image enhancement system can contribute to the effect of enhancement techniques on input images. The input image will be converted into YCbCr colour space by using Equation (4) as the information of intensity and colour are then stored in luminance and chrominance component respectively. Data consumption is used in YCbCr colour space much less than other colour space. The quality of image will not be affected although less data is consumed. Luminance component will be manipulated in this paper as the main objective of histogram equalization is improving intensity level of the image without altering colour information.

$$\begin{aligned} Y &= 16 + \frac{65.738R}{256} + \frac{129.057G}{256} + \frac{25.064B}{256} \\ Cb &= 128 - \frac{37.945R}{256} - \frac{74.494G}{256} + \frac{112.439B}{256} \\ Cr &= 129 + \frac{112.439R}{256} - \frac{94.154G}{256} - \frac{18.285B}{256} \end{aligned} \quad (4)$$

B. 2nd Stage of FEHE: Exposure Based Histogram Equalization with Adaptive Sigmoid Function

The number of occurrence of gray levels in each region are counted and computed by using Equation (5), forming a histogram which represents the distribution of gray levels. Histogram of image is then used in computation of average exposure level. The calculation of the average exposure level is computed as shown in Equation (5).

$$AE = round(L*(1-\frac{\sum_{i=1}^{L} h(i)*x(i)}{(K)*(\sum_{i=1}^{L} h(i))})), \quad (5)$$

Where
x = Range of gray level (0-255)
$h(i)$ = Number of pixels having i^{th} gray level
L = Number of intensity levels (256)
K = Maximum intensity levels in image

By using average exposure level as threshold, the image is partitioned into two sub images which are underexposed and overexposed region [13]. Mean pixel value is computed for each sub image and acts as a guideline for clipping the histogram of image so that none of the regions is suffering from over enhanced phenomenon. It means that the number of pixels for certain gray level is greater than the limit, the number of pixel for that gray level will be set to limit. It also ensures that pixels of image occupy all range of gray levels.

A sigmoid function is used to transform the histogram of each sub image to a smooth continuous S shape curve. For S shape curve, both ends of the curve are touching values 0 and 1. A good quality of image whose pixels occupies all range of gray levels. Therefore, cumulative density function is normalized and fit to a range of -5 to 5 so that there are pixels occupy at both ends of gray levels. Equation (6) is used for the underexposed region while Equation (7) is used for the overexposed region.

$$cdf_{new}(x(i)) = \frac{5(x(i)-m)}{AE}, \quad (6)$$

$$cdf_{new}(x(i)) = \frac{5(x(i)-m)}{L-1-AE}, \quad (7)$$

Where m = Median of cumulative density function

If the histogram is not fitted, the normalized pixels that left at the range before -5 and after 5 will be transformed by sigmoid function to 0 and 1. This results in an imbalanced histogram. A gain value is introduced to increase the slope of sigmoid curve. This amount of gain value is depending on the average exposure value of input image and is shown in Equation (8) and Equation (9). Gain value calculated in Equation (8) is used for increase contrast of underexposed region while gain value calculated by using Equation (9) is used for increase contrast of overexposed region.

$$g = 1 - \frac{AE}{2}, \quad (8)$$

$$g = \frac{1-AE}{2}, \quad (9)$$

The modified sigmoid function as Equation (10) will be applied to the histogram. Output of sigmoid function is histogram equalized followed by contrast stretching as Equation (11) before mapping function. The histogram equalization is applied for the underexposed and overexposed region. The output image will be converted by to RGB colour model. By using this proposed method, the contrast level of the image will be improved. If very dark images are used, recursive FEHE is encouraged to be used to get the best result.

$$s(x(i)) = \frac{1}{1+e^{-g(cdf_{new}(x(i)))}}, \quad (10)$$

$$T(k) = \min(x(i) + \alpha(u(x(i)) - \min u(x(i))), \quad (11)$$

Where
AE = Average exposure value
$x(i)$ = Range of gray levels (0-255)

III. Results

30 endoscopy images with abnormalities are enhanced with developed technique and three existing techniques which are Contrast Limited Adaptive Histogram Equalization (CLAHE), Dynamic Histogram Equalization (DHE) and Bi Histogram Equalization (BHE). 5 images are randomly chosen as shown in the paper.

