A Review of Robust Image Enhancement Algorithms and Their Applications

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***Abstract*—The essential target of image enhancement is to minimize noise from a digital image by keeping the intrinsic information of the image preserved. The main difficulty in image enhancement is determining the criteria for enhancement and, therefore, more than one image enhancement techniques are empirical and require interactive procedures to obtain satisfactory results. In this paper robust image enhancement algorithms are discussed, implemented to noisy images and compared according to their robustness. The algorithms are especially able to improve the contrast of medical images, fingerprint images and selenography images by means of software techniques. When deciding that one image has better quality than another image, quality measure metrics are needed. Otherwise comparing image quality just by visual appearance may not be objective because images could vary from person to person. That is why quantitative metrics are crucial to compare images for their qualities. In this paper Peak Signal to Noise Ratio (PSNR) and Mean Squared Error (MSE) quality measure metrics are used to compare the image enhancement methods systematically. All the methods are validated by the performance measures with PSNR and MSE. It is believed that this paper will provide comprehensive reference source for the researchers involved in image enhancement field.**

Keywords-image enhancement algorithm; histogram matching; histogram equalization; fuzzy set theory

I. INTRODUCTION

Image enhancement is a powerful tool which is widely used in computer vision. It is a popular sub-specialization of image processing. Image enhancement is the improvement of image quality to a better and more understandable level for visual appearance for future automated image processing, such as analysis, detection, segmentation and recognition [1]. Improving interpretability or perception of data in images can be thought as main goal of image enhancement process so that human viewers or future automated image processing can benefit from the new enhanced image [2]. When dealing with image enhancement it must be kept in mind that image enhancement implementation doesn't have effect upon the intrinsic information content of the data. What is effect is to increase the dynamic range of the intensity values of image [3]. Over the years a variety of image enhancement methods have been proposed with the developments in image processing field. These methods have been independently studied for several different applications, resulting in a large body of research. Although there is a wide range of methodologies, classification and comparison of techniques become difficult because each technique is often designed for specific applications and not necessarily for specific types of problems or data. However the approaches differ in information on which enhancement relies. Briefly stated, the researchers or scientists who intend to enhance images should establish the connection between the changes in the images/targets of enhancement and the type of enhancement methods which can most appropriately be applied.

The work done in literature by various researchers can be summarized as follows;

K. M. Yasmin et. al. [4] studied on brain image enhancement techniques. Brain images contain anatomic sense for neurologic research, diagnosis and treatment. Therefore to evaluate brain images becomes a crucial issue. In that paper brain image enhancement techniques were compared to analyze the brain images precisely in order to effectively diagnose and examine the diseases and problems. J. K. Hasikin et. al. [5] made use of fuzzy set theory for their image enhancement purposes. This is a low contrast image enhancement technique. This technique is worked by maximizing fuzzy measures contained in the image. Image is enhanced by modification of membership function. Wadud et. al. [6] studied an a smart contrast enhancement technique based on conventional histogram equalization (HE) algorithm. Researcher interested in more specific aspects of image enhancement can refer to publications by Kamran et.al. for ultrasound image enhancement [7], Suganthi et.al. for edge enhancement [8], Anand et.al. for mammographic image enhancement [9], Hossain et.al. for contrast enhancement [10], Babu et.al. for speckle reduction using fuzzy logic on coefficient of variations [11], Deka et.al. for removal of correlated speckle noise [12], Janani et.al. for infrared image enhancement techniques [13], Imtiaz et. al. for endoscopic image enhancement [14], Bhattacharya et.al. for localized image enhancement [15].

II. METHODOLOGY

Many image enhancement algorithms have been developed to improve the appearance of images. In this paper four commonly used image enhancement techniques are explained, compared and corresponding experimental results are shown. These enhancement techniques are as followings,

- Fuzzy Set Theory Image Enhancement Method

- Histogram Equalization Image Enhancement Method
- Histogram Matching Image Enhancement Method
- Equalized Histogram Equalization Image Enhancement Method

A. Fuzzy Set Theory Image Enhancement Method

The problem whether a pixel should become darker or brighter than it already is, can be considered as the principal goal of the fuzzy set theory image enhancement technique [16]. Algorithm can be summarized as follows. To begin with input image is taken into digital form environment. Then image histogram is computed to be able to decide whether corresponding image histogram is applicable for fuzzy set theory with s-shape membership function image enhancement method or not. Last but not least it is concluded that fuzzy logic s-shape image enhancement method is applicable to this specific noisy image if histogram range lies down in a narrow band. On top of that processed image is converted to fuzzy plane. At the following step membership function is modified by means of appropriate membership function modification formula. Lastly enhanced image is displayed as output.

