NONLINEAR IMAGE CONTRAST ENHANCEMENT BASED ON MUNSELL'S SCALE

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ABSTRACT

Contrast is a measure of the variation in intensity or gray value in a specified region of an image. The region can be most or all of the image, giving rise to a global concept of contrast. The region might, on the other hand, be a small window in which case the concept of contrast is a locally defined expression. In this work, we introduce a nonlinear local contrast enhancement method. This method utilizes the Munsell Value scale which is based upon human visual perception. Use of the Munsell Value scale allows for the partitioning of the gray scale into ten discrete subintervals. A contrast enhancement function then thresholds the gray values in a subinterval in a smooth manner about a locally computed quantity called the mean edge gray value. By enhancing the contrast in this way the original shades of gray are preserved tuned to human perception.

1. INTRODUCTION

Contrast is a measure of the variation in intensity or gray value in a specified region of an image. The region can be a small window in which case the concept of contrast is localized. The region might, on the other hand, be most or all of the image giving rise to a global concept of contrast. Typically in contrast enhancement, however, one is concerned with the difference of gray values within small windows and not over the entire image. Local methods of contrast enhancement will therefore detect and enhance changes in gray values occurring in small regions or windows of an image. For this reason, in applications, local methods and locally-defined contrast are more often of interest.

There are two basic types of contrast enhancement techniques, the indirect method and the direct method of contrast enhancement as defined by Dash and Chatterji [2]. In the indirect method, the contrast is enhanced without the computation and utilization of a quantitative measure of contrast [14] [12]. Examples of the indirect method are background subtraction [5], functional mapping of the gray scale using some linear or nonlinear function [5] [12], histogram equalization [6], histogram hyperbolization [4], iterative histogram thinning [13] [11], fuzzy contrast intensification [10], and transform amplitude sharpening [9]. In the direct method, a quantitative measure of contrast is calculated and used. Examples of this method can be found in the works by Kim [7], Gordon [3], and Beghdadi and Le Negrate [1].

Our approach uses ideas from both the direct and indirect methods. As in the direct method we compute a measure of contrast. However, unlike the direct method, we do not use this measure to directly enhance the contrast of an image. Similar to some applications of the direct method, we compute a mean edge gray value. We also utilize a nonlinear gray value- mapping function which is a concept from the indirect method.

Considering the direct method and being concerned with a local method of contrast enhancement, we compute a local measure of contrast in a neighborhood of a pixel located at coordinates (i,j) as

$$C_{ij} = \frac{|x_{ij} - \overline{E}_{ij}|}{x_{ij} + \overline{E}_{ij}} \tag{1}$$

where x_{ij} is the gray value associated with the pixel at (i,j), and $\overline{E}_{ij}$ is the associated mean edge gray value which will be defined below. In this application, we used a 3x3 neighborhood to compute C_{ij}. A larger size neighborhood would make the local contrast and the mean edge gray value (which will be computed below) less sensitive to noise. However, a larger size window would also result in a loss of fine details (small changes in these quantities). Clearly, C_{ij} is a real number lying in the unit interval. We have borrowed this measure of local contrast as well as the concept of a mean edge gray value from a paper by Beghdadi and Le Negrate [1].

Let us focus on the numerator of the expression for the local contrast. The numerator represents the unnormalized local contrast. Intuitively, it is just a difference (or distance) between two gray values, the gray value at (i,j) and its associated mean edge gray value. the numerator This interpretation will be useful later in providing insight into the operation of the contrast enhancement method.

Now, the mean edge gray value which figures prominently

*This work was supported in part by the NSF Grant CCR-9704262, (Corresponding author; e-mail:rui@uci.edu)

in the computation of the local contrast is defined in a neighborhood, N_{ij} of a pixel at (i,j) as

$$\overline{E}_{ij} = \frac{\sum_{(k,l)\in N_{ij}} \Delta_{kl} x_{kl}}{\sum_{(k,l)\in N_{ij}} \Delta_{kl}} \tag{2}$$

where Δ_{kl} is the edge value (computed using Sobel operators [5]) associated with the pixel at (k,l), and x_{kl} is the gray value of the pixel at (k,l).

