Image Enhancement Based on Logarithmic Transform Coefficient and Adaptive Histogram Equalization

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Abstract

This paper will present an enhancement technique based upon a new application of contrast limited adaptive histograms on transform domain coefficients called logarithmic transform coefficient adaptive histogram equalization (LTAHE). The method is based on the properties of logarithmic transform domain histogram and contrast limited adaptive histogram equalization. A measure of enhancement based on contrast measure with respect to transform will be used as a tool for evaluating the performance of the proposed enhancement technique and for finding optimal values for variables contained in the enhancement. The algorithm's performance will be compared quantitatively to classical histogram equalization using the aforementioned measure of enhancement. Experimental results will be presented to show the performance of the proposed algorithm alongside classical histogram equalization.

1. Introduction

Digital image enhancement is necessary to improve the visual appearance of the image or to provide a better transform representation for future automated image processing such as image analysis, detection, segmentation and recognition [1-2]. To discern the concealed but important information in the images, it is deemed necessary to use various image enhancement methods such as enhancing edges, emphasizing the differences, or reducing the noise [3-8]. Processing techniques for image enhancement can be classified into spatial domain enhancement and transform domain enhancement.

Linear contrast stretching and global histogram equalization are two of the most widely used non transform based uniform enhancement technique. Histogram equalization attempts to alter the spatial histogram of an image to closely match a uniform distribution. Adaptive histogram equalization [9], contrast-limited adaptive histogram equalization [10] belongs to spatially non uniform enhancement technique. Spatial domain enhancement techniques deal with the image's direct intensity values. While the spatially uniform methods use a transformation applied to all pixels of the image, the later methods use an input output transformation that varies adaptively with the local characteristics of the image. Histogram equalization suffers from the problem of being poorly suited for retaining local detail due to its global treatment of the image. Histogram equalization tends to over-enhance the image contrast if there is a high peaks in the histogram resulting in a undesired loss of visual data, of quality and of intensity scale [11-12]. Also small scale details that are often associated with the small bins of the histogram are eliminated. AHE applies locally varying gray-scale transformation on each small region of the image. This method does not completely eliminate noise enhancement in smooth regions. A survey of the spatial domain enhancement techniques can be found in [13-14].

In case of transform domain enhancement techniques, the image intensity data are mapped into a given transform domain by using transform such as 2-D discrete cosine transform (DCT), Fourier transform and other fast unitary transforms. The basic idea in using this technique is to enhance the image by manipulating the transform coefficients. One of the well-known and proven enhancement techniques is alpha rooting, which was modified later on into log-alpha-rooting, modified unsharp masking and filtering [15-21] as well as methods based on wavelet transforms [22-24]. The main disadvantage in using the alpha rooting method relates to the difficulty of selection of the value of parameter alpha. This value should be chosen in an optimal way to enhance all parts of the image very well. Transform based image enhancement techniques suffers from some disadvantages such as they introduce certain

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objectionable artifacts, they cannot simultaneously enhance all parts of the image very well and it is difficult to automate the image enhancement procedure. The other drawbacks of all of the above methods is that the brightness is changed and the enhanced images look far from natural and the extend of enhancement is not controllable.

To solve these problems transform histogram can be used [25]. This paper explains a method of image enhancement which combines adaptive histogram equalization and logarithmic transform enhancement. This method gives better performance as it combines both spatial domain and transform domain enhancement technique.

The rest of the paper is organized in the following way. In Section 2 presents necessary background. This includes discrete orthogonal transform, logarithmic transform, adaptive histogram equalization, histogram mapping and performance measure of enhancement. Section 3 discusses about the proposed method. Section 4 discusses some experimental results. Section 5 concludes the experiments and algorithm. Section 6 gives list of necessary references used.

2. Background

In this section, description about necessary background is given so that the proposed method can be understood easily.