1) Algorithm

Step-1: Find image histogram using any software technique. If histogram range lies down in a narrow band fuzzy set theory with s-shape membership function image enhancement method is applicable to this specific noisy image.

Step-2: Once decided that aforementioned method is applicable assign minimum intensity value (g_{min}) and maximum intensity value (g_{max}) of the image.

Step-3: Next is defuzzification step. Shift minimum intensity value to 0, maximum intensity value to 1, and other intensity values between 0 and 1 using fuzzy formula shown below.

Conversion to Fuzzy Plane:

$$\mu_{(g)} = \frac{g - g_{min}}{g_{max} - g_{min}} \qquad (1)$$

Step-4: This step involves membership function modification. There are many membership functions in literature. Decision for selecting membership function is dependent on image intrinsic content such as image histogram. In this paper s-shape membership function is used now that image histogram is suitable. Membership function is modified using following formula.

Membership S-Shape Function:

$$S(z;\, a,b,c) = \begin{cases} 0 & z<a \\ 2\left(\frac{z-a}{c-a}\right)^2 & a\leq z\leq b \\ 1-2\left(\frac{z-c}{c-a}\right)^2 & b<z\leq c \\ 1 & z>c \end{cases} \qquad (2)$$

This spline-based curve is a mapping on the vector z, and is named because of its S-shape. The parameters a and c locate the extremes of the sloped portion of the curve where b is arithmetic mean of a and c.

Step-5: To stretch contrast of the processed image multiply each pixel by a constant number.

Step-6: Convert image to its original plane from fuzzy plane (defuzzification) and examine the enhanced image.

B. Histogram Equalization Image Enhancement Method

Histogram equalization is a popular method in low level image enhancement using the histogram of the image. The principle is that an image is said to be the best in visual appearance, when its histogram looks like the uniform distribution. Probability density function is the key point operator in the histogram equalization method. A new image with equally distributed intensity level from the lowest pixel value (0) to the highest pixel value (L-1) is formed using probability density function. By means of this idea, handicapped intensity values are increased whereas excessive intensity values are decreased therefore the contrast of the image is increased.

C. Histogram Matching Image Enhancement Method

Histogram matching is an extensive revision of the histogram equalization. Difference is that in histogram equalization, the histogram of the output image is desired to be uniformly distributed whereas in histogram matching method, the histogram of the output image is manipulated as to follow according to that users determine. It becomes the best approach to have the control of adjusting the shape of the histogram. The method used to generate a processed image that has a specified histogram is called histogram matching [17].

D. Equalized Histogram Equalization Image Enhancement Method

Equalized histogram equalization method is an improved conventional histogram equalization method. First of all the input image is enhanced using the algorithm described in section B. Obtained output image is summed up with input image. By this way loss parts in output image can be recovered [18].

1) Algorithm

Step-1: Compute probability density function (pdf) of the input image.

$$pdf(i) = \frac{number\ \ of\ the\ \ pixel\ \ with\ intensity\ \ i}{total\ \ number\ \ of\ pixels\ \ in\ image\ \ x} \quad 0< i < L \qquad (3)$$

where L is highest intensity value.

