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SOME ALGORITHMS FOR IMAGE ENHANCEMENT INCORPORATING HUMAN VISUAL RESPONSE

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Abstract—Any image processing technique which is used to improve the appearance of an image for human perception or machine analysis should incorporate the characteristics of the human visual system. One of the major characteristics of the human visual system is the logarithmic response to light intensity, which we have attempted to include in this paper. Some new algorithms for image enhancement, edge detection and smoothing have been described and their results are presented. Only the edge detection technique is space-variant. All the techniques are simple and economical, and can be supplied to each pixel in parallel.

Image processing Human visual system Logarithmic response Enhancement
Edge detection Noise smoothing

I. INTRODUCTION

Image enhancement is an attempt to improve the appearance of an image for recognition or further processing. Image quality is studied in a variety of ways, depending on the type of the image. The various methods used in image enhancement are rather loosely structured, because in many cases it is difficult to find a universally acceptable criterion for optimisation. However, attempts have been made to study the problem in a systematic manner and the literature on the subject is rather rich.[1,2]

Enhancement usually concerns contrast stretching, smoothing, sharpening and pseudo-coloring. An offshoot of the process is edge or region detection and segmentation, which is very useful in automatic recognition and description of the picture. The tasks are done either by frequency or spatial domain techniques. The choice of technique depends mainly on the problem and processing cost, convenience and fidelity. The popular technique for contrast stretching is histogram modification.[1–3] Smoothing and sharpening are done, respectively, by low-pass and high-pass filtering in the frequency domain, while integration and differentiation are the respective standard techniques in the spatial domain. Sometimes referred to as spatial filters, the techniques have different variations, such as mean filter and median filter. Standard deviation over a certain type of mask has also been used.[4] The differentiation in the discrete domain has different approximations, such as the Robert gradient[5], and higher order differentiation, such as Laplacian, is also popular.

In almost all the tasks stated for enhancement as well as for edge detection and segmentation, some form of thresholding is necessary. The threshold depends on the nature of the picture and the kind of enhancement to be done. Some optimum thresholding are discussed in literature.[6–8] Iterative techniques[9,10] have better flexibility in man–machine interaction, while multiple objective approaches[11] have greater versatility.

When the objective of enhancement is human or machine recognition of objects in images, it is legitimate to expect in any technique the inclusion of a component that takes care of the human visual response.[12,13] One of the major characteristics of the human visual system is the logarithmic response to light intensity that seems to be neglected in the literature. The present work is an attempt to include it in image processing problems.

The problems of contrast magnification, edge detection and noise smoothing have been formulated in Section II. In all cases the logarithmic response has been included. While the histogram modification and edge detection are non-statistical, statistical property has been used in smoothing. The smoothing technique is new and its apparent similarity to that in Nagao and Matsuyama[4] can be discriminated by noting that Nagao and Matsuyama is a special case of the present method. The formulations can be used iteratively and hierarchically and, hence, are flexible in man–machine interaction. Illustrative examples are given for each case in Section III and the results are compared with those obtained using existing standard methods.

II. PROBLEM FORMULATION

The basis of the logarithmic response of the human visual system is that the visual detectability depends on the ratio, rather than the difference, between intensities I and $I + \Delta I$, where ΔI is the just noticeable difference in intensity. The response curve is reasonably linear over the workable range. In the following subsections, the problems have been formulated using this property.

A. *Histogram modification*

Let the imaging system be space-invariant. Then a gray scale transformation must have the same form at every position of the picture. The transformation, expressed as a mapping

$$Z' = \xi(Z)$$

from gray level Z to Z', can be used for histogram modification.

To incorporate human visual response we assume the boundary conditions

$$GL \leq Z_i \leq GH$$

$$DL \leq Z'_i \leq DH$$

where DL and DH are the respective lower and upper limit of the dynamic range of discrete gray level accepted in visual system, while GL and GH are the respective lower and upper limit of the discrete gray level present in the original image. Z_i and Z'_i are the intensities at the ith level in the original and transformed images. It is assumed that both the old and new gray scales are in the allowable range of gray levels, i.e. from the scotopic threshold to the glare limit. Assuming $I \equiv Z'_i$ and $I + \Delta I \equiv Z'_{i+1}$, we may write

$$\frac{Z'_2}{Z'_1} = \frac{Z'_3}{Z'_2} = \ldots = \frac{Z'_m}{Z'_{m-1}} = K \quad \text{(say)}$$

where $m = GH - GL + 1$. Then we get

$$K^{GH-GL} = \frac{Z'_m}{Z'_1} = \frac{DH}{DL},$$

i.e.

$$K = \left(\frac{DH}{DL}\right)^{\frac{1}{GH-GL}}.$$

From which it follows that

$$Z'_i = DL\left(\frac{DH}{DL}\right)^{\frac{Z_i - GL}{GH-GL}} \qquad (1)$$

This simple gray scale transformation stretches and shifts the gray scale to occupy the full range $[DH, DL]$ and increases overall contrast. The transformation can be used piecewise or uniformly, depending on the problem in hand.