2.1. Discrete orthogonal transforms

Orthogonal transforms are commonly used in image enhancement technique for their various properties. One of the most common properties is that orthogonal transform produces DC values in the top-left corner and high frequency content in the lower right corner. The common orthogonal transform functions those are used for image enhancement are Discrete Cosine Transform, Discrete Fourier Transform and Discrete Hartley Transform. The forward and inverse N-point 2-D Discrete cosine transform are defined as

$$y(u,v) = \frac{2}{N} C_u C_v \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} x(n,m) \cos\left[\frac{(2n+1)u\pi}{2N}\right] \cos\left[\frac{(2m+1)v\pi}{2N}\right] \cdots \quad \text{...(1)}$$

$$x(m,n) = \frac{2}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} C_u C_v y(u,v) \cos\left[\frac{(2n+1)u\pi}{2N}\right] \cos\left[\frac{(2m+1)v\pi}{2N}\right] \text{...(2)}$$

Where $C_u = C_v = \frac{1}{\sqrt{2}}$ for u=v=0, $C_u = C_v = 1$ otherwise.

n,m=0,1,…….N-1; y(u,v) is the 2-D DCT and x(m,n) is the original 2-D function.

2.2. Logarithmic transformation

Logarithmic transform helps us to show the frequency content of an image. This transformation maps a narrow range of low gray level values in the input image into a wider range of the output level. The opposite is true of higher values of input level. This type of transformation is used to expand the values of dark pixels in an image while compressing the higher level values. The log function has the important characteristic that it compresses the dynamic range of images with large variation of pixel values. However, the histogram of this data is usually compact and uninformative as shown in figure (1).

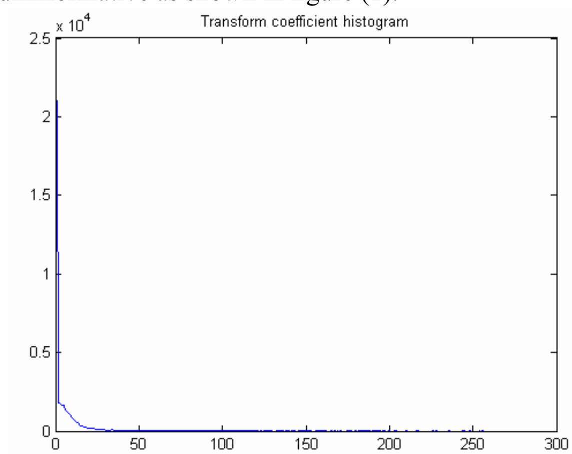

Figure 1.(a): A transform coefficient histogram

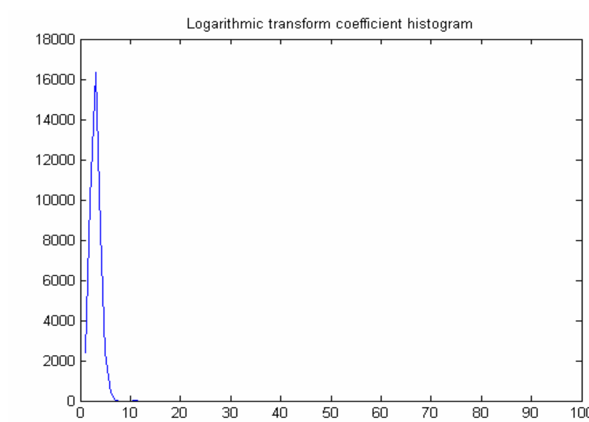

Figure 1.(b): A logarithmic transform coefficient histogram

Log transformation is done in two steps. The first step requires the creation of a matrix to preserve the phase of the transform image. This will be used later to restore the phase of the transform coefficients. In the second step logarithm is taken on the modulus of the coefficients according to the following equation.

$$\hat{X}(i,j) = \ln\left(\left|X(i,j)\right| + \lambda\right) \ldots\ldots\ldots\ldots\ldots(5)$$

where λ is a shifting coefficient, usually set to 1.