Table 1 illustrates the summary for endoscopy images enhanced with histogram equalization techniques. The average illuminations of the image shown from Figure 1 to Figure 5 are improved when enhancement techniques are applied. The contrast level of the image can be increased by dynamic histogram equalization (DHE) and bi histogram equalization (BHE) is much greater than FEHE and contrast limited histogram equalization (CLAHE) is shown Figure 1(d) and Figure 1(e).

Average brightness of image enhanced by DHE in Figure 2(d) and BHE in Figure 2(e) are higher than image enhanced by CLAHE. Figure 3(c) shows inflamed region in image appears lighter than the original input image and its color is similar to the normal region. CLAHE may not suitable to enhance images which is the same type with Figure 3(a). The enhancement performance of FEHE on inflamed region in the image which is shown in Figure 4(b) is the greatest when it is compared with other techniques. The histogram of all enhanced image are balanced as all range of gray levels are occupied.

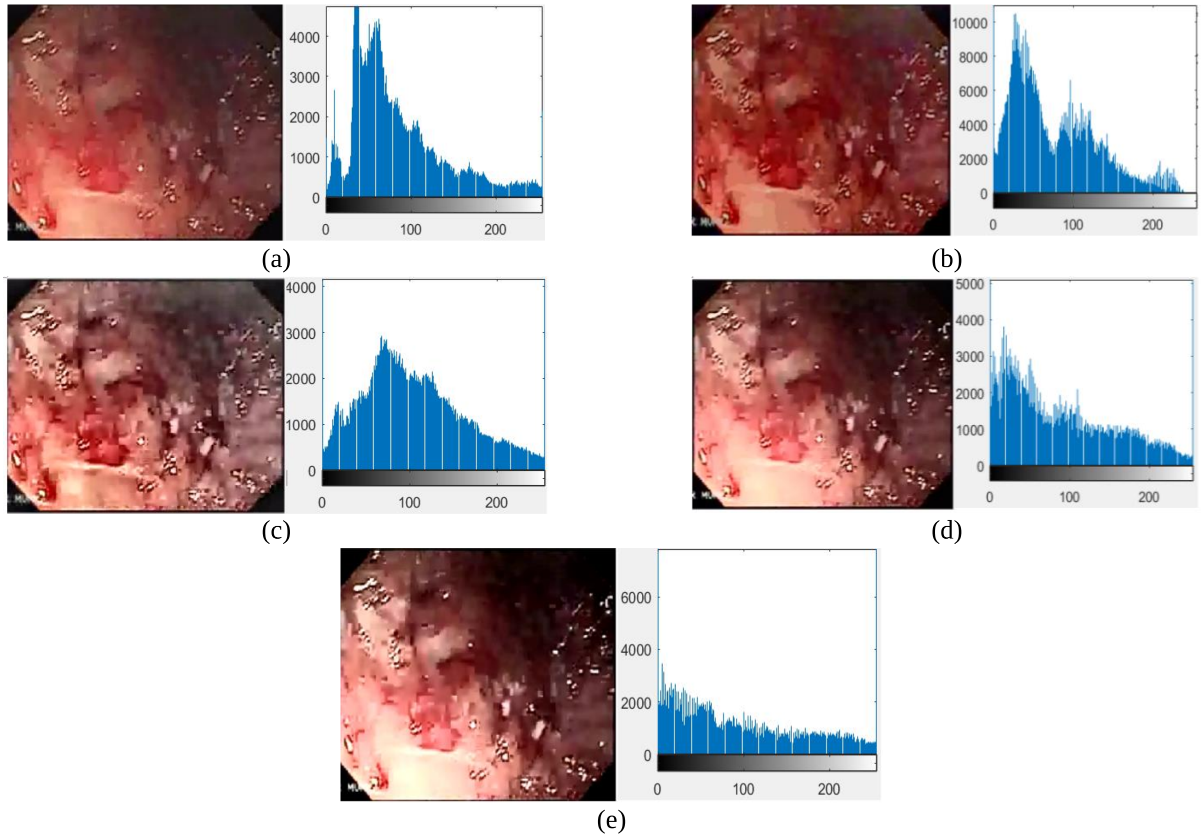


Figure 1: Endoscopy image of Acid Reflux with Hiatal Hernia and its image histogram. (a) Original endoscopy image, (b) FEHE, (c) CLAHE, (d) DHE, (e) BHE

