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Image Enhancement Techniques: A Comprehensive Review

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Abstract - Image enhancement is most crucial preprocessing step of digital image processing. It is used to enhance features of digital image in order to improve its visual appearance and to make it more suitable for autonomous machine perception. Image enhancement is subjective process of improvement and is application dependent. Apart from visible region, digital images can also be created from remaining electromagnetic spectrum like x-rays, infrared rays, gamma rays etc. The improvement of digital image can be done by removing noise, enhancing contrast and by removing blurring. In this paper, review and comparison of different existing image enhancement techniques in spatial and frequency domain have been done and conclusion will be made that in which application or condition a particular enhancement technique can be used.

***Keywords* - Enhancement, Contrast, Histogram, Spatial Domain, Frequency Domain.**

1. Introduction

Image enhancement technique improve the quality of an image by taking input as low quality image and by giving output as high quality image for particular application. Digital image enhancement techniques are used to get detail that is not cleared, or to highlight certain features of interest in image. In image enhancement process one or more attributes of image are modified. Image enhancement can be applied to different areas of science, engineering and medical diagnostic. Image enhancement is basically improving the interpretability or perception of information in images for human viewers and providing `better' input for other automated image processing techniques [1]. The prime objective of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific observer. During this process, one or more attributes of the image are modified. The choice of attributes and the way they are modified are specific to a given task. Image enhancement is a subjective process. Observer-specific factors, such as the human visual system and the observer's experience, will introduce a great deal of subjectivity into the choice of image enhancement methods. There exist many techniques that can enhance a digital image without spoiling it. Carrying out image enhancement understanding under low quality image is a challenging problem because of these reasons. Due to low contrast, we cannot clearly extract objects from the dark background. Most color based methods will fail on this matter if the color of the objects and that of the background are similar [2]. The review of available techniques is based on the existing techniques of image enhancement, which can be classified into two broad categories:

- Spatial Domain Enhancement Techniques
- Frequency Domain Enhancement Techniques.

Spatial based domain image enhancement improves quality of image by directly manipulating the pixels value. The main advantage of spatial based domain technique is that they conceptually simple to understand and the complexity of these techniques is low which is useful in real time implementations [3]. But these techniques generally lacks in providing adequate robustness and imperceptibility requirements. The spatial filtering process consists simply moving the filter mask from point to point in an image. At each point, the response of the filter at that point is calculated using a predefined relationship. Spatial filters can be further classified into linear and non-linear filters.

Linear filtering is filtering in which the value of an output de-noised pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. Whereas a filter is said to non-linear if its output is not a linear function of input [4]. Frequency based domain image enhancement is a term used to describe the analysis of mathematical functions or signals with respect to frequency and operate directly on the transform coefficients of the image, such as Fourier transform, discrete cosine transform, curvelet transform and wavelet transform. The filters in frequency domain are more effective than in spatial domain while reducing noises because it is to identify noise in frequency domain. When an image is transformed into the Fourier domain, the low frequency components usually correspond to smooth regions or blurred structures of the image, whereas high-frequency components represent image details, edges, and noises. Thus, one can design filters according to image frequency components to smooth images or remove noise.

2. Noise in Digital Images

Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera [5]. The noise in the digital medical images is due to transmission media, acquisition noise by equipment, image quantization and other organs such as body fat and breathing motion, which degrades the quality of image as a result area of interest is difficult to study. Image noise is considered as an undesirable by-product of image capture. These unwanted fluctuations are known as "noise" by analogy with unwanted sound they are inaudible .The noise has also some benefits in some applications, such as dithering [5]. The characteristics of noise depend on its source. The filter or the operator which best reduces the effect of noise also depends on the source. The types of noise are following:-

2.1 Gaussian Noise

The standard model of amplifier noise is additive, Gaussian, independent at each pixel and independent of the signal intensity [6]. Gaussian noise is statistical noise and it has its probability density function equal to that of the gaussian distribution. In other words, the values that the noise can take on are Gaussian-distributed. A special case is white Gaussian noise, in which the values at any pairs of times are statistically independent. In applications, Gaussian noise is most commonly used as additive white noise to yield additive white Gaussian noise. If the white noise sequence is a Gaussian sequence, then is called a white Gaussian noise (WGN) sequence [5]. It has a bell shaped probability distribution function given by,

$$P(z) = \frac{1}{\sqrt{2\Pi\sigma^2}} e^{\frac{-(z-m)^2}{2\sigma^2}}$$

where z represents the gray level, m is the mean of the function, and σ is the standard deviation of the noise. Practical results of adding Gaussian noise in matlab are given below.

