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Comparison of Diverse Enhancement Techniques for Breast Mammograms

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Abstract: Image enhancement is one of the key issues in high quality pictures such as medical images. Enhancement is to improve the visual appearance of an image, or to provide a better transform representation for future automated image processing. As it provides a multitude of choices for improving the visual quality of images it is used in a huge number of applications with important challenges such as noise reduction, degradations, improving clarity of images for human viewing, removing blurring and noise, increasing contrast, and revealing details etc. This paper presents a literature review on some of the image enhancement techniques for enhancing digital mammograms. Various spatial and frequency domain techniques are discussed. Comparison of all the techniques concludes the better approach for its future research.

Keyword: Enhancement, denoising, visual quality, deblurring, increasing contrast.

I. INTRODUCTION

Enhancement is one of the vital parts in medical image processing. The main aim of enhancement is to increase the quality of the image for further automated process like segmentation and classification. Mammogram being the easiest diagnosis technique for early detection of breast cancer is often used in diagnosis of the same. The information contained in the mammogram may not be enough for a complete analysis. Image enhancement simply means, transforming an image f into image g using T. Let the values of pixels in images f and g are denoted by r and s, respectively. As said, the pixel values r and s are related by the expression, s = T(r), where T is a transformation that maps a pixel value r into a pixel value s. The results of this transformation are mapped into the grey scale range as we are dealing here only with grey scale digital images. So, the results are mapped back into the range [0, L-1], where L=2k, being the number of bits in the image being considered. The image may have information which will be visible only if enhanced. So enhancement is done to mammogram images. An image can be enhanced by changing any attribute of the image. The selection of the attribute for modification is based on the selected enhancement nature. The two types of enhancement are the spatial domain enhancement and the frequency domain type. Spatial domain enhancement type directly deals with the pixels. The major advantages of spatial domain enhancement are that those methods are straightforward and are chiefly utilized in real time applications. But it lags in producing adequate robustness and imperceptibility requirement. Frequency domain describes the analysis of mathematical functions specifically they operate directly on the transform co efficient of the image [1]. This algorithm spreads out the central modes of the histogram to more evenly occupy the dynamic range, without overly altering the relative proportions of light and dark tones. The basic limitation is it cannot concurrently enhance all parts of image very well and it is complicated to automate the image enhancement procedure. Some of the enhancement types are compared here with their results. Adaptive histogram equalization produced a better result, but the image is still not free from washed out appearance. The sharpness is poor and the background information as well as the plane is still fogged and poor in contrast. Alpha rooting makes the entire image in a dark tone [2]. A hybrid technique makes use of the Gauss filter processing to enhance image details in the frequency domain and smooth the contours of the image by the top-hat and bottom-hat transforms in spatial domain [3]. A nonlinear non-dynamic stochastic resonance-based technique for enhancement of dark and low contrast images treats a low contrast image as a sub threshold signal and noise-enhanced signal processing was applied to improve its contrast. This technique uniquely utilizes the addition of external noise to neutralize the effect of internal noise of a low contrast image [4]. Context aware technique enhances the image without introducing artifacts, enhances dark images, sharpens edges, reveals details in textured regions, and preserves the smoothness of flat regions. But it does not recover information from the dark area of the image that had near black intensities [5].

Fuzzy gray scale enhancement technique maximises fuzzy measures contained in the image and requires only minimum processing time. But this method does not enhance only the low contrast images [6]. Enhancement via image fusion may increase the contrast and enhance the complete image but sharpness of the image may be lost [7]. This paper presents a review of various enhancement techniques for enhancing digital mammograms.

II. Comparison of Techniques

Various enhancement techniques are discussed below. The simulation results of those techniques are shown and their PSNR values are also tabulated.

A. *Logarithmic Enhancement Transformation*

The universal form of the log transformation is given as

$$s = c * \log(1 + r) \qquad (1)$$

The log transformation maps a limited range of low input grey level values into a broad range of output values. The inverse log transformation performs the contrary transformation. Log functions are predominantly useful when the input grey level values may have an extremely large range of values [8]. This transform is used to expand values of dark pixels and compress values of bright pixels. The only disadvantage is that it over enhances the image.

