

Transform Coefficient Histogram and Edge Preserving Image Enhancement Using Contrast Entropy

K. Sundar Srinivas¹, K. Naga Lakshmi Kalyani²

¹M.Tech, Dept. of ECE, Nova College of Engineering & Technology, A.P., India.

²Asst.Professor, Dept. of ECE, Potti Sriramulu College of Engineering & Technology, A.P., India.

sundar_srinivas@yahoo.co.in

Abstract

Enhancing an image in such a way that maintains image edges is a difficult problem. Many current methods for image enhancement either smooth edges on a small scale while improving contrast on a global scale or enhance edges on a large scale while amplifying noise on a small scale. Many applications of histograms for the purposes of image processing are well known. However, applying this process to the transform domain by way of a transform coefficient histogram has not yet been fully explored. This paper proposes three methods of image enhancement: a) logarithmic transform histogram matching, b) logarithmic transform histogram shifting, and c) logarithmic transform histogram shaping using Gaussian distributions. They are based on the properties of the logarithmic transform domain histogram and histogram equalization. The presented algorithms use the fact that the relationship between stimulus and perception is logarithmic and afford a marriage between enhancement qualities and computational efficiency. A human visual system based quantitative measurement of image contrast improvement is also defined. This helps choose the best parameters and transform for each enhancement. A number of experimental results are presented to illustrate the performance of the proposed algorithms.

Keywords— Transform Histogram, Contrast Entropy, Image Enhancement, Contrast Measure, Discrete transform (DCT, DFT), human vision system.

1. Introduction

Producing digital images with good contrast and detail is a strong requirement in several areas including vision, remote sensing, biomedical image analysis, and fault detection. Producing visually natural images or transforming the image such as to

enhance the visual information within is a primary requirement for almost all vision and image processing tasks. Methods that implement such transformations are called image enhancement techniques [1][2]. The task of image enhancement is a difficult one considering the fact that there is no general unifying theory of image enhancement at present, because there is no general standard of image quality that can serve as a design criterion for an image enhancement processor [3]. Developing image enhancement methods which maintain or improve image edges is a difficult problem. Many commonly used state-of-the-art image enhancement methods currently enhance contrast on a large scale while smoothing edges on a small scale or enhance edges on a large scale while amplifying noise on a small scale. The goal of image enhancement techniques is to improve a characteristic or quality of an image, such that the resulting image is better than the original, when compared against specific criteria [4]. Current research in image enhancement covers such wide topics as algorithms based on the human visual system [5], histograms with hue preservation [6], JPEG based enhancement for the visually impaired [7], and histogram modification techniques [8]. Two major classifications of image enhancement techniques can be defined: spatial domain enhancement and transform domain enhancement.

Spatial domain enhancement techniques deal with the image's direct intensity values. A common non-transform based enhancement technique is global histogram equalization, which attempts to alter the spatial histogram of an image to closely match a uniform distribution. Histogram equalization suffers from the problem of being poorly suited for retaining local detail due to its global treatment of the image. It is also common that the equalization will over enhance the image, resulting in an undesired loss of visual data, of quality, and of intensity scale.

The basic limitations of the transform based image enhancement methods are: 1) they introduce certain artifacts which Aghagolzadeh and Ersoy called "objectionable blocking effects"; 2) they cannot simultaneously enhance all parts of the image very well; 3) it is difficult to automate the image enhancement procedure. Both of these methods have their merits and their shortcomings, given their differing interpretations of image data. It then becomes obvious to ask the question: is it possible to develop a new method, which has the best properties from both transform and spatial domain techniques? For example, is there a way of somehow combining histogram equalization and transform enhancement? The answer: yes, using transform histograms, which have, as of yet, been mostly unexplored.

2. Background

In this section, we will cover the background topics necessary to understand the proposed methods. An explanation of histogram equalization and of histogram mapping will be given, followed by a definition of various discrete orthogonal transforms. Alpha-rooting will be presented next, followed by an explanation of the logarithmic transform domain. Finally, our measure of enhancement will be introduced along with methodology for choosing optimal parameters, transforms, measures, and methods.