2.3. Adaptive histogram equalization

Histograms are the basis for numerous image processing techniques. Histogram equalization maps the input image's intensity values so that the histogram of the resulting image will have an approximately uniform distribution. Let the variable r represents the gray level of an image to be enhanced, T is the transformation function and s is the transformed value. Then s can be represented as

$$s = T(r) = \int_0^r p_r(w)dw \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

If p_r and p_s represents the probability density function of r and s respectively then then p_s can be obtained by applying a simple formula

$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Given a transformation function T(r) we can get p_s so that $p_s(s)$ follows almost uniform distribution which results histogram equalized image.

Histogram equalization expands dynamic range of intensity values while flatten the histogram. On many images, histogram equalization provides satisfactory results, but due to its global treatment of the image, sometimes it over enhance the image.

Adaptive histogram equalization enhances the contrast of images by transforming the values in the intensity image. Unlike histogram equalization, it operates on small data regions, rather than the entire image. The contrast transform function is calculated for each of these regions individually. The optimal size of regions depends on the type of the input image, and it is best determined through experimentation. Contrast factor prevents over-saturation of the image specifically in homogeneous areas. These areas are characterized by a high peak in the histogram of the particular image tile due to many pixels falling inside the same gray level range. The contrast of each region is enhanced, so that the histogram of the output region approximately matches the specified histogram. The neighboring tiles are then combined using bilinear interpolation in order to eliminate artificially induced boundaries. The contrast, especially in homogeneous areas, can be limited in order to avoid amplifying the noise which might be present in the image.

2.4. Histogram mapping

Histogram equalization automatically determines a transformation function that seeks to produce an output image that has a uniform distribution. Histogram mapping is a more generalized version of histogram equalization which allows us to specify the shape of the histogram that we wish the processed image to have. The method used to generate a processed image that has a specified histogram is called histogram matching or histogram specification. Let $p_r(r)$ is the probability density function of the given image and p_{z}-(z) is the specified probability density function where

$$G(z) = \int_0^z p_z(t)dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Then for histogram equalization G(z) should be equal to T(r) of equation (6) i.e. G(z)=T(r)…………....(9)

$$z = G^{-1}[T(r)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Histogram mapping method is done in three steps: 1) equalize the original image 2) histogram equalize the desired output image and 3) apply the inverse of the second transform to the original equalized image.

2.5. Performance measure of enhancement

A processed image can be said to have been enhanced over the original image if it allows the observer to better perceive the desirable information in the image. The improvement in images after enhancement is difficult to measure, and therefore difficult to specify the objective and subjective validity of enhancement method [16]. There is no universal measure which can specify both the objective and subjective validity of the enhancement method. In practice many definition of contrast measure are used [25]. For example, Gordon and Rangayan used the local contrast defined by the mean gray values in two rectangular windows centered on a current pixel. Begchladi and Negrate defined an improved version of the aforementioned measure by basing their method on local edge information of the image. It is natural to modify the Michelson and Weber contrasts in such way that they can be used as a suitable measure of the contrast in complex images. Note that Fechner's law [26] gives a relationship between brightness and light intensity which is given by the following equation.

$$B = k'\ln\left(\frac{f}{f_{\max}}\right) + k'\ln\left(\frac{f_{\max}}{f_{\min}}\right) \ldots\ldots\ldots\ldots\ldots(11)$$