Figure 1 Digital Image with Gaussian Noise

2.2 Salt and Pepper Noise

Salt and Pepper noise also known as an impulse noise. We can also referred it as intensity spikes. The value of these spikes can be either 0 or 1. The pixels which are corrupted are set alternatively to maximum or the minimum value which gives the image a salt and pepper like structure. The main cause of salt and pepper noise is data transmission error. As compared to additive noise this impulse noise is difficult to remove. An image containing salt-and-pepper noise will have dark pixels in bright regions and bright pixels in dark regions [7]. Along with data transmission error the Salt and Pepper noise can be caused by dead pixels, analog-to-digital converter errors etc. This noise is named for the salt and pepper appearance an image takes on after being degraded by this type of noise [6,7]. The probability distribution function for Salt and Pepper noise is given by,

$$P(z) = \begin{cases} P_a & \text{for } z=a \\ P_b & \text{for } z=b \\ 0 & \text{otherwise} \end{cases}$$

Where z represents gray level, if b>a , gray level b will appear as a light dot in the image. Conversely, level a will appear like a dark dot. Practical results of adding Gaussian noise in matlab are given below.

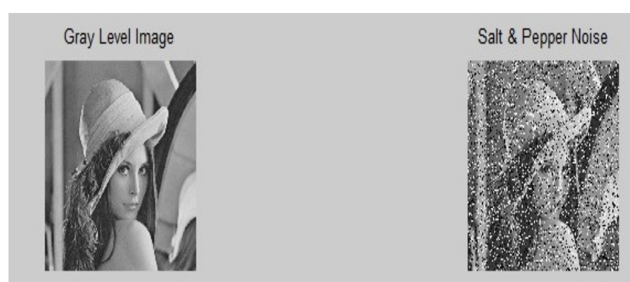

Figure 2 Digital Image With Salt and Pepper Noise

2.3 Speckle Noise

Speckle is a particular kind of noise which occurs in images obtained by coherent imaging systems like ultrasound. The coherent imaging in simple terms is lensless imaging. Speckle noise is a multiplicative noise which occurs in the coherent imaging, while other noises are additive noise. Speckle is caused by interference between coherent waves that, backscattered by natural surfaces, arrive out of phase at the sensor [7]. Speckle can be described as random multiplicative noise. This type of noise is an inherent property of medical ultrasound imaging. and because of this noise the image resolution and contrast become reduced, which effects the diagnostic value of this imaging modality. So, speckle noise reduction is an essential preprocessing step, whenever ultrasound imaging is used for medical imaging [8]. The probability distribution function for speckle noise is given by gamma distribution,

$$P(z) = \frac{z^{\alpha - 1}}{(\alpha - 1)!\,a^{\alpha}} e^{-z/a}$$

Where z represents the gray level and variance is $a^2\alpha$. Practical results of adding Gaussian noise in matlab are given below.

Figure 3 Digital Image with Speckle Noise

3. Need Of Image Enhancement

Image enhancement is subjective process of improvement and is application dependent [9[. Apart from visible region, digital images can also be created from remaining electromagnetic spectrum like x-rays, infrared rays, gamma rays etc. some of areas in which image enhancement widely used are given below.

- In atmospheric sciences, image enhancement is used to reduce the effects of haze, fog, and turbulent weather for meteorological observations. Image enhancement helps in detecting shape and structure of remote objects in environment sensing. Satellite images undergo image restoration and enhancement to remove noise.
- In Medical Diagnosis, de-noising of medical images is important because in order to get good result of diagnosis, the area of interest in digital medical images must be sharp, clear and free from noise. A medical image can be corrupted with noise during acquisition, transmission, storage and the retrieval process. Most commonly speckle noise occurs in medical images which is inherited in coherent images.
- In Study of Oceans images reveals interesting features of water flow, sediment concentration, geomorphology and bathymetric patterns to name a few. These features are more clearly observable in images that are digitally enhanced to overcome the problem of moving targets, deficiency of light and obscure surroundings.

The number of other fields including security, manufacturing, satellite images, microbiology, biomedicine, bacteriology, etc., benefit from various image enhancement techniques. These benefits are not limited to professional studies and businesses but extend to the common users who employ image enhancement to cosmetically enhance and correct their images.