B. *Edge detection*

As stated earlier, edge detection can be done either in the frequency domain or in the spatial domain. In the following, we discuss a spatial domain technique using a derivative and incorporate visual characteristics into it.[14] The general way of finding an edge is thresholding the derivative at the point in question. Thus, a point (j, k) is an edge if

$$\nabla f(j, k) \geq t$$

where ∇ denotes the derivative of any order of gray level f at point (j, k) and t denotes the threshold. If $f(j, k) \equiv Z_i$ then, from equation (1), we have

$$\nabla f'(j, k) = A \log_e B \, . \, B^{f(j,k)} \, . \, \nabla f(j, k) \qquad (2)$$

where f' denotes the modified level at (j, k) and

$$A = DL\left(\frac{DH}{DL}\right)^{\frac{-GL}{GH-GL}}$$

and

$$B = \left(\frac{DH}{DL}\right)^{\frac{1}{GH-GL}}$$

From equation (2) it is seen that the edges obtained after gray level stretching are the same as the edges obtained before the stretching if the threshold t in the former case is

$$t' = A \log_e B \, . \, B^{f(j,k)} \, . \, t. \qquad (3)$$

Hence t' is not space-invariant. Equation (3) suggests that the general form of a threshold function should be

$$t(j, k) = \alpha \beta^{f(j,k)}, \qquad (4)$$

so that human visual response can be incorporated. Here α and β are positive quantities. For $\beta = 1$, equation (4) gives a constant threshold. In general $\beta > 1$ should be used to incorporate human visual response. It can be seen that the method is iterative and hierarchical.

C. *Smoothing*

For smoothing, we find a technique different from the conventional mode or median filter, and in this procedure the human visual response can be incorporated in the following manner. Consider blocks A, B, C, D, E, F, G and H around the candidate pixel, (j, k) to be smoothed as in Fig. 1. Find the average of gray levels of pixels of these neighbouring blocks. Let this be f_b. Modify f, the gray level of pixel (j, k), to f' such that it has a component of ratio of difference to $f_b - f$ to f, which is similar to $\Delta I/I$ in human visual response. Thus let

$$f' = f\left(1 - \gamma\frac{f_b - f}{f}\right) \qquad (5)$$

where $0 < \gamma < 1$ is a weighting factor. This allows reasonable flexibility in a picture for adaptation. On simplification, equation (5) takes the form

$$f' = (1 - \gamma)f + \gamma f_b,$$

which is nothing but the weighted average of f and f_b, and can also be expressed by proper choice of p and q as

$$f' = \frac{p}{p+q} f + \frac{q}{p+q} f_b.$$

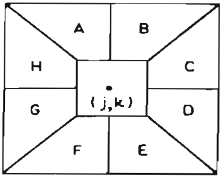


Fig. 1. Neighboring blocks surrounding candidate pixel.

Let the blocks A, B, C, D etc. be called b_i, $i = 1, 2, \ldots, 8$ and let the average of gray levels of pixels within and on the boundary of b_i be f_{b_i}, then we can write

$$f' = \frac{pf}{p + \Sigma q_i} + \frac{\Sigma q_i f_{b_i}}{p + \Sigma q_i}. \quad (6)$$

Now, f_{b_i} is given by

$$f_{b_i} = \frac{n\mu_i - f}{n - 1}$$

where $(n - 1)$ is the number of pixels in block b_i and μ_i is the average, including the candidate pixel (j, k), gray level.

From (6) and (7) we obtain

$$f' = \frac{pf}{p + \Sigma q_i} + \frac{\Sigma \left[q_i \dfrac{n\mu_i - f}{n - 1} \right]}{p + \Sigma q_i}$$

or

$$f' = \frac{1}{p + \Sigma q_i} \left[p - \frac{\Sigma q_i}{n - 1} \right] f + \frac{n}{n - 1} \left[\frac{\Sigma q_i \mu_i}{p + \Sigma q_i} \right]. \quad (8)$$

If we put, $p = \Sigma F_i^m$ and $q_i = (n - 1)\, F_i^m$ in (8), then

$$f' = \frac{\Sigma (F_i^m \times \mu_i)}{\Sigma F_i^m}$$

where, F_i is new weighting coefficient.