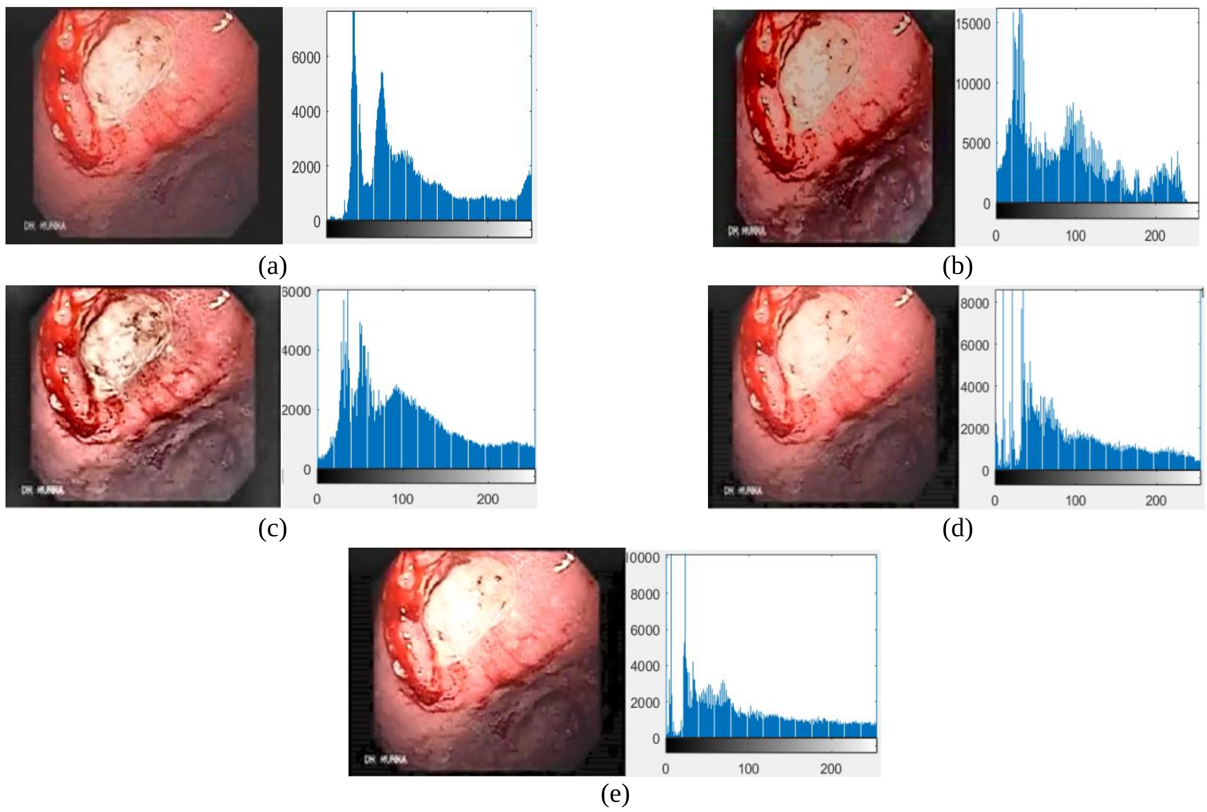


Figure 2: Endoscopy image of Gastric Ulcer and its image histogram. (a) Original endoscopy image, (b) FEHE, (c) CLAHE, (d) DHE, (e) BHE