B. *Histogram Equalization*

The histogram of an image represents the frequency of occurrence of all the gray levels in an image [9]. If n(k) is the frequency of k^{th} intensity level and n is the total number of pixels in the gray-level image then the normalized histogram is given by the equation

$$P(k)= \frac{n(k)}{n} \qquad (2)$$

The conventional histogram equalization is based on cumulative frequency distribution which is given by the equation

$$C(k)= \sum_{j=0}^{k} p(k)\ k) \qquad (3)$$

If it could `stretch out' the grey levels at the dark end to produce a more uniformly distributed histogram then the image would become much clearer. The method is constructive in images with backgrounds and foregrounds that are both bright or both dark. It is a fairly straightforward technique and an invertible operator. This usually results in an enhanced image, with an increase in the dynamic range of pixel values. The histogram of output image is only approximately, and not exactly, uniform. It may increase the contrast of background noise, while decreasing the usable signal. Histogram equalization may not always produce desirable results, particularly if the given histogram is very narrow. In discrete space, it cannot be proved in general that this discrete transformation will produce the discrete equivalent of a uniform probability density function, which would be a uniform histogram. It can produce false edges and regions. It can also increase image "graininess" and "patchiness."

C. Contrast Stretching

Contrast stretching is a simple image enhancement technique that endeavours to improve the contrast in an image by 'stretching' the range of intensity values it contains to an extent of a desired range of values. Contrast stretching (also called Normalization) attempts to improve an image by stretching the range of intensity values it contains to make full use of possible values. It increases the dynamic range of the gray levels in the image. Unlike histogram equalization, contrast stretching is restricted to a linear mapping of input to output values. The result is less dramatic, but tends to avoid the artificial appearance of equalized images. It only applies a linear scaling function to the image pixel values which results a less harsh enhancement [10].

Before the stretching is performed it is necessary to specify the upper and lower pixel value limits over which the image is to be normalized. Often these limits would be the minimum and maximum pixel values of the image. Call the lower and the upper limits a and b respectively. The simplest kind of normalization scans the image to find the lowest and highest pixel values currently present in the image. Name these c and d. Then each pixel P is scaled using the following function:

$$P_{out} = (P_{in} - c)\frac{(b-a)}{(d-c)} + a \qquad (4)$$

The trouble with this is that a single outlying pixel with either a very high or very low value can sternly affect the value of c or d and this could escort to very unrepresentative scaling.

D. Histogram Matching

Histogram equalization automatically resolves a transformation function seeking to produce an output image with a uniform histogram [11]. The Histogram matching Algorithm can be extended to find a monotonic mapping between two sets of histograms. The steps involved in histogram matching are given below.

1. Find the histogram $p_r(r)$ of the input image and find its equalization transformation

$$S=T(r)=(L-1)\int_0^r P_r(w)dw$$

2. Get the transformation function

$$G(z)=(L-1)\int_0^r P_r(w)\,dw$$

3. Find the inverse transformation $z = G^{-1}(S)$ the mapping from s to z:

$$Z=G^{-1}[Tr]=G^{-1}(S)$$

4. Obtain the output image by equalizing the input image first; then for each pixel in the equalized image, do the inverse mapping to acquire the corresponding pixel of the output image.

Histogram matching enables us to "match" the gray scale distribution in one image to the gray scale distribution in another image.

E. Laplacian Enhancement

Any feature with a spiky discontinuity (noise) will be enhanced by a Laplacian operator.

The Laplacian operator is realized in IDL as a convolution among an image and a kernel. The Laplacian kernel can be assembled in a 3-by-3 kernel. In image convolution, the kernel is cantered on each pixel in turn, and the pixel value is restored by the sum of the kernel multiplied by the image values [12]. In the particular kernel used here the contributions of the diagonal pixels as well as the orthogonal pixels in the filter operation is calculated. It is prone to introduction of artifacts while enhancement.

