Image Enhancement Technique on Contrast Variation: A Comprehensive Review

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***Abstract*— Image enhancement is very important, especially for the analysis and diagnosis of detailed information. Most of the studies conducted in image enhancement focus on contrast normalization. Generally, contrast determines how information in images can be perceived easily, how various details in the image can be easy distinguished or how objects of interest can be located. In this paper, a comprehensive review of image enhancement based on spatial domain (Histogram Equalization (HE) and Homomorphic Filtering) and frequency domain (Discrete Wavelet Transform (DWT)) is presented. The improvement and modification of methods were explained systematically. The objective of this work was to study the advantages and drawbacks for each of the method based on a comparison of the results performance. Besides that, this research focuses on various types of applications, emphasizing the importance of contrast enhancement for the improvement of its performance, especially in terms of accuracy and sensitivity. Previous studies were reviewed and critically compared to gain a better understanding of image enhancement. New ideas for further research improvement in image enhancement were proposed.**

***Index Terms*— Contrast; Enhancement; Histogram; Homomorphic; Review; Wavelet.**

I. INTRODUCTION

What is a contrast? In general, a contrast is defined as the difference in brightness. Often, it is the difference between individual objects or features in the image, or between objects and their background. Normally, contrast refers to the difference or relationship between the intensity of a given feature and its surroundings [1]. The contrast variation frequently caused by sunlight, noise environment, occlusion, and illumination is highly nonlinear and expressive [2]. Image enhancement deals with improving the quality of images, where the goal is to emphasize wanted features and make them less obscured. Recently, many researchers have presented a new image enhancement model to solve the luminosity and contrast variation problem. Theoretically, image enhancement technique can be divided into spatial domain and frequency domain. Spatial domain is manipulating or changing an image representing an object in space to enhance the image for a given application. Techniques are based on direct manipulation of pixels in an image. The frequency domain is a technique based on modifying the spectral transform of an image and transform the image to its frequency representation. In this paper, a review on two types of image enhancement approach, which are spatial domain and frequency domain are studied. The review focuses on popular enhancement technique, such as Histogram Equalization (HE), Homomorphic Filtering and Discrete Wavelet Transform (DWT). The aim of the review are to find and explore the benefits of image enhancement algorithms and to find the shortcomings in existing algorithms and techniques. This paper is organized in the following sections: Section I (A-D) describes the image enhancement approach and Section II provides the conclusion of the work.