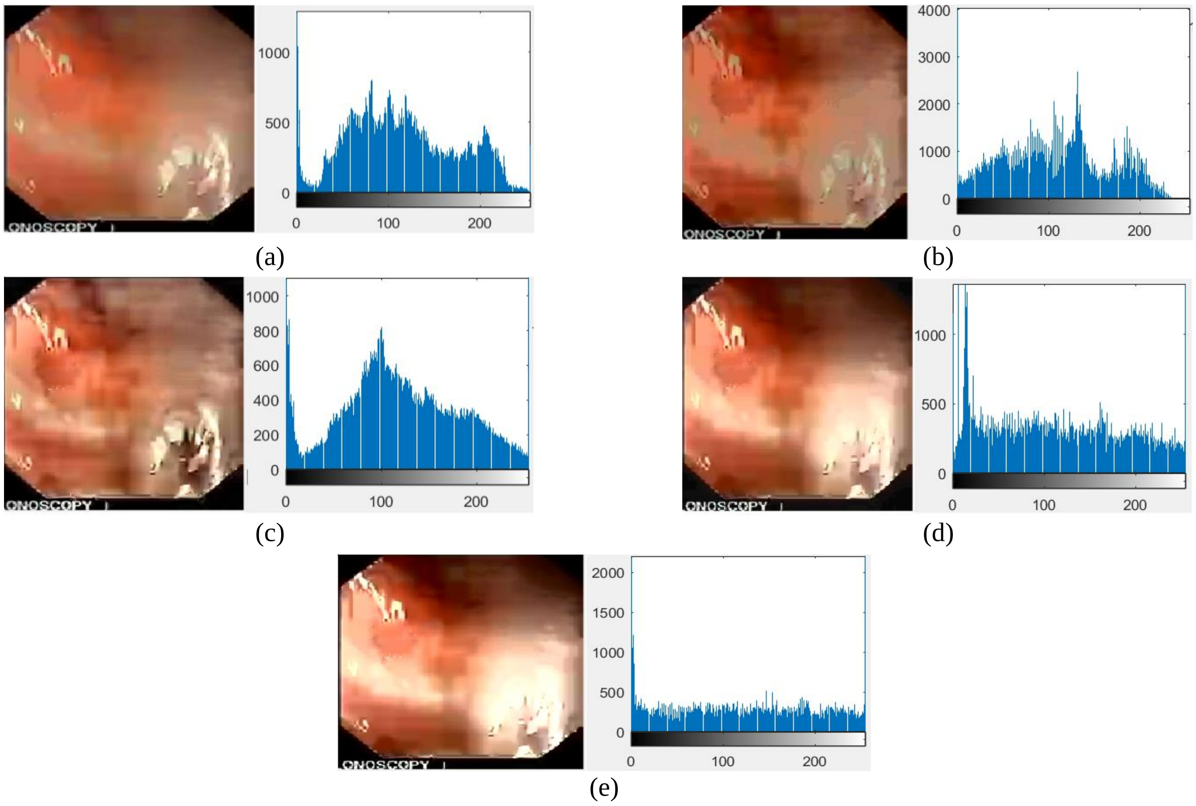


Figure 3: Endoscopy image of Acid Reflux and its image histogram. (a) Original endoscopy image, (b) FEHE, (c) CLAHE, (d) DHE, (e) BHE