The expression in equation (2) states that the mean edge gray value is the average of the pixel gray values weighted by their edge values. It is also the mean gray value of pixels located on object boundaries. For pixels that are are some distance away from the object boundary, the edge values are low, and consequently the sum of the gray values weighted by the edge values is also low. For pixels that are near an object boundary, the edge values are high, and thus the sum of the gray values weighted by their edge values is also high. Now, in a region of constant intensity, the edge values will be zero, and consequently the mean edge gray value will be the indeterminate $\frac{0}{0}$. The indeterminate is resolved (through the application of L'Hôpital's rule) by setting the mean edge gray value equal to the original constant intensity of the current neighborhood. This yields zero contrast which is the contrast in regions of constant intensity.

2. A NEW METHOD FOR CONTRAST SHARPENING

Based on the principles outlined earlier, we introduce here a new method for contrast enhancement [8]. Now, since pixel intensity is given by I = RL, where I is intensity, R is reflectance, and L is illumination, intensity is proportional to reflectance. As a consequence, if we assume a constant level of illumination, the measured reflectances mentioned in the previous chapter can be mapped to intensity values from 0 to 255. This is done by mapping the reflectance corresponding to a Value of 10 to 255 and mapping all other reflectances in a corresponding linear manner, producing a partition of [0,255] into ten subintervals in the process. Reflectances computed from equation (14) need to be multiplied by 255/0.995 = 256.305 to map them to intensity values. The contrast enhancement algorithm described here utilizes reflectance values calculated from equation (14) to partition the interval into ten subintervals: [0,3], (3,8], (8,16], (16,30], (30,49], (49,75], (75,107], (107,147], (147,196], and (196,255].

The new contrast enhancement method takes the ten subintervals and thresholds the gray (intensity) values in each subinterval by utilizing the mean edge gray value (computed by using a 3x3 neighborhood of the pixel) associated with each pixel as the threshold value. If the gray value of a pixel is less than or equal to its associated mean edge gray value, then the output gray value is the lower endpoint of that subinterval. If the gray value is greater than its associated mean edge gray value, or if the gray value is simultaneously equal to the mean edge gray value and the upper endpoint of the subinterval, then the output gray value is the upper endpoint of that subinterval. Thus, for a pixel at (i,j) with gray value x_{ij} in the subinterval [a,b] and corresponding mean edge gray value E_{ij}, the input-output map is given by

$$f(x_{ij}) = \begin{cases} a, & x_{ij} \le \overline{E}_{ij} \\ b, & x_{ij} > \overline{E}_{ij}, \text{ or } x_{ij} = \overline{E}_{ij} = b \end{cases} \tag{3}$$

Maximum contrast enhancement in all regions occurs when the enhanced gray value is selected to be a maximum distance away from the mean edge gray value. The simple contrast enhancement function defined in equation (15) accomplishes this by setting the output gray value to be either the upper or lower endpoint of the subinterval containing the corresponding original gray value. There is an inherent problem, though, with the simple threshold function that will be discussed in the next subsection. For this reason, a contrast enhancement function needs to be carefully chosen.

2.1. The Proper Selection of a Contrast Enhancement Function

An undesirable outcome of the use of the threshold step function is the reduction in the number of gray values from 256 to 11. This leads to a loss of information and detail in the output image and causes jagged edges. A jagged edge is characterized by several discontinuous line segments, whereas a normal non-jagged edge consists of a straight line segment or a continuous curve.