The basic idea of the present method is to consider the area consisting of pixels within and on a triangular mask around the pixel to be smoothed. The procedure follows the following steps.

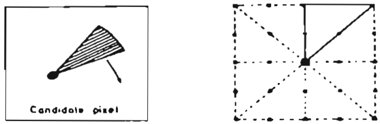
[a] A triangular mask is rotated around the candidate pixel $f(j, k)$ and for each of the 8 positions of the mask the mean μ_i and variance σ_i of the gray levels in the mask are calculated (Fig. 2).

[b] A weighting coefficient is defined as

$$F_i = \frac{\min_i \{\sigma_i\}}{\sigma_i} \quad (9)$$

and the gray level $f'(j, k)$ of the smoothed image is given by

$$f'(j, k) = \sum_{i=1}^{8} (F_i^m \mu_i) / \sum_{i=1}^{8} F_i^m \quad (10)$$



(a) Triangular Mask (b) Discrete Realization

Fig. 2.

where m is a non-negative quantity.

It can be seen that the procedure works in various ways, depending on the value of m. For $m = 0$, the gray level of the smoothed image becomes

$$f'(j, k) = \sum_{i=1}^{8} \mu_i / 8$$

which is very similar to unweighted ordinary averaging technique. As the value of m increases, the effects of the mean gray level of the region with higher non-homogeneity decreases. Also, as $m \to \infty$ the technique approaches towards that of Nagao and Matsuyama,[4] which gives the candidate pixel the mean gray level of the region with least variance. Practically, for $m > 16$ the candidate pixel (j, k) attains a gray level almost equal to that of the region with highest homogeneity. Clearly, the approach can operate with a wide range of quality, can be iterated quickly and has great flexibility.

III. RESULTS AND DISCUSSION

The algorithms have been simulated in a general purpose EC 1033 computer in the Fortran Language and tested on a set of pictures. The pictures are of size 64×64 and each pixel has been digitised into 32 gray levels. Both the input and output hard copy of the pictures was generated in the computer line printer using overprinting facility because a better hard copy instrument was unavailable.

The method of histogram modification described in Section IIA is a nonlinear histogram stretching technique including human visual response. Figure 3(a) shows some objects in the original picture. Figs. 3(b), 3(c) and 3(d) are the results of nonlinear and linear histogram stretching and histogram equalization, respectively of Fig. 3(a). Although image quality is subjective, it can be seen that the present method is better than other methods for a class of pictures.

Figure 4(a) has been used for edge detection by the approach given in Section IIB. The edges for some particular values of α and β are given in 4(b)(i) and 4(c)(i), using Roberts average magnitude and 2×2 Hueckel operators, respectively. Figures 4(b)(ii) and 4(c)(ii) show the edges for the respective operators using a space-invariant constant threshold. Here α and β can be adjusted by a trial and error approach. However, the procedure converges more quickly if a gradient histogram and/or approximate values of α

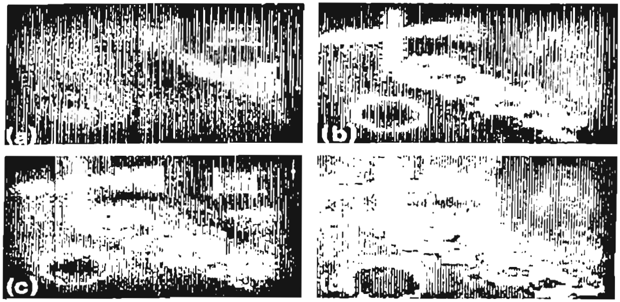


Fig. 3.(a) Original image. (b) Enhanced image obtained through logarithmic stretching. (c) Enhanced image obtained through linear stretching. (d) Enhanced image obtained through histogram equalization.

and β obtained from equation (2) are used. Clearly, a variable threshold leads to visually better edges of the picture.