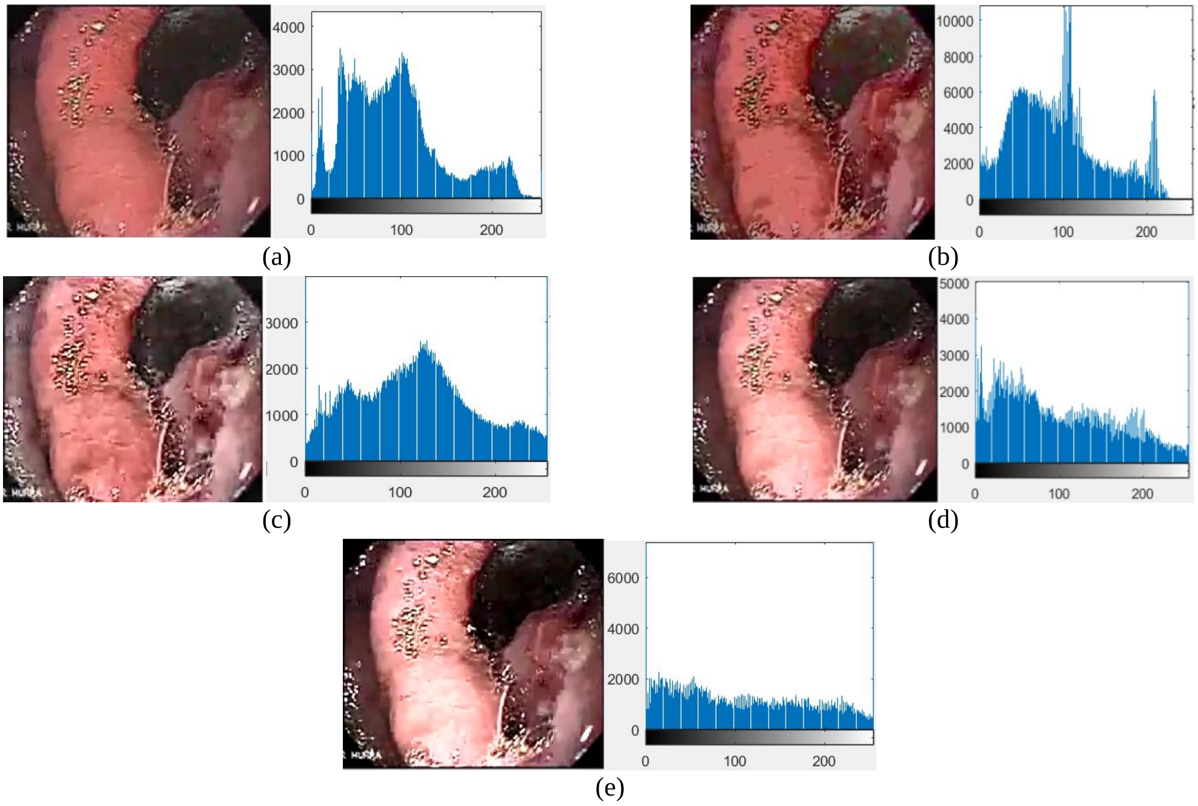


Figure 4: Endoscopy image of Gastric Cancer and its image histogram. (a) Original endoscopy image, (b) FEHE, (c) CLAHE, (d) DHE, (e) BHE

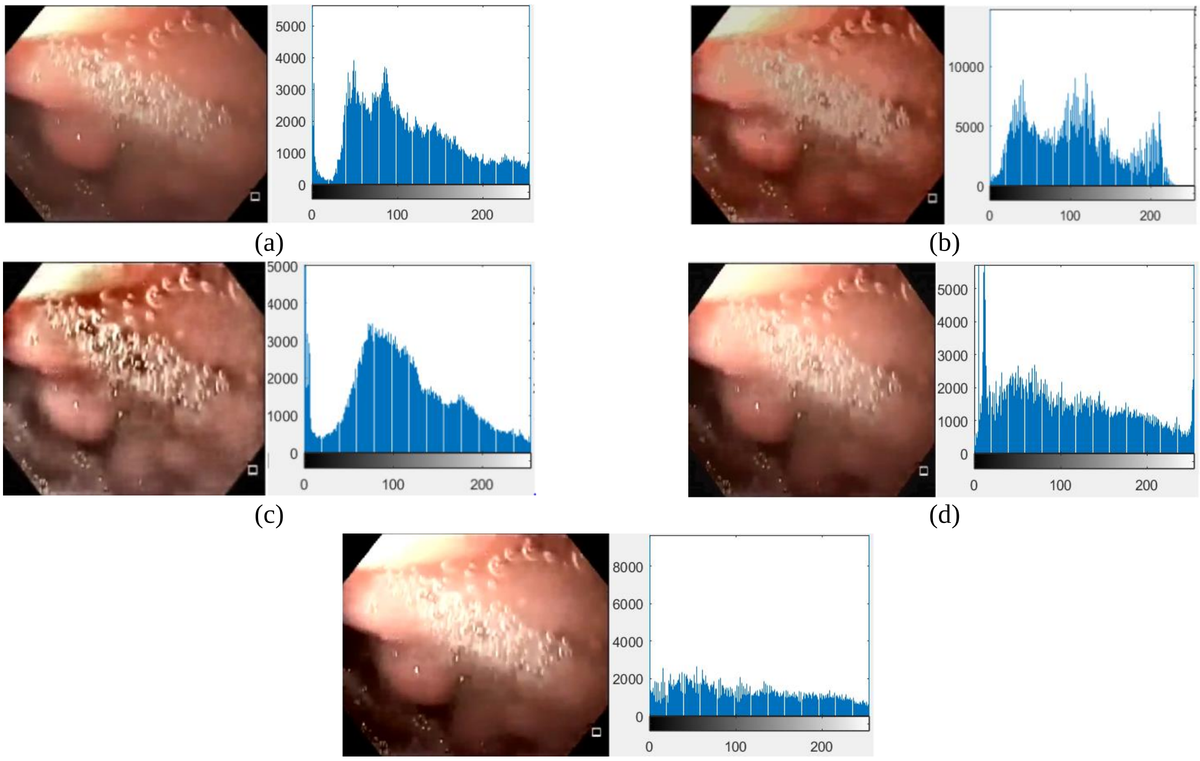
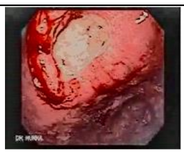
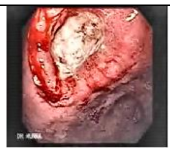