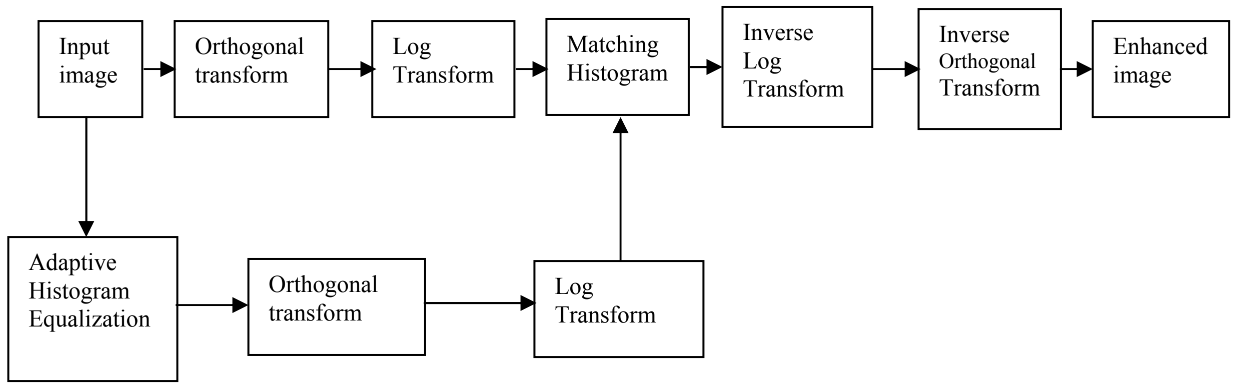

Figure 2: Block diagram of the proposed method

Where $k^{/}$ is a constant, and f_{max} and f_{min} are the maximum and minimum luminance values in a block of the image. Fechner's law provides the basis for the contrast measure based on contrast entropy. To measure the quality (or contrast) of images and select the optimal processing parameters, we use the following quantitative measure of image enhancement proposed in [16].

$$EME_{\alpha,k_1,k_2}(\Phi)=\frac{1}{k_1k_2}\sum_{l=1}^{k_1}\sum_{k=1}^{k_2}20\ln\frac{I^{w}_{\max;k,l}(\Phi,par)}{I^{w}_{\min;k,l}(\Phi,par)+c} \quad \text{....(12)}$$

Where an image x(n,m) be split into k_1k_2 blocks, Φ is a given classical orthogonal transform, α is an enhancement parameter, I^{w}max;k,l and I^{w}min;k,l are the maximum and minimum intensity value in a given block and c is a small constant equal to 0.0001 to avoid dividing by 0. $EME_{\alpha,k_1k_2}(\Phi)$ is called measure of enhancement or contrast measure with respect to transform Φ.

3. The proposed method

Transform coefficient adaptive histogram matching is a simple and effective procedure of image enhancement. Here we use adaptive histogram equalization as a baseline to enhance the given image. Figure (2) shows the block diagram of our proposed method. This method uses the following steps.

The first step of this method is to take an image and apply orthogonal transform like DCT, Fourier or cosine transform which involve mapping the intensity data into the given transform.

In the second step logarithmic transformation is applied on the magnitude of orthogonal transformed values which compresses the dynamic range and makes the histogram informative. In this step the phase of the transformed image is preserved by creating a matrix which will be used later to restore the phase of the transform coefficients.

In parallel with this, we use adaptive histogram equalization of the original image. This is operated on small data regions and the contrast transform function is calculated for each of these regions individually as described in section 2.3.

Orthogonal transform is applied to the adaptively histogram equalized image.

Log transform is applied to the magnitude of orthogonal transformed values.

In this step we need to match the transformed data of the original image to the transformed data of adaptively histogram equalized image by using histogram mapping.

Then the matched data are exponentiated and previously separated phase is restored.

In the last step inverse orthogonal transform is applied which gives the output enhanced image.

By mapping the image to the adaptively equalized histogram and returning the data to the spatial domain, the dynamic range of the image has been expanded, improving contrast and enhancing details throughout.

4. Experimental results

We have proposed a method of image enhancement where transform domain is combined with adaptive histogram equalization. This method proved a powerful and fast method for image enhancement. This method was investigated to show the performance of transform domain adaptive histogram enhancement compared to only histogram equalization technique. For this purpose three images are shown in figure (3), figure (4) and figure (5) respectively..