A. Histogram Equalization

Histogram equalization maps the input image's intensity values so that the histogram of the resulting image will have an approximately uniform distribution [16][25]. Given an image $A(x,y)$ and a desired output image $B(x,y)$ there is some transformation function, f , which maps A to B . All

intensity values in A in the region of values n_A to $n_A + dn_A$ will have their values mapped to a corresponding region in B in the values range of n_B to $n_B + dn_B$. Each of these images will have a probability density function (PDF) $p_A(n_A)$ and $p_B(n_B)$. Assuming a 1-1 mapping, it is easy to show that

$$p_B(n_B)dn_B = p_A(n_A)dn_A$$

Using this relationship, it can be shown that the mapping function from A to B is

$$f(n_A) = n \int_0^{n_A} p_A(u)du = nF_A(n_A)$$

Where $F_A(n_A)$ is the cumulative probability distribution function of the original image. Therefore, to return a histogram equalized image, an image must be transformed using its cumulative probability function. The primary reason for histogram equalizations success at image enhancement is because it expands the dynamic range of intensity values while flattening the histogram.

B. Histogram Mapping

Histogram mapping, a more generalized version of histogram equalization, allows us to alter the data so that the resulting histogram matches some desired curve. This is also known as histogram matching and histogram specification [9]. In our case we will use the example of transforming a random exponential PDF to a hyperbolization of our original histogram, effectively mapping the histogram of the data to match our desired PDF. The heart of histogram mapping lies at solving an equation that compares the integrals of the probability density function, basically comparing their cumulative density functions.

$$\int_0^{n_B} p_B(y)dy = \int_0^{n_A} p_A(x)dx$$

Where, $P_B(n_B)$ is our desired hyperbolization of our histogram, and $P_A(n_A)$ is our original histogram, which we will approximate as an exponential.

$$p_A(n_A) = A_0 e^{-n_A}, \quad p_B(n_B) = B_0 n_B e^{-n_B^2}$$

Plugging into the integral equation and solving we get:

$$B_0 \int_0^{n_B} y e^{-y^2} dy = A_0 \int_0^{n_A} e^{-x} dx$$

$$B_0 \left(\frac{1 - e^{-n_B^2}}{2} \right) = A_0 (1 - e^{-n_A})$$

$$n_B = \sqrt{-\ln \left(1 - \frac{2A_0}{B_0} (1 - e^{-n_A}) \right)}$$

The resulting equation is the transformation of an exponential distribution to a hyperbolization of that histogram. A common implementation of this general histogram mapping method is done in three steps: 1) equalizing the original image, 2) histogram equalize

the desired output image, 3) and apply the inverse of the second transformation to the original equalized image.

$$T_1 = F_A(n_A) = \int_0^{n_A} p_A(y) dy$$

$$T_2 = F_B(n_B) = \int_0^{n_B} p_B(x) dx$$

$$T = T_2^{-1}(T_1(n_A))$$

Therefore, the algorithm we use attempts to minimize a cost function to keep the results as close as possible to a desired result. The cost function is defined below.

$$\text{cost} = |c_1(T(k)) - c_0(k)|$$

where c_0 is the cumulative histogram of the original image and c_1 is the cumulative histogram of the desired histogram.

3. Low Curvature Image Simplifier

The importance of multi-scale descriptions of images has been recognized from the early days of computer vision. Witkin first introduced this idea in, where he iteratively processed an image with a low pass Gaussian kernel, obtaining smoother and smoother images. The goal behind this was to represent an image as a collection of scales, where one can use the later scales to identify the overall image objects and regions, and then use the earlier scales to determine more detailed image information. One issue with this, however, was that the Gaussian kernel does not consider the natural image boundaries, blurring everything in the image in the same manner. This damaged image boundaries, making it difficult to segment the later scales.

It was later shown by Koenderink and Hummel that this process was a solution to the heat diffusion equation. As such, anisotropic diffusion was proposed by Perona and Malik to produce a multi-scale description of images with better regard for image edges. In this manner, one can have an image with smooth regions but sharp edges between the regions. This can result in a common problem known as "staircasing", however, which occurs when an area with steady gradient is represented as a series of level steps.

The low curvature image simplifier (LCIS) is one of many modified anisotropic diffusion methods [10] designed to address these issues. It uses a different method of calculating the conductance values in order to achieve steady ramps where necessary and sharp edges where necessary, while still smoothing inside the regions of the image. The LCIS method can be summarized with the block diagram in figure 3, and the equations are summarized afterward.