Step-2: Calculate cumulative distribution function (cdf) considering pdf(i) for each pixel.

$$cdf(i) = \sum_{k=0}^{L-1} pdf(i)$$

Step-3: Get the value of the pixels by multiplying cdf(i) by L-1 and then round it to the nearest integer.

$$s_k = \sum_{k=0}^{L-1} (L-1) * pdf(i)$$

Step-4: Add new image to the input image to get the enhanced output image.

$$E = s_k + x \tag{4}$$

E = enhanced output image
x = input image

III. Experimental Results

Above image enhancement methods are implemented to three different image types, these image types are Medical Image, Fingerprint Image and Selenography Image. Results are demonstrated in Figure 1, Figure 2 and Figure 3, respectively. Corresponding image histograms are also shown in these figures. Figure 1A is a noisy MR image of a patient's knee before enhancement process. Figure 1B is enhanced MR image using Equalized Histogram Equalization Image Enhancement Method (EHE), Figure 1C is enhanced MR image using Histogram Matching Image Enhancement Method (HS), Figure 1D is enhanced MR image using Histogram Equalization Image Enhancement Method (HE) and lastly Figure 1E is enhanced MR image using Fuzzy Set Theory Image Enhancement Method (Fuzzy). Figure 2 and Figure 3 are results for Fingerprint and Selenography Images respectively. An image is said to be the best in visual appearance, when its histogram looks like the uniform distribution. From the figures it can be seen that image histograms are uniformed after enhancement process comparing with histograms before enhancement process. In image processing it is quite difficult to compare the enhancement results by visual appearance and just looking at the images with naked eye. Therefore to compare the result and to make comment image quality metrics are used in this paper.

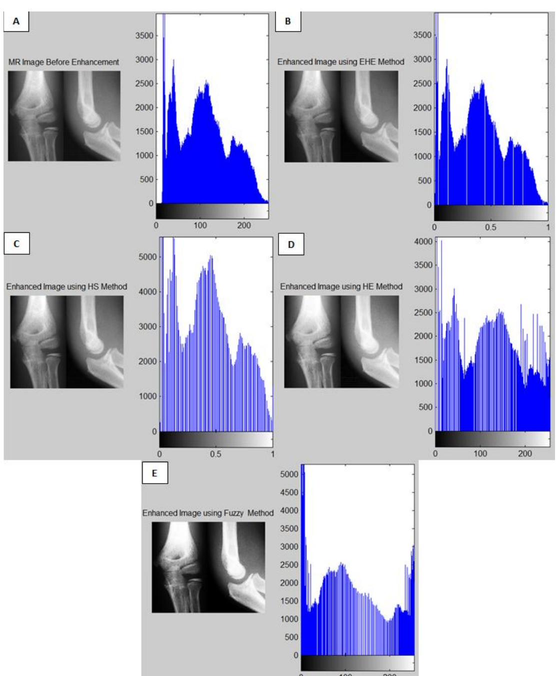

Figure 1. Noisy MR image (A), enhancement results and corresponding histograms using method EHE (B), HS (C), HE (D) and Fuzzy (E).

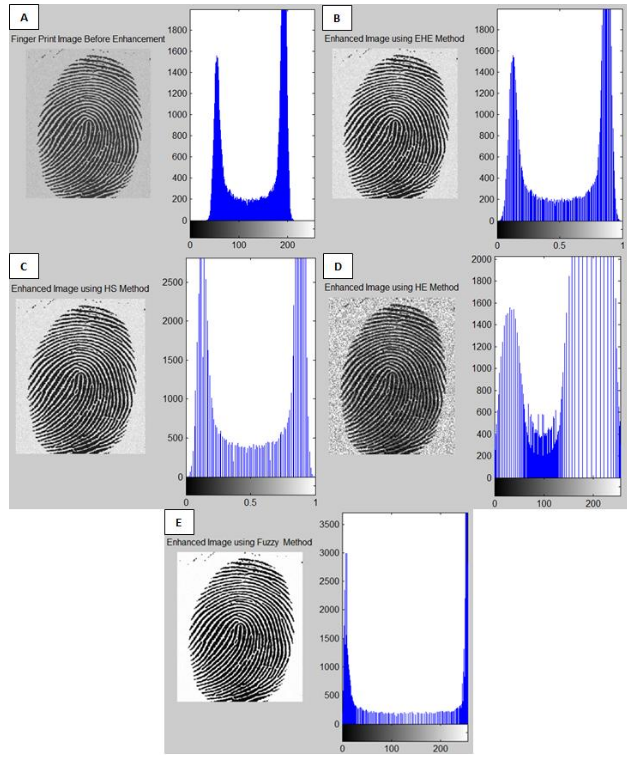

Figure 2. Noisy fingerprint image (A), enhancement results and corresponding histograms using method EHE (B), HS (C), HE (D) and Fuzzy (E).