F. Median filter

Median filter is one of the non linear processes which are very useful in reducing impulsive or salt and pepper noise. t is also useful in preserving the edges in an image while reducing random noise. The median filter deems each pixel in the image in turn and looks at its nearby neighbours to decide whether or not it is representative of its surroundings [13]. As a replacement to replace the pixel value with the mean of neighbouring pixel values, it replaces it with the median of those values. The median is calculated by first sorting all the pixel values from the surrounding neighbourhood into numerical order and then replacing the pixel being considered with the middle pixel value. If the neighbourhood under consideration contains an even number of pixels, the average of the two middle pixel values is used. Larger neighbourhoods will produce more severe smoothing. Despite changing some characteristics of an image, the impulse noise will be radically suppressed by median filter.

G. Contrast Limit Adaptive Histogram Equalization

Contrast limited AHE differs from ordinary adaptive histogram equalization in its contrast limiting. CLAHE is a useful technique for improving image contrast, but its effect is too severe for many purposes. In the case of CLAHE the contrast limiting procedure has to be applied for each neighbourhood from which a transformation function is derived [14]. It operates on small areas called tiles. Each tiles contrast is enhanced so that the histogram of the output region approximation matches the histogram specified by the distribution parameter. The neighbourhood pixels are combined using bilinear interpolation to eliminate artificially induced boundaries. The contrast especially in homogeneous areas can be limited to avoid amplifying any noise that may be present in the image. It may introduce artifacts and may affect the decision process.

H. Contrast Enhancement

Contrast enhancements improve the perceptibility of objects in the scene by enhancing the brightness difference between objects and their backgrounds. Contrast enhancement processes adjust the relative brightness and darkness of the image to improve their visibility. The contrast and tone of the image can be changed by mapping the gray levels in the image to new values via a gray-level transform. It makes images easier to interpret by making object features easier to distinguish. A contrast stretch improves the brightness differences uniformly across the dynamic range of the image, whereas tonal enhancements improve the brightness differences in the shadow (dark), midtone (greys), or highlight (bright) regions at the expense of the brightness differences in the other regions. It addresses the need for robust, generally applicable, contrast enhancement algorithm of images with multimodal histograms [15].

I. Power-law transformations

The power law transformation is given by $s = Cr^{\gamma}$ [16]. For $\gamma<1$ maps a narrow range of dark i/p values into a wider range of o/p values and with the opposite being true for higher values of i/p. By varying γ a family of possible transformation is obtained. For curves generated with values $\gamma>1$ the effect is opposite. This transformation function is also known as gamma correction. For various values of γ different levels of enhancements can be obtained. The Log and Power-Law transformations resulting values are often quite unique, depending upon control parameters like λ and logarithmic scales.

The results of these values should be mapped back to the grey scale range to get a gist output image. It results in considerably enhanced images without the introduction of artifacts.

J. Spatial Enhancement

Spatial enhancement is the mathematical processing of image pixel data to emphasize spatial relationships. This process defines homogeneous regions based on linear edges. Spatial enhancement techniques use the concept of spatial frequency within an image. Spatial frequency is the manner in which gray-scale values change relative to their neighbours within an image. If there is a slowly varying change in gray scale in an image from one side of the image to the other, the image is said to have a low spatial frequency. If pixel values vary radically for adjacent pixels in an image, the image is said to have a high spatial frequency [17].

It produces an image of higher contrast than the original by darkening the levels below a value m and brightening the levels above m in the original pixel spectrum. The values of r below m are compressed by the transformation function into a narrow range of S towards the dark end of the spectrum; the opposite effect takes place for values of r above m.

K. Background Removal Enhancement

A direct method of reducing the slowly varying portions of an image, to allow increased gray level variation in the image details, is background subtraction. It is usually performed by subtracting a low-pass filtered version of the image from itself. Unsharp masking is a simple version of this procedure. The unsharp masking is combined with negative image, which creates an image which is less blurred than the original. The output image, although clearer may be a less accurate in representing the images subject. Spline filtering and gray-scale morphological processing are two methods of estimating the image background which have been used successfully for this purpose. The background extraction technique should be adaptive to local image characteristics to truly identify the image background [18].