4. Image Enhancement Techniques

4.1 Histogram Processing

A histogram is a chart based representation of the distribution of data. An image histogram is a representation of the number of pixels in an image as a function of their intensity. The histogram equalization technique is used to stretch the histogram of the given image in order to distribute uniformly among all intensity levels. The histogram distributed uniformly means that the contrast of the image is good [10]. In other words if the contrast of the image is to be increased then it means the histogram distribution of the corresponding image needs to be widened. Histogram equalization is the most widely used enhancement technique in digital image processing. In an image processing context, the histogram of an image normally refers to a histogram of the pixel intensity values. The histogram is a graph showing the number of pixels in an image at each different intensity value found in that image. For an 8-bit grayscale image there are 256 different possible intensities, and so the histogram will graphically display 256 numbers showing the distribution of pixels amongst those grayscale values. Several variations are made for improvement of histogram equalization based contrast enhancement which are given below.

- Brightness Preserving Bi-Histogram Equalization
- Dualistic Sub-image Histogram Equalization
- Recursive Mean-Separate Histogram Equalization

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- Mean Brightness Preserving Histogram Equalization
- Dynamic Histogram Equalization
- Brightness Preserving Dynamic Histogram Equalization

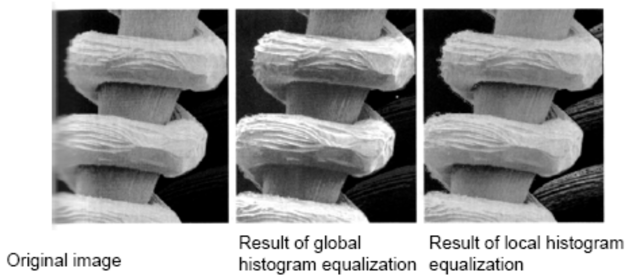

Figure 4 Histogram Processing

4.2 Log Transformation

The log transformation maps [11] a narrow range of low input grey level values into a wider range of output values. The inverse log transformation performs the opposite transformation. Log functions are particularly useful when the input grey level values may have an extremely large range of values. Sometimes the dynamic range of a processed image far exceeds the capability of the display device, in this case only the brightest parts of the images are visible on the display screen. To solve this problem an effective way to compress the dynamic range of pixel values is to use the Log Transformations, which is given by,

$$g(x,y)= c.\log(1+r)$$

where c is constant and $r \geq 0$.

This transformation maps a narrow range of low-level grey scale intensities into a wider range of output values. Inverse log transform function is used to expand the values of high pixels in an image while compressing the darker-level values. Inverse log transform function maps the wide range of high-level grey scale intensities into a narrow range of high level output values.

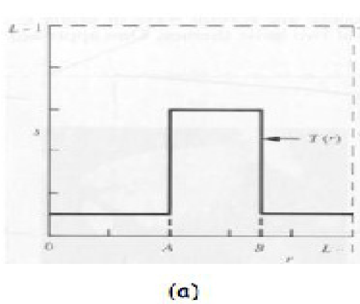

Figure 5Transformation Function

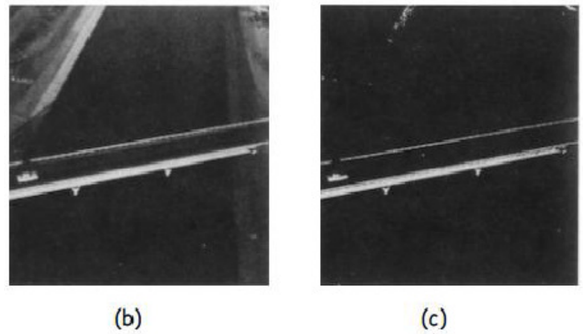

Figure 6 Original and Processed image

4.3 Thresholding Transformation

Thresholding transformations are particularly useful for segmentation in which we want to isolate an object of interest from a background [12]. Thresholding can be categorized into two main categories: global and local. Global thresholding methods choose one threshold value for the entire document image, which is often based on the estimation of the background level from the intensity histogram of the image; hence, it is considered a point processing operation. Global thresholding methods are used to automatically reduce a grey-level image to a binary image. The purpose of a global thresholding method is to automatically specify a threshold value T, where the pixel values below it are considered foreground and the values above are background.

Local adaptive thresholding uses different values for each pixel according to the local area information. Local thresholding techniques are used with document images having non-uniform background illumination or complex backgrounds, such as watermarks found in security documents if the global thresholding methods fail to separate the foreground from the background. This is due to the fact that the histogram of such images provides more than two peaks making it difficult for a global thresholding technique to separate the objects from the background, thus; local thresholding methods are the solution.