Figure 5: Endoscopy image of Hyperplastic Polyp and its image histogram. (a) Original endoscopy image, (b) FEHE, (c) CLAHE, (d) DHE, (e) BHE

Table 1: Table of summary for endoscopy images enhanced with histogram equalization techniques

No	Input Image	FEHE	CLAHE	DHE	BHE
1					
2					
3					
4					
5					

IV. Discussion

30 endoscopy images that enhanced by techniques are then tested with image quality assessment methods. Image quality assessment methods that will be used to test the quality of enhanced image including entropy measurement, mean absolute error, correlation and structural content. The average value of entropy measurement, mean absolute error, correlation and structural content for 30 images are calculated.

A. Image Quality Assessment I: Entropy Measurement

The main task of histogram equalization is the redistribution of gray level in the image. The entropy of enhanced image is normally computed to measure the uniformity of distribution of gray levels. Enhanced image with uniform distribution of gray level also can be explained that fine details have still remaintained in image as gray level with less amount of pixel occupied is not eliminated. Therefore, entropy measure can be related to the amount of information contained in the image [11]. The quality of image normally is related to the amount of loss of information. The enhanced image is considered good quality if there is a small difference of entropy value between enhanced image and original image. Therefore, a small variation between entropy of original input image and processed image is expected in every enhancement process. Entropy of image is calculated based on the probability of gray level image as shown in Equation (12).

$$E(I) = -\sum_{i=1}^{L} p(x(i)) \log_2 (p(x(i))), \qquad (12)$$

Where
$x(i)$ = Arrays which store range of gray level (0-255)
$p(i)$ = Arrays which shows number of pixels occupy gray level
L = Standard number of gray levels (256)

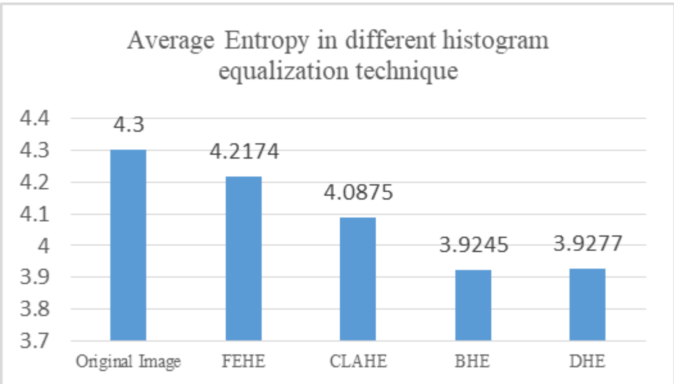


Figure 6: The graph of entropy in different histogram equalization techniques

Figure 6 shows a graph of average entropy measurement of the input image and enhanced image. According to Figure 6, entropy values of all enhanced images are less than original images. It can be explained that some information is lost during the enhancement process. Among histogram equalization techniques, entropy value of enhanced image with the proposed method is the closest to the entropy value of original image. It can be analyzed that the amount of information maintained in an enhanced image is the most complete to process image with other histogram equalization techniques. Images processed by bi histogram equalization and dynamic histogram equalization has the largest difference in entropy value with original endoscopy images. The difference in entropy value between them is about 0.5 which is 5 times difference in entropy value between the original image and image processed with FEHE. The amount of information preserved in the image processed by bi histogram equalization and dynamic histogram equalization is very similar. Therefore, entropy measurement shows that FEHE achieves better performance in information preservation.