L. Histogram Warpring.

As the low-contrast image's histogram is narrow and centered toward the middle of the gray scale, if the histogram is distributed to a wider range the quality of the image will be improved. The histogram warping transformation y= T(x) is defined by a mapping of corresponding gray level values $b_k=T(a_k)$ and their contrast adjustments $d_k=T'(a_k)$.Thus, the histogram which could be locally controlled is shifted $a_k \neq b_k$, compressed $0 \leq b_k<1$, or stretched $d_k>1$. The requirement is that the sequence a_k is strictly increasing, b_k is increasing, and d_k is finite and nonnegative. A continuously differentiable C^1 transformation is needed in order to avoid artificial discontinuities in the resulting histogram $f(T^{-1}(y))\,(T'(T^{-1}(y)))^{-1}$. So, for best image quality, piecewise exponential and piecewise linear histogram transformations should be avoided unless efficiency is the overriding concern. The transformation must be monotonic $T(x)' \geq 0$ to preserve the natural order of gray levels so that the polarity of the image is not reversed. For instance, the commonly used cubic spline histogram transformations may fail to be monotonic in regions of heightened contrast $d_k > 3r_k$. Hence histogram warping method is based on a piecewise rational quadratic, C^1 interpolating monotonic spline [19].

$$T(x)=b_{k-1}+((r_k t^2+d_{k-1}(1-t)t)(b_k-b_{k-1})/((r_k+(d_k+d_{k-1}-2r_k)(1-t)t \qquad (5)$$

Where $r_k=(b_k-b_{k-1})/(a_k-a_{k-1})$

$t=(x-a_{k-1})/(a_k-a_{k-1})$

$x \in [a_{k-1},a_k]$

This algorithm spreads out in the central modes of the histogram to more evenly occupy the dynamic range, without overly altering the relative proportions of light and dark tones. Because its design combines aspects of linear contrast stretch with histogram equalization, this technique appears to balance the limited distortion well.

M. Fixed Neighbourhood Statistical Enhancement

In many classes of images, a slowly varying background contributes little to the interpretation of the image, and can be removed to allow expansion of the gray level variations in local image features, and thus increase contrast. Local enhancement techniques use statistical properties in the neighbourhood of a pixel to estimate the background, suppress it, and increase local contrast.

A method calculates the local mean and variance, and performs a transformation to a desired local mean and variance. Some methods use the global mean, local mean, and local standard deviation to obtain the gray level transformation.

$$Y=k\frac{M}{c}(x-\mu)+\mu \qquad (6)$$

Where p and μ are the local mean and standard deviation, M is the global mean, and k is an empirically determined scaling factor. A given neighbourhood size and shape may not be equally effective in enhancing all areas of an image [20].

III. Performance Metrics

A. PSNR

The phrase signal to noise ratio is an engineering term for the ration between maximum possible signal power to the noise power. It is most commonly used as a measure of quality of reconstruction of codec's. The signal in this case is the pectoral muscle removed image, and the noise is difference caused by the enhancement technique.

PSNR is defined as

$$\mathrm{PSNR} = 10.\log_{10}\left(\frac{\mathrm{MAX}^2{}_I}{\mathrm{MSE}}\right) \qquad (7)$$

$$= 20.\log_{10}\left(\frac{\mathrm{MAX}^2{}_I}{\sqrt{\mathrm{MSE}}}\right) \qquad (8)$$

$$= 20.\log_{10}(\mathrm{MAX}_I) - 10.\,\mathrm{Log}_{10}(\mathrm{MSE}) \qquad (9)$$

Where MAX_I is the maximum possible pixel value of the image. The higher the PSNR value, the higher the reconstruction of the image [22].

B. Mean Square Error

Any error is most easily defined via the mean squared error (MSE) [22]. Given a noise-free m×n monochrome image I and its noisy approximation K, MSE is defined as,

$$\mathrm{MSE} = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2 \qquad (10)$$

Where i and j are the rows and columns of the image.