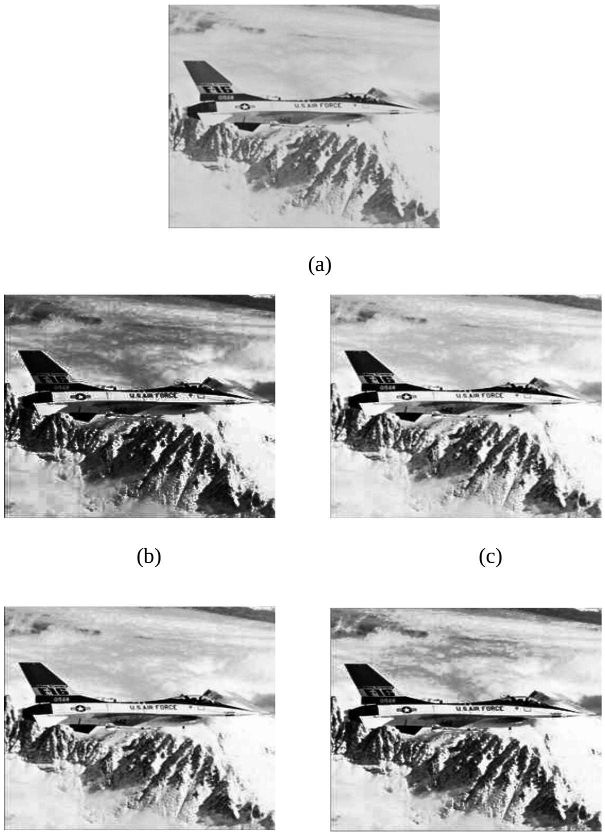
A. Histogram Equalization

In digital images, Histogram equalization (HE) is a popular technique to improve the image quality. This technique is simple, yet it is efficient for contrast enhancement [3]. Basically, the HE technique is divided into two categories; global histogram methods and local histogram methods. The global histogram methods, as pointed out by [4], modify the global histogram of the image. These methods are simple to implement, require no interaction from the user, and provide significant visual enhancement of the image. The main problem with these methods is that a relatively uniform region may be lost as their gray values are combined with the values of their background. This problem takes place because the corresponding pixel values, to which due to their low occurrence, are considered to have low information content. The problem of a full-frame histogram equalization failing to enhance small local details was first addressed by Ketcham [5], who suggested a local-area histogram equalization (LAHE), also known as adaptive histogram equalization (AHE). In this method, the enhancement is performed based on a local histogram in a local two-dimensional sliding window. This method was also independently suggested by Pizer [6] for the enhancement of medical images, and by Hummel [7]. There are a number of problems with the LAHE method. Its failure is due to the use of a fixed size window. For example, the window is too small and does not contain multiple objects, or the window is too large and the objects of interest do not occupy a significant portion of the local histogram. Additionally, Rehm and Dallas [8] found that LAHE produces undesirable edge artifacts at sharp natural boundaries. This artifact is caused by a change of transformation as the sliding window passes over that boundary.

An adaptive-neighbourhood histogram equalization (ANHE) method was done by Paranjape *et al.* [4]. In this method, instead of using a fixed size window, such as in LAHE, an arbitrary shape and size is used for the region from which the histogram is computed. This region is obtained from an adaptive neighborhood of each pixel being processed, an approach first suggested by Gordon and Rangayyan [9]. In contrast to LAHE, ANHE is a more adaptive method for contrast enhancement, since it uses a contextually based region, as opposed to a fixed rectangular window used in LAHE. The edge artifacts at sharp natural boundaries, which LAHE tends to produce, are non-existent since all the seed pixels in a given region have the same gray level transformation. ANHE, however, similarly to LAHE, suffers from the undesired enhancement of noise, especially in relatively uniform regions.

Adaptive contrast enhancement (ACE) [10] is a method that builds upon Gordon's method [9], where contrast enhancement is performed over an adaptive neighborhood. In this method, a contrast measure is defined by detecting contours in the image. Mukherjee and Chatterji [11] proposed Adaptive Neighbourhood Extended Contrast Enhancement (ANECE). This method combines NHE [22] and ACE [10]. It performs the same flow of contrast enhancement as the ACE technique, but in contextual regions that are obtained based on the ANHE technique. It uses the region-growing approach from ANHE, and the contrast enhancement based on a contrast measure from ACE [10]. The problem of over-enhancement is addressed by power variation, where the amount of enhancement is varied between two fixed limits depending on local image statistics.

Recently, a research conducted in 2005 indicated that Histogram Equalization (HE) was used in order to increase the performances of the Illumination Compensation based on Multiple Regression Model (ICR) and Affine Transform (AT) algorithms [12]. The disadvantage of this approach is that some local features of the face image have slightly weaken. In a different study, Salah-eldin *et al.* [13] explained a method to solve the illumination effect on face images using Histogram Equalization (HE). An input image from HE undergoes the combination of gamma correction and the Retinal filter's compression function is known as GAMMA-HM-COMP. The retinal filter is useful as an image enhancement; yet, the result is effective as compared to other enhancement techniques, such as the histogram equalization [14], gamma correction [15] and log transformation [14]. On the other hand, Santamar and Palacios [16] presented a comprehensive review of comparisons between a normal distribution (NORM), histogram equalization (HE), histogram matching (HM) [14] and Gamma Intensity Correction (GIC) [17] and finally presented a simple technique using Local Normal Distribution (LNORM). The result of Yale Face Database B showed that the LNORM achieved less than 1% of error rate compared to the other methods. Perhaps, the most serious disadvantage of this method is that it produces a non-realistic image that apparently has a lot of noise. In 2007, an adaptive smoothing filter using iterative convolution and two discontinuity measures, which are spatial gradient and local inhomogeneity for illumination correction was studied by Kyung and Kyu [18]. The above findings contradicted the study done by Azani *et al.* [19]. They suggested a smoothing filtering using a mean filter. The double mean filtering was performed to obtain the background normalization and smoothing. Finally, using a simple algorithm, the background correction was merged with the original image to produce the final result. Recently, the famous methods proposed based on histogram equalization (HE) are the Bi-histogram equalization (BBHE) [20], Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [21] and Dualistic Sub-Image Histogram Equalization (DSIHE) [22]. Figure 1 shows the comparison results between a few popular techniques based on HE. Nowadays, a lot of new algorithms had been proposed to find the superior contrast enhancement results.