B. Image Quality Assessment II: Mean Absolute Error (MAE)

Mean absolute error is the most frequent parameter used in image quality measure. For image compression, it is used for measuring restoration level of the processed image. High mean absolute error in image compression means that there is the restored image is much different from the original image. For image enhancement area, it is used to measure dissimilarity between original input image and its processed image [12]. It also can be considered as enhanced level of image enhancement technique. Variance of intensity level is the main ingredient for the calculation of mean square error. The calculation of mean square error is shown in Equation (13). Two same size of images are required in the calculation.

$$MAE(x,y) = \frac{1}{n}\sum_{a=1}^{r}\sum_{b=1}^{c}\left|O(a,b) - P(a,b)\right|, \qquad (13)$$

Where
n = Total number of pixels
r,c = Rows and columns of image
O = Original image
P = Enhanced image

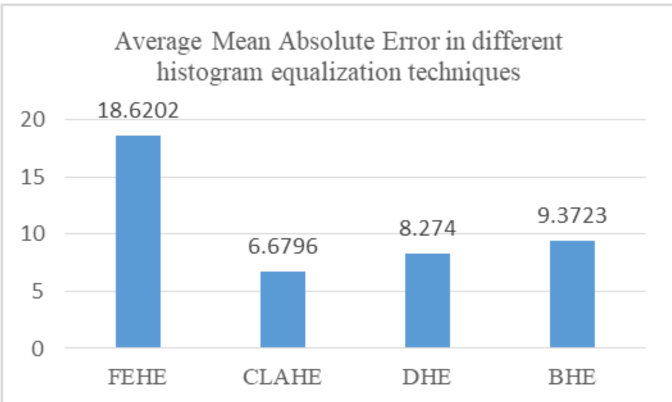


Figure 7: Graph of average Mean Absolute Error in different histogram equalization techniques

Figure 7 shows an average absolute error of image processed by FEHE, CLAHE, DHE and BHE. All mean absolute errors for output image are more than 0 which also means that all images are enhanced. The highest dissimilarity by comparing values of pixels between output images and original input image is image enhanced by the developed method (FEHE) followed by BHE, DHE and CLAHE. It can be estimated that increment in luminance level of FEHE is the highest as compared to other histogram equalization techniques. The performance of luminance enhancement by dynamic histogram equalization and bi histogram equalization are similar. The luminance level of image cannot be improved through contrast limited histogram equalization. Therefore, performance of FEHE in enhancing luminance level of the image is the best among histogram equalization techniques.

C. *Image Quality Assessment III: Correlation (Corr)*

Edges are the place where there are clear changes of intensity happened. It also can be defined as boundary of the object. The segmentation of an object usually is done by referring edges in the image. Therefore, edges of the object should be maintained or enhanced after every image processing technique. The sharpness of edges in the processed image can be known by referring the correlation parameter [13]. In another word, the number of edges being preserved after the enhancement process is measured by this parameter. Original input image is required in this measurement for comparison. The enhanced image should have same size as the original image. Equation (14) shows how the correlation parameter is calculated.

$$corr = \frac{\sum_{a=1}^{r}\sum_{b=1}^{c}(P(a,b)-\overline{P})(O(a,b)-\overline{O})}{\sqrt{(\sum_{a=1}^{r}\sum_{b=1}^{c}(P(a,b)-\overline{P})^2)(\sum_{a=1}^{r}\sum_{b=1}^{c}(O(a,b)-\overline{O})^2)}}, \quad (14)$$

Where

r, c = Rows and columns of images

$O(a,b)$ = Value of pixel at (a,b) position in original image

$P(a,b)$ = Value of pixel at (a,b) position in enhanced image

$\overline{O}$ = Average pixel value of original image

$\overline{P}$ = Average pixel value of enhanced image

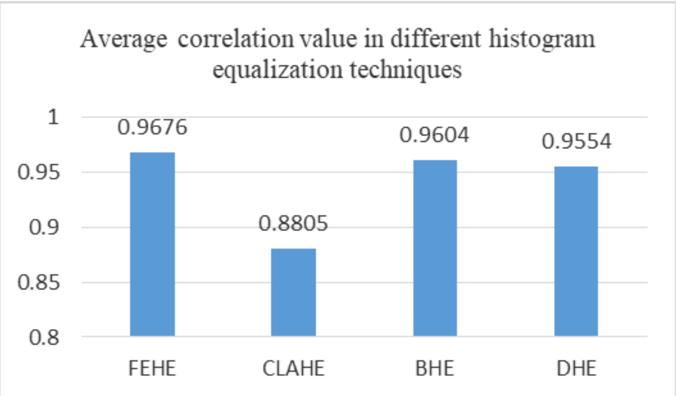


Figure 8: Graph of average correlation of image processed by different histogram equalization techniques