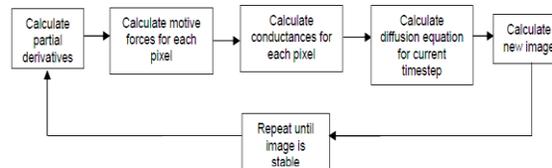


Fig. 3. Block Diagram for the LCIS method

Developing enhancement algorithms which are able to effectively preserve edges while improving contrast is a difficult problem. Many spatial enhancement methods like diffusion enhance contrast on the large scale while blurring edges on the small scale, whereas many frequency methods such as unsharp masking and alpha rooting enhance edges on the large scale while amplifying noise on the small scale.

In an enhancement algorithm based upon the LCIS method was introduced to attempt to enhance image contrast while maintaining sharp edges and avoiding noise. This method makes use of the system diagram where the enhancement blocks utilize linear scaling. Effectively, the range of the smooth image output by the LCIS method was compressed with regard to the difference image, and the two images were then recombined. However, the only enhancement method considered was this scaling. By utilizing other enhancement algorithms, this diffusion based enhancement method can be improved.

3.1. Alpha Rooting

Alpha rooting is a transform based enhancement algorithm. It works by performing some orthogonal transform, such as the Fourier Transform; modifying the coefficients with the phase kept invariant, and performing the inverse transform. The coefficient magnitudes are modified as follows:

$$O(p,s) = X(p,s) \times |X(p,s)|^{\alpha-1}$$

Where $O(p,s)$ is the 2-D Fourier Transform of the output image, $X(p,s)$ is the 2-D Fourier transform of

the input image, and the range of alpha is $0 \leq \alpha \leq 1$. As alpha rooting reduces the magnitude of the transform coefficients, it naturally compresses the range of an image. Also, as the phase data remains unchanged, image edges are preserved. Because of this, it is understandable that this would be used to process the smoothed image.

3.2. Logarithmic Transform Coefficient Histogram Shifting

Logarithmic Transform Shifting (LTS) is a logarithm domain enhancement. It works by taking some orthogonal transform, such as the Fourier Transform, then taking the Logarithmic Transform of these coefficients, and modifies the Logarithmic Transform coefficients. The LTS algorithm is performed by taking the histogram of the Logarithmic Transform coefficients and applying a shift in the positive direction. LTS applies a shift in the logarithmic domain, which results in a relatively larger shift for larger coefficients when compared to smaller coefficients. In this way, the most important frequencies are emphasized with regard to the less important frequencies.

3.3. Edge Preserving Image Enhancement

To summarize the proposed method, we build on the enhancement method proposed in to obtain a straightforward and effective enhancement method which preserves edges while improving contrast and correcting for difficult to see image regions. We utilize the LCIS method to achieve anisotropic diffusion, resulting in a smoothed image with crisp edges. we calculate the difference image based upon this smoothed image and the original image.

4. Conclusion

The application of histograms to transform coefficients is a relatively new concept. In this work, we have developed and presented three methods of contrast enhancement based upon the properties of the logarithmic transform coefficient histogram using contrast entropy as a measure of performance and optimization. The performance of these algorithms was compared to two popular enhancement techniques: histogram equalization and alpha-rooting. This paper also introduced a variety of measures of contrast enhancement. The first method was the logarithmic transform histogram matching with equalization algorithm. Logarithmic transform histogram matching was demonstrated to show an algorithm that mimics the ability of histogram

equalization without suffering from the side effects of an over expansion of the dynamic range. This method has the distinct advantage of being incredibly quick with no built in recursion making it a simple and fast solution for image enhancement based on the transform histogram. Logarithmic transform histogram shifting has been shown to be a powerful method for enhancing images. It also affords a relatively simple and quick implementation that our results have shown to outperform popular enhancement techniques, such as histogram equalization and alpha-rooting, both visually and numerically

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AUTHORS PROFILE



K. Sundar Srinivas pursuing his M.Tech(ECE) specialization in Embedded Systems at Nova College of Engineering & Technology, under the guidance of K. Naga Lakshmi Kalyani, Asst.Professor, Dept. of ECE, at Potti Sriramulu College of Engineering & Technology, Affiliated to JNTUK, Kakinada, A.P., India. My research Interests includes Embedded Systems and Digital Signal Processing.



K. Naga Lakshmi Kalyani working as Asst. Professor, Department of Electronics and Communication Engineering at Potti Sriramulu College of Engineering & Technology, Affiliated to JNTUK, Kakinada, A.P., India. My research interests includes Embedded Systems, Communications Systems and Digital Signal Processing.