(a) (b) (c) (d) (e)

Figure 1: Result comparison based on histogram modification [21]; (a) original image, (b) Histogram Equalization, (c) BBHE, (d) MMBEBHE and (e) DSIHE

B.Homomorphic Filtering

Homomorphic filtering is a popular method, especially for contrast enhancement. This technique is based on the frequency domain. It has been used in a variety of applications such as shadow identification, underwater image pre-preprocessing and contrast enhancement for raised or indented characters. Homomorphic filtering sharpens the features in an image by enhancing the high frequencies and sharpening the object edges [14]. Figure 2 shows that the Homomorphic Filtering technique is a combination of Log Transformation, Fourier Transform, and Exponential.

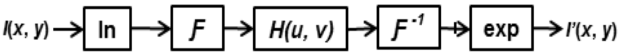


Figure 2: The basic homomorphic filtering flow

Delac *et al.* [23] proposed a slight modification of the original Homomorphic filtering algorithm. In this method, the input image was divided into sub-images based on the horizontal and vertical direction and homomorphic filtering was applied on each sub-image individually. Finally, the sub-result from the filtering step was merged and represented as the normalized face image. This technique had significantly improved the contrast and eliminated the illumination in face images. Previous studies reported a method based on the brightness adjustment across an input image [24]. They obtained the gray level value of the image as information region to develop the illumination normalization model. The Homomorphic filtering was used to separate an image into two parts, which are the face feature and the illumination information. The outcome was simultaneously normalized and then the contrast was improved. The findings were consistent with the findings of past studies [25], where a comprehensive method based on affine transformation lighting model had been presented. This method operates successfully after estimating the gain using homomorphic filtering and estimates the background via a multi-resolution low-pass filter. The results of this study indicated a better performance compared to Histogram Equalization (HE), Histogram Matching (HM), Local Range Modification [26], and Adaptive Histogram Equalization (AHE) [27]. The main drawback of this approach is the difficulties to recognize from the image itself if the change of grayscale value is due to the lighting effects. In a very extreme illumination, the algorithm does not perform perfectly to enhance the illumination. Figure 3 shows the resulting image and histogram with the original image and result after applying homomorphic filtering.

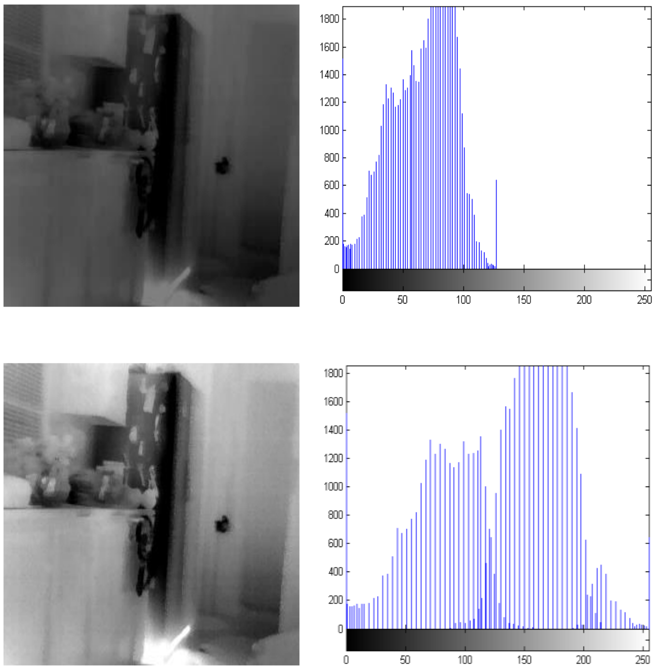


Figure 3: (above) The original image and histogram, (bottom) The result of homomorphic filtering and histogram [28].

The research by Ardizzone *et al.* [29] recommended an approach using Homomorphic filtering in Magnetic Resonance (MR) images application. The most interesting finding was that they presented a new function of Guillemaud filtering, especially to reduce the effect of streak artifacts. This approach has a number of advantages: firstly, no hypothesis is made on tissue classes; second, it can be performed on a variety of medical images, and the implementation is simple. In 2014, Azani *et al.* [30] explained an interesting review of six types of a filtering technique in order to improve the image quality. The six types of filtering technique are the Low-pass filter, High-pass filter, High-boost filter, Homomorphic using a Low-pass filter, Homomorphic using High-pass filter and Homomorphic using a High-boost filter. This comparison was applied to retinal images and the result showed that the Homomorphic using High-pass filter was powerful and effective to eliminate the contrast variation. Furthermore, in 2015, Azani *et al.* [31] again proposed a new enhancement method to improve the retinal segmentation result. This approach was based on a combination of superimpose Low-pass and Gaussian filtering. The advantages are that the method is simple and easy to implement. Yet, the result performance is impressive and shows the increments of illumination correction achieved at 78.55%.