4.4 Contrast Stretching

To expand the range of brightness values in an image the contrast enhancement techniques are used, so that the image can be efficiently displayed in a manner desired by the analyst [12]. The level of contrast in an image may vary due to poor illumination or improper setting in the acquisition sensor device. Therefore, there is a need to manipulate the contrast of an image in order to compensate for difficulties in image acquisition. The idea behind contrast stretching is to increase the dynamic range of the gray levels in the image being processed. The idea is to modify the dynamic range of the grey-levels in the image. Linear Contrast Stretch is the simplest contrast stretch algorithm that stretches the pixel values of a low-contrast image or high-contrast image by extending the dynamic range across the whole image spectrum from 0 – (L-1).

4.5 Mean Filter

It is a traditional method of filtering. A mean filter [11] acts on an image by smoothing it. i.e., it reduces the variation in terms of intensity between adjacent pixels. The mean filter is used to suppress additive noise but edge preservation is not well with mean filter. The mean filter is a simple moving window spatial filter, which replaces the center value in the window with the average of all the neighboring pixel values including that centre value. It is implemented with a convolution mask, which provides a result that is a weighted sum of the values of a pixel and its neighbor pixels. It is also called a linear filter [13]. The mask or kernel is a square. Often a 3× 3 square kernel is used. If the sum of coefficients of the mask equal to one, then the average brightness of the image is not changed. If the sum of the coefficients equal to zero, then mean filter returns a dark image. Average filter method is also called neighbourhood average method. The essential idea of this method is to replace gray scale value of the centred pixel by average value of neighbourhood pixel gray scale. It is used to reduce AWGN but it can cause blurring effect. Its filter features are analyzed as follows:

Suppose the noise model for any digital image is given as

$$G(x,y) = F(x,y) + N(x,y)$$

The image after neighbourhood smoothing is

$$\hat{G}(x, y) = \frac{1}{M} \sum_{(x,y)\in S} F(x, y) + \frac{1}{M} \sum_{(x,y)\in S} N(x, y)$$

4.6 Wavelet Filter

Wavelets are simply mathematical functions and these functions analyze data according to scale or resolution. They aid in studying a signal at different resolutions or in different windows. Wavelet domain comes under non-data adaptive transform of transform domain [14]. Wavelet functions are distinguished from other transformations such as Fourier transform because they not only dissect signals into their component frequencies but also vary the scale at which the component frequencies are analyzed. A wavelet is, as the name might suggest, a little piece of a wave. The finite scale multiresolution representation of a discrete function can be known as a discrete wavelet transforms (DWT). It is a fast linear operation on a data vector, whose length is an integer power of 2. Discrete wavelet transform is invertible and orthogonal, where the inverse transform expressed as a matrix is the transpose of the transform matrix. The orthonormal basis or wavelet basis is defined as

$$\Psi_{(j,k)}(x) = 2^{j/2}\, \Psi(2^{j}x - k)$$

And the scaling function is given as

$$\Phi_{(j,k)}(x) = 2^{j/2}\, \Phi(2^{j}x - k)$$

Where is Ψ wavelet function and j and k are integers that scale and dilate the wavelet basis or function. The factor 'j' in the above equations is known as the scale index and it indicates the wavelet's width. The factor 'k' provides the position. The wavelet function is dilated by powers of two and it is translated by the integer *k*. In terms of the wavelet coefficients, the wavelet equation is

$$\Psi(x) = \sum_{k}^{n-1} g_k \sqrt{2}\Phi(2x - k)$$

Here g_0, g_1….. are high pass wavelet coefficients. These Wavelet coefficients calculated by a wavelet transform represent change in the time series at a particular resolution. By considering the time series at various resolutions, it is then possible to filter out the noise. After applying wavelet transform small coefficients are dominated by noise, while coefficients with a large absolute value carry more signal information than noise. Replacing the smallest, noisy coefficients by zero and a backwards wavelet transform on the result may lead to a reconstruction with the essential signal characteristics and with less noise [14]. So, choosing of threshold level is important task.

5. Conclusion

Image enhancement algorithms offer a wide variety of approaches for modifying images to achieve visually acceptable images. The choice of such techniques is a function of the specific task, image content, observer characteristics, and viewing conditions. The review of Image enhancement techniques in Spatial domain have been successfully accomplished and is one of the most important and difficult component of digital image processing and the results for each method are also discussed. Based on the type of image and type of noise with which it is corrupted, a slight change in individual method or combination of any methods further improves visual quality. In this survey, we focus on survey the existing techniques of image enhancement, which can be classified into two broad categories as spatial domain enhancement and Frequency domain based enhancement. We show the existing technique of image enhancement and discuss the advantages and disadvantages of these algorithms. Although we did not discuss the computational cost of enhancement algorithms it may play a critical role in choosing an algorithm for real-time applications. We also have described recent developments methods of image enhancement and point out promising directions on research for image enhancement in spatial domain for future research.

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