What is needed is a function that smoothly approximates the step function and passes through the points (a,a), (E,E), and (b,b), where a is the lower endpoint of the subinterval [a,b], E is the mean edge gray value associated with a given pixel, and b is the upper endpoint of the subinterval [a,b]. In addition, this function should have zero slope at the subinterval endpoints. This requirement causes the contrast enhancement function to have a shape that will provide good enhancement for pixels whose gray values are some distance away from the mean edge gray value. It also insures that contrast enhancement functions on successive subintervals join in a smooth fashion. As a consequence, the smooth connection of contrast enhancement functions defined on the ten subintervals forms a smooth approximation to the staircase function consisting of threshold step functions defined on the ten subintervals.

After setting up and solving an appropriate isoperimetric problem [8], the contrast enhancement function is found to have the following form:

$$f(x) = \begin{cases} E - \sqrt{(E-a)^2 - (x-a)^2}, & x \le E \\ E + \sqrt{(b-E)^2 - (x-b)^2}, & x > E \end{cases} \tag{4}$$

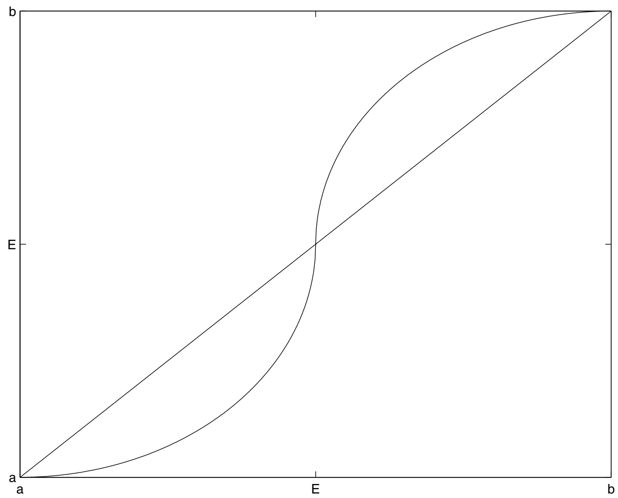

Figure 1: Plot of the Two Quarter-Circle Functions

Figure 1 shows a plot of the contrast enhancement function consisting of two quarter-circle functions, as well as the identity function, i(x) = x. This curve will be symmetric about E as shown only if E is the midpoint of the subinterval [a,b]. Contrast enhancement occurs when the contrast enhancement function deviates from the identity function. That is, enhancement occurs when the portion of the contrast enhancement function defined on [a,E] is less than the identity function or when the portion of the contrast enhancement function defined on [E,b] is greater than the identity function.

2.2. Experimental Results

Figures 2 and 3 show the results of applying the contrast enhancement technique to a blurred image of a house. The input image was blurred by convolving the image with a 5x5 lowpass filter. The initial mean contrast of the image in figure 2 is 0.0399. The enhanced mean contrast of the image in figure 3 is 0.0768.

Figure 2: Blurred Input Image

Figure 3: Result After Applying Contrast Enhancement Method

3. CONCLUSIONS

A new method for the contrast enhancement of gray scale images has been presented. This technique utilizes the novel concept of gray scale partitioning which makes use of the Munsell Value scale and is based upon human visual perception. Gray scale partitioning involves a two-step process. First, the reflectances of a set of gray chips are measured and used to construct a Value (intensity) scale. A functional relationship is established between Value and reflectance. Then, given the ten Values and the equation relating Value and reflectance, one can reconstruct the set of measured reflectances. Second, the reflectances are then mapped into intensity values (assuming a constant level of illumination). These intensity values form the endpoints of subintervals, thereby partitioning the gray scale into ten subintervals in the process. Once the subintervals have been determined, processing occurs in the subinterval in which the gray value associated with a given pixel lies.

This method determines the enhanced gray value associated with a pixel by applying a suitable contrast enhancement function to the corresponding original gray value. This function smoothly thresholds the gray values about the mean edge gray value. As a consequence, this function must be monotonically increasing. In addition, it must be a smooth approximation to the discontinuous threshold step function. Finally, it must have zero slope at the subinterval endpoints. This forces the contrast enhancement function to have a shape that will produce good enhancement for pixels whose gray values are some distance away from the mean edge gray value. It also insures that contrast enhancement functions on successive subintervals join in a smooth fashion. As a consequence, the smooth connection of contrast enhancement functions defined on the ten subintervals forms a smooth approximation to the staircase function consisting of threshold step functions defined on the ten subintervals.