IV. Results

For a biopsy tested cancer proven image from MIAS database, all the above given techniques are implemented using Matlab codes and the result is shown in Figure 1. The PSNR and MSE for all these techniques are tabulated in Table 1. All the enhancement techniques are applied to the pectoral muscle removed mammogram image.

Figure 1: Comparison of various enhancement methods

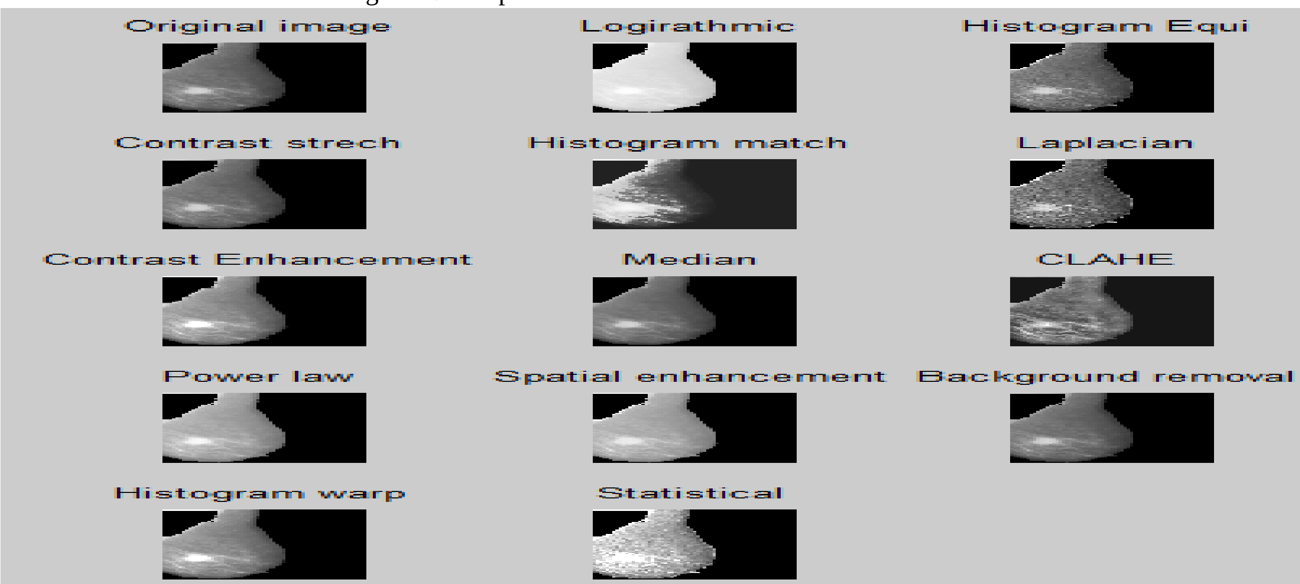

TABLE I
PSNR VALUES FOR THE ENHANCED IMAGES

S.NO	TECHNIQUE	PSNR	MSE
1	Logarithmic	11.3008	12.3655
2	Histogram equalization	9.9526	5.9004
3	Contrast stretch	2.472	0.71540
4	Histogram matching	9.9578	7.3257
5	Laplacian	9.9526	9.2544
6	Median	9.9520	8.2111
7	CLAHE	21.1367	24.9582
8	Power law	9.9660	4.2222
9	Contrast enhancement	22.6642	30.4788
10	Spatial enhancement	19.4652	11.4423
11	Background removal	10.6511	14.5696
12	Histogram wrapping	21.0008	24.9754
13	Fixed neighbour statistical	10.6840	17.2544

V. CONCLUSION

In this paper thirteen various enhancement techniques are presented along with its PSNR and MSE value. Out of the thirteen methods contrast enhancement gives the higher PSNR value and the second higher is the CLAHE technique. Figure 1 shows all the enhanced techniques performed to a single image. Table 1 describes the PSNR and MSE values for all the techniques performed. In future further more techniques can be compared. To prove the accuracy along with PSNR and MSE, entropy and much more accurate calculations are performed.

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