C. *Discrete Wavelet Transform*

Recently, wavelet transform technology has been widely applied in image processing and pattern recognition. There are many wavelets transforms that have been developed, and each has its own features. Wavelet-based image enhancement is mainly used to enhance the perceptual quality of an image. Due to its band-pass nature, through which edges in an image can be located, the Wavelet Transform (WT) is well suited for improving the edge features in images. An example of enhancement using wavelets is a method proposed by Jin *et al.* [32]. In this method, over-complete dyadic spline wavelets were used, where the image was decomposed into 2 frequency bands (2 levels) with high frequency and low frequency. A local histogram equalization (LAHE) was performed in each frequency band with a different size of the local histogram window. The advantage of this method comes from combining the local enhancement capability of LAHE, and the selectivity of spatial-frequency components. Laine *et al.* [33] introduced a scale dependent mammogram enhancement method that selectively weights and scales the details using the first derivative of a Gaussian wavelet. Mammograms were decomposed into a multi-resolution hierarchy of localized information at different spatial frequencies. This multi-resolution representation provided an adaptive support for local contrast enhancement.

A wavelet transform is also called as a bank of multi-scale matched filters. This method is especially useful for the enhancement of subtle details like microcalcifications and was studied by Strickland and H. Hahn [34]. In 2005, Du and Ward [35] published a paper that described a wavelet-based normalization technique to normalize the illumination effect. This technique improves the contrast as well as the edges of face images simultaneously and in the frequency domain using the wavelet transform, to facilitate face recognition. Duan *et al*. [36] explained that a wavelet analysis can be used to obtain the invariance of illumination before proposing a novel algorithm. This approach is known as Improved Variable Illumination on Wavelet (IVIW). This paper also presented a comprehensive review of some traditional methods to normalize the illumination. The techniques can be worked on the real system and it also can improve the system's robustness and adaptability. In another study, Teoh and Goh [37] examined a new way using a combination of rotation of invariant local binary patterns and the fusion of wavelet transform. The low and high-frequency components in the input image were separated using DWT techniques. A major advantage of this technique is that it is simple, easy to implant and able to remove the illumination effect of the facial images effectively. In addition, this technique does introduce some noises. Based on the Equal Error Rate (EER), the performance is more effective compared to a few other methods. The details are shown in Table 1.

A research by Gomez *et al.* [39] only focused on a low pass band of the discrete wavelet transform to extract the illumination from the images. Therefore, this technique also involved the homomorphic filtering function to obtain the illumination model. This approach may be effective on video sequences. Using the same objective, Hu [40] conducted numerical experiments on face images under different lighting conditions. A new method known as the multi-scale dual-tree complex wavelet transform (DT-CWT) was proposed in order to reduce the halo artifacts in the non-uniform image. Recently, a comprehensive review to find the best methods for illumination normalization between homomorphic filter [23], LogAbout [41] and wavelet method was done by Mendoca [42]. Finally, the Principle Component Analysis (PCA) was obtained and the result showed that the wavelet method was the best method compared to the other methods. The wavelet methods had not only enhanced the contrast, yet improve the edges and detail that will further facilitate the face recognition task. There have been a number of longitudinal studies involving normalization techniques that have been reported. In 2005, according to an investigation by Provenzi *et al.* [38], the illumination correction was proposed based on a Single-Scale Retinex. Unlike the Homomorphic Filtering techniques, the retinex method measured the luminance image close to the actual scene. The interesting detail about this method is the uneven illumination was successfully eliminated, thus enhancing high-frequency information such as edges and they cannot perfectly avoid uneven contrast. However, interestingly, this is contrary to a study conducted by Park *et al.* [43] who presented a slight modification of the basic function of the retinex theory. The different process with the previous method was that these techniques estimated the illumination by iteratively convolving the input image with a 3 × 3 averaging mask weighted by an efficient measure of the illumination discontinuity at each pixel. This approach has a number of advantages: firstly, it is a fast illumination normalization and secondly, it can normalize the strong shadow in the input images.