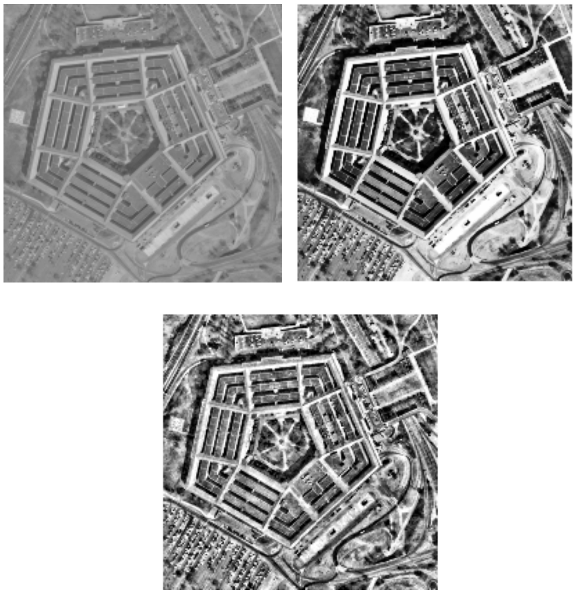

Figure 3: Original, histogram equalized and logarithmic transform coefficient adaptive histogram equalized pentagon image.

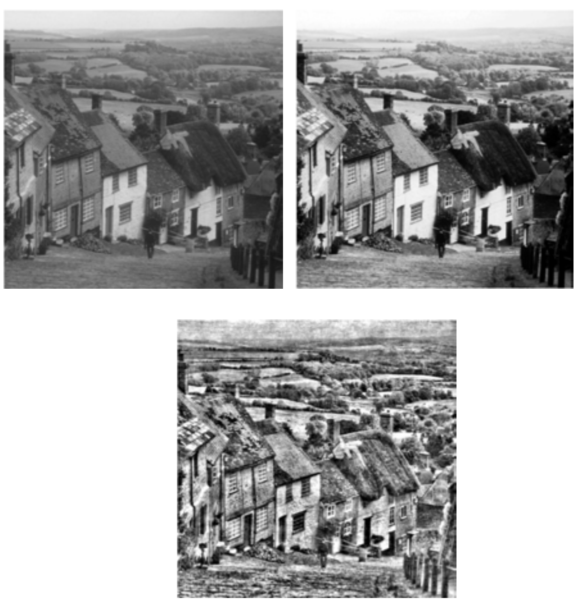

Figure 4: Original, histogram equalized and logarithmic transform coefficient adaptive histogram equalized image respectively.

Figure 5: Original, histogram equalized and logarithmic transform coefficient adaptive histogram equalized image respectively.

Table (1) shows the numerical results of the proposed method and histogram equalization with respect to EME using some test images.

Table 1. Comparison EME of original image, histogram equalized image and LTAHE image

Image	**Original**	**HE**	**LTAHE**
pentagon	4.3252	90.1316	122.5339
Image 2	15.8936	62.91	150.888
Image 3	37.2485	74.52	121.43

Investigating the figures (3), (4) and (5) respectively it can be seen that the proposed method gives better visual quality than general histogram equalization technique.

Investing table (1) it can be observed that the original pentagon image has vary low EME value of 4.4352. After applying our algorithm to the image the EME has risen to122.5, which is a drastic improvement from the low EME value of the original image. Compared to straight histogram equalization, which caused artifacts and an EME of 90.13, LTAHE enhanced the image better and avoided the undesirable side effects.

From table (1) it can also be observed that original image 2 has EME value of 15.8. After histogram equalization EME becomes 62.9 Using the proposed method EME increase to 150. This method also shows improved performance for image 3.

From table (1) and figure(3), (4) , (5) respectively it can be observed that the proposed method gives much impressive performance in the field of image enhancement.

5. Conclusion

This paper proposed a method of image enhancement based upon the logarithmic transform coefficient adaptive histogram equalization using EME as a measure of performance. The performance of this algorithm was compared to a classical histogram equalization enhancement technique.

LTAHE has been shown to be a powerful method for enhancing images. This method has advantage of being quick making it simple based on transform adaptive histogram. The results of this technique shows outperform from commonly used enhancement technique like histogram equalization.

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