The best function (in the sense of providing the highest degree of contrast) has infinite slope at the mean edge gray value, E. The effect of this is that for $x < E$ and x in a neighborhood of E, f(x) increases very rapidly up to E. For $x >$

E and x in a neighborhood of E, f(x) increases very rapidly away from E.

By using the isoperimetric problem from the calculus of variations along with appropriate endpoint conditions (fixed points at the subinterval endpoints and infinite slope at the mean edge gray value), we found the optimal contrast enhancement function to be a function consisting of two quarter-circles, one defined on [a,E] and the other defined on [E,b]. This function has the desired properties; it is monotonic increasing, has zero slope at a and b, and has fixed points at a, E, and b. Also this function possesses the properties that for a gray value, x, with $x \leq E$, $f(x) < x$ and for $x > E$, $f(x) > x$. In addition, this function has an infinite slope at E.

Since our contrast enhancement function maps each subinterval into itself, it enhances the contrast while preserving the original shades of gray. That is, the clustering of gray values by subinterval is preserved. As a result, no gray value distortion is introduced into the image, while the contrast is tuned to human visual perception.

4. REFERENCES

[1] Beghdadi, A. and A. Le Negrate, "Contrast Enhancement Technique Based on Local Detection of Edges", *Computer Vision, Graphics, and Image Processing*, Vol. 46, pp. 162-174, 1989.

[2] Dash, L. and B.N. Chatterji, " Adaptive Contrast Enhancement and De-enhancement", *Pattern Recognition*, Vol. 24, No. 4, pp. 289-302, 1991.

[3] Dhawan, A.P, G. Buelloni, and R. Gordon, " Enhancement of Mammographic Features by Optimal Adaptive Neighborhood Image Processing", *IEEE Transactions on Medical Imaging*, Vol. MI-5, No. 1, pp 8-15, March 1986.

[4] Frei, W., "Image Enhancement by Histogram Hyperbolization", *Computer Graphics and Image Processing*, Vol. 6, pp. 286-294, 1977.

[5] Gonzalez, R.C. and P. Wintz, *Digital Image Processing*, Addison Wesley, Reading, Massachusetts, 1987.

[6] Hummel, R., "Image Enhancement by Histogram Transformation", *Computer Graphics and Image Processing*, Vol. 24, pp. 363-381, 1983.

[7] Kim, V. and L. Yaroslavaski, "Rank Algorithms for Picture Processing", *Computer Vision, Graphics, and Image Processing*, Vol. 35, pp. 234-258, 1986.

[8] Matz, Sean C., and Rui J.P. de Figueiredo, "A Nonlinear Image Contrast Sharpening Approach Based on Munsell's Scale", *To appear in the IEEE Transactions on Image Processing*

[9] Mitra, S. and T. Yu, "Transform Amplitude Sharpening: A New Method of Image Enhancement", *Computer Vision, Graphics, and Image Processing*, Vol. 40, pp. 205-218, 1987.

[10] Pal, S. and R. King, "Image Enhancement Using Fuzzy Sets", *Electronics Letters*, Vol. 16, pp. 376-378, 1980.

[11] Peleg, S., "Iterative Histogram Modification, 2", *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 8, pp. 555-556, 1978.

[12] Pratt, William K., *Digital Image Processing*, John Wiley & Sons, Inc., New York, 1991.

[13] Rosenfeld, A. and L. Davis, "Iterative Histogram Modification", *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 8, pp. 300-302, 1978.

[14] Rosenfeld, A. and A. Kak, (Eds.), *Digital Picture Processing*, Academic Press, New York/London, 1982.