Table 1
The Equal Error Rate (EER) result of a few enhancement methods [37].

Preprocessing Methods	EER(%)		
	Yale B Experiment (A)	Yale B Experiment (B)	CMU PIE
None	44.59	56.27	54.05
Histogram Equalization (HE)	40.03	50.15	50.87
Homomorphic Filtering	41.18	58.02	51.65
Single-Scale Retinex (SSR) [38]	48.19	50.83	40.01
IVIW [36]	48.74	56.53	53.26
Wavelet-based Illumination Normalization [35]	36.09	49.43	45.17
Extracting Illumination using Wavelet Transform using CDF9/7 filter [39]	27.53	37.83	22.13
Wavelet Fusion and Local Binary Patterns [37]	8.75	11.69	13.11

D. Other Methods

The contrast problem may seriously affect the diagnostic process and its result, especially if an automatic computer-based procedure is used to derive diagnostic parameters. Kubecka *et al.* [44] explained that the contrast variability and luminosity in retinal images, especially in the background regions, is very important to be normalized before going to the next stages. They proposed a new technique based on a combination of the B-spline shading model and Shannon's entropy to solve the illumination problem. This method had normalized up to 70% of artificially introduced illumination variability. Figure 4 shows the resulting image after applying the Kubecka method.

Youssif *et al.* [45] gave a comprehensive review on contrast enhancement and illumination equalization methods. The main purposes of all methods were to enhance the contrast and improve the segmentation result for retinal vasculature. In this research, it was interesting to compare the results obtained from nine different techniques in order to enhance the quality retinal fundus images. Based on the evaluation, the adaptive histogram equalization techniques were the best method to improve the segmentation algorithm. A significant analysis and discussion on the retinal image normalization were presented by E. Grisan *et al*. [46]. They proposed a method based on hue, saturation, and value (HSV) by applying a new algorithm to estimate and correct the image for illumination normalization. According to a previous review, the main limitation when applying a filter based had suffered and failed, especially when dealing with large lesions or retinal features that existed. However, to solve the above problem, this method points out a fit on the illumination model using the information contained in the retinal background pixels. Non-linear point transformation techniques were founded by Wang *et al.* [47] which had been involved in the adjustment of the brightness of the image. Besides, from the experimental image, this author also proposed another method to exploit the vessel pixel segmentation, evaluate the function of cluster illumination in the pixel and its elimination. The advantage of this method is that it is good for luminosity; however, it is poor for contrast enhancement.

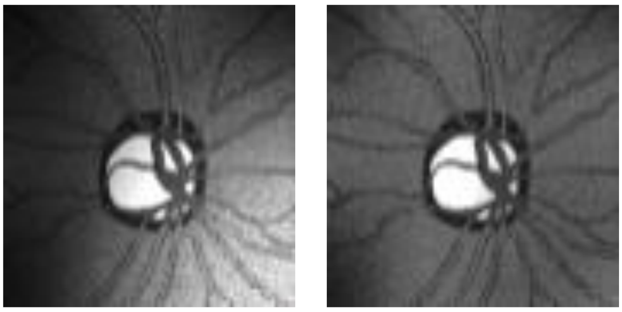


Figure 4: (Right) Original illumination retinal image. (Left): The resulting image finding by [44].

II. Conclusion

This paper discussed an interesting survey of various techniques of contrast enhancement. The methods proposed in the literature were classified into three different groups; the Histogram Equalization (HE) method, Homomorphic Filtering method and Discrete Wavelet Transform (DWT). The drawbacks and advantages of the methods had been explained in detail. The main objective of the literature review was to find and explore the benefits of image enhancement algorithms and to find the shortcomings in existing algorithms and techniques. Based on the review, the basic limitation of the HE method is that it introduces noise and the computational time is very slow. However, the method based on filtering technique is very hard and it is difficult to find the specific cut-off in a badly contrast variation image. The wavelet methods have not only enhanced contrast, but it also improved edges and detail which will further facilitate the face recognition task. Many researchers agreed that it is very difficult and impossible to construct a perfect mathematical algorithm to solve the illumination and contrast problem at the same time. Image enhancement is found to be one of the most important elements in vision applications because it has the ability to enhance the visibility of the images. This study was done to find the gaps in the existing research and possible solutions to overcome these gaps in the future.

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