Figure 8 shows the average correlation measurement of image processed by FEHE, CLAHE, DHE and BHE. The correlation value computed in image that processed by FEHE, DHE and BHE which is almost the same and very close to 1.00. Images enhanced by contrast limited histogram equalization have the lowest correlation value among the histogram equalization techniques. This can be analyzed that some edges like features contained in the image are eliminated or the sharpness of edges is reduced during the enhancement process. Average correlation value for image enhanced by the proposed method is 0.9676 which is higher than CLAHE. The performance of edge like features preserving of the proposed method is better than CLAHE but similar to the performance of DHE and BHE. Therefore, distortion in low level features caused by FEHE is still in an acceptable range.

D. *Image Quality Assessment IV: Structural Content (SC)*

Structural information can be defined as a fundamental part of image as it will not be altered by changes of brightness. Therefore, structural information is widely used in the classification system. Another information-based performance measure is structural content. Structural content is used to compare the level of enhancement on structural information between the original input image and enhanced image. If structural content is less than 1, it means that structural information is lost during the enhancement process. Structural content is obtained by taking ratio of total amount of pixels value in input image and total amount of pixels value contained in the enhanced image [14]. The calculation of structural content is shown in Equation (15).

$$SC = \frac{\sum_{a=1}^{c}\sum_{b=1}^{r}P(a,b)}{\sum_{a=1}^{r}\sum_{b=1}^{c}O(a,b)}, \quad (15)$$

Where

P = Enhanced image

O = Original image

r, c = Rows and columns of image

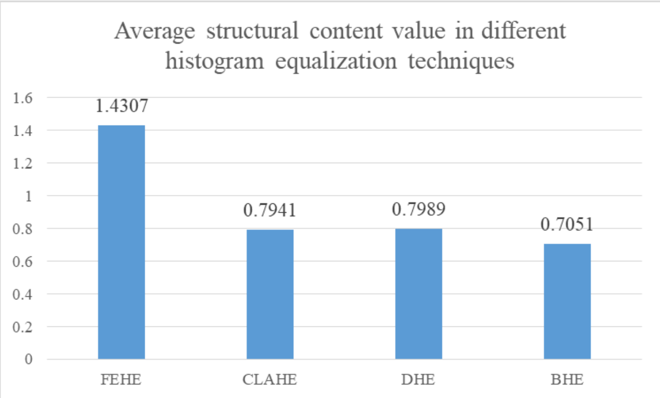


Figure 9: Graph of average structural content of image processed by different histogram equalization techniques

Figure 9 depicts the graph of average structural content measurement of the image processed by FEHE, CLAHE, DHE and BHE. It can be observed that FEHE possessed the highest average value of structural content compared to the other techniques. The average structural content of the FEHE is almost twice as compared to other techniques. The enhanced image which having the lowest structural content when it is compared with original input image is image processed by BHE. Structural content that has a value of less than 1 means that the pixels value contained in enhanced image is less than the original image. On the other hand, the structural content with value of more than 1 means that the structural information of enhanced image is greater than the original image. Thus, the pixels value contained in the FEHE is higher than other histogram equalization techniques. It can be explained that structural information of image is enhanced by the proposed method.

V. Conclusion

In this paper, fusion exposure-based histogram equalization technique (FEHE) is designed for endoscopic images. Abnormalities such as bleeding area and inflamed region in the endoscopic image are enhanced. The proposed histogram equalization is carried out in two stages which are fusion based low light enhancement technique and exposure based histogram equalization technique with adaptive sigmoid function. The performance of proposed method is evaluated in terms of enhancement level and amount of information preserved. The average entropy value, average mean absolute error, mean correlation value and mean structural content value of FEHE are 4.2174, 18.6202, 0.9676 and 1.4307 respectively. The calculated performance metric shows that the contrast of image is increased and the amount of information preserved in enhanced image is processed by FEHE. Contrast enhancement techniques of endoscopy images improve the appearance of abnormalities so that time spent on diagnosing diseases can be reduced.

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