To check the effectiveness of the smoothing algorithm of Section IIC, we have applied this algorithm to pictures corrupted with additive noise. The noise picture and its smoothed version obtained through the use of the aforesaid smoothing algorithm are shown in Figs. 5(a) and 5(b), respectively. The fluctuation in gray level is gradually reduced by several iterations, which is an indication of convergence. Both the effectiveness and efficiency of a neighbour-weighting method de-

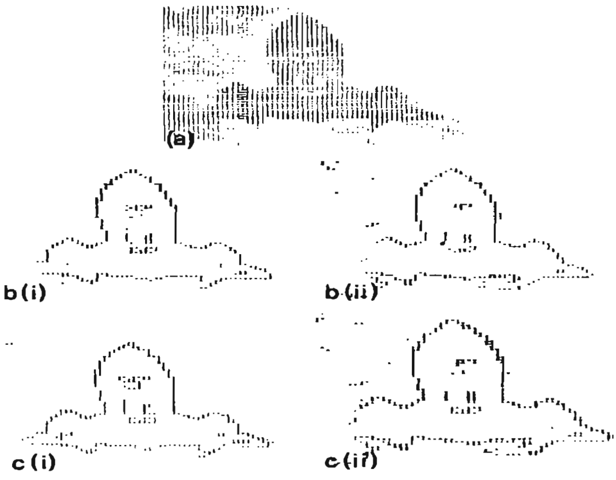


Fig. 4.(a) Original image of a JET. (b)(i) Edge of (a) using a Roberts gradient in a magnitude-average sense and a space-variant threshold with $\alpha = 5.5$ and $\beta = 1.12$. (b)(ii) Edge of (a) using a Roberts gradient in a magnitude-average sense and a space-invariant threshold. (c)(i) Edge of (a) using a Hueckel operator over a 2×2 window and a space-variant threshold with $\alpha = 5.5$ and $\beta = 1.15$. (c)(ii) Edge of (a) using a Hueckel operator over a 2×2 window and a space-invariant threshold.

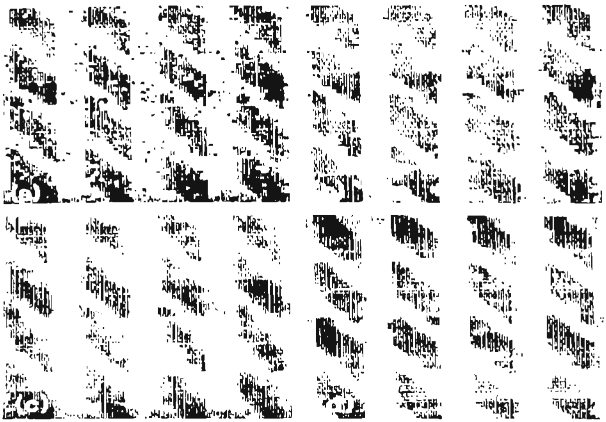


Fig. 5. (a) Original noisy image. (b) Smoothed version of (a) using $m = 16$ after 10 iterations. (c) Result of mean filtering over (a). (d) Result of median filtering over (a).

pends on the size of the neighborhood considered. A larger neighborhood (as well as mask) gives better estimation, but it leads to more computation and estimation problems at the extremes of the picture. A compromise approach is to use a small mask and to iterate for better estimation. Figures 5(c) and 5(d) show the results of mean and median filtering applied to the same noisy picture. It can be seen from Fig. 5(c) that mean filtering blurs the edges during smoothing. Also, a comparative study of Fig. 5(b) and 5(d) shows that the picture edge sharpness is better with our method.

IV. CONCLUSION

All of the techniques discussed in this paper satisfy some important visual fidelity criteria. Enhancement and smoothing techniques improve the appearance of the picture to a human observer. The smoothing technique can also be used to extract regions with almost uniform intensity, even in complex picture. The results [Fig. 4] show that the proper selection of parameters may give near optimum edges using the proposed algorithm for edge detection. The described algorithms can be implemented iteratively and hierarchically and, hence, are flexible in man-machine interaction.

SUMMARY

Digital image processing techniques have two principal application areas: the first is to improve the appearance of the image for human perception or subsequent machine analysis and the second is automatic machine recognition of a given image. As human beings are the supreme judge of the subjective quality, as well as the description or recognition algorithms developed on the basis of human intelligence, all the techniques for image processing should incorporate the characteristics of the human visual system. However, this idea seems to be neglected in most of the literature. The present work is an attempt to include it in image processing problems.

One of the major characteristics of the human visual system is the logarithmic response to light intensity incident on the eyes, which states that the visual detectibility depends on the ratio, rather than just the difference, between intensities I and $I + \Delta I$, where ΔI is the just noticeable difference in the intensity. We have used this concept to formulate all three image processing algorithms, for enhancement, edge detection and noise smoothing.

Experimental results for each of the algorithms have been given and their corresponding merits are discussed in the paper by comparing them with the results obtained through the use of standard existing techniques. It is shown that the present algorithms yield visually better results in each case.

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