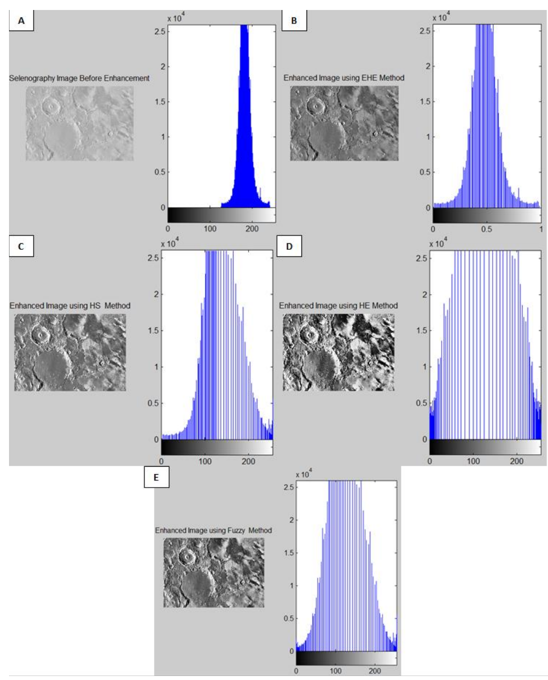

Figure 3. Noisy selenography image (A), enhancement results and corresponding histograms using method EHE (B), HS (C), HE (D) and Fuzzy (E).

To validate the enhancement in images and the visual quality of image, Peak Signal to Noise Ratio (PSNR) and Mean Squared Error (MSE) are often used to compare the results of methods. When deciding that one image has better quality than another image, quality measure metrics are needed. The golden rule is that the higher the PSNR, the better noisy images has been enhanced and the better the enhancement algorithm. This would occur when we minimize the MSE between the images with respect the maximum signal value of the image. PSNR is the ratio between the maximum possible value (power) of a signal and power of the noise corrupted by the signal. In image processing, MSE measures the average of the squares of the "errors", that is, the difference between the enhanced image and noisy image [19]. MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss [20]. The less the MSE the best result for enhancement.

TABLE I. IMAGE QUALITY MEASURES ACCORDING TO METHOD USED

IMAGE TYPE	METHOD	PSNR	MSE
MR IMAGE	EHE	31.7524	43.4347
	HS	30.3380	60.1563
	HE	19.9431	658.8181
	FUZZY	17.9600	1040.1654
FINGER PRINT IMAGE	EHE	19.6638	702.5886
	HS	19.1625	788.5485
	HE	18.5780	902.1604
	FUZZY	13.4963	2907.1000
SELENOGRAPHY IMAGE	EHE	12.2846	3842.6000
	HS	11.1830	4952.0000
	HE	10.7374	5487.1000
	FUZZY	10.1107	6338.8000

IV. CONCLUSION

Image enhancement is an important sub-area of digital image processing field. More than one image enhancement techniques occur in image processing. These image enhancement techniques improve visual appearance of any portion or feature of the images by suppressing the information in other portions or features. Image enhancement techniques propose a wide variety of algorithms for improving images to obtain visually acceptable images. The selection of such techniques is a matter of the specific task and image content. In this paper four up to date and useful image enhancement methods are analyzed for their effectiveness. For enhancement purposes three important image types are used as database. These image types are medical image, fingerprint image and selenography image. Four image enhancement methods are implemented to these noisy images and compared according to their robustness with respect PSNR and MSE image quality metrics. The algorithms are especially able to improve the contrast of medical images, selenography images and finger prints images by means of software techniques. The results are shown in Table 1. From the table it is said that EHE method is the best method for image enhancement problems. HS method, HE method and Fuzzy method are the other better image enhancement methods respectively. However fuzzy method is a good enhancement method for low contrast images only. This order is validated by using PSNR and MSE. PSNR and MSE results show the same result deduction and confirm each other. The algorithms have been successfully applied and desired enhanced images have been showed.

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