ISCAS 2000 - IEEE International Symposium on Circuits and Systems, May 28-31, 2000, Geneva, Switzerland

DIRECTIONAL-RATIONAL APPROACH FOR COLOR IMAGE ENHANCEMENT

Faouzi Alaya Cheikh and Moncef Gabbouj

Signal Processing Laboratory
Tampere University of Technology
P.O. Box 553 FIN-33 101 Tampere, Finland
email: faouzi@cs.tut.fi

ABSTRACT

In this paper, we present an unsharp masking-based approach for noise smoothing and edge enhancing in multichannel images. The proposed structure is similar to the conventional unsharp masking structure, however, the enhancement is allowed only in the direction of maximal change and the enhancement parameter is computed as a nonlinear function of the rate of change. The proposed scheme enhances the true details, limits the overshoot near sharp edges and attenuates noise in flat areas. Moreover the use of the control function eliminates the need for the subjective coefficient λ used in the conventional unsharp masking technique.

Simulations results show that the processed image presents sharp edges which makes it more pleasant to the human eye. Moreover, the amount of noise in the image is clearly reduced.

1. INTRODUCTION

Image segmentation and edge detection are basic operations in computer vision applications. Moreover, they are becoming a key operations due to the growing interest in object-oriented video coding and content-based indexing and retrieval in image and video database systems. These two operations are extremely sensitive to noise and blur in the image. Therefore, it is common to apply a preprocessing operator to attenuate the noise and sharpen the edges of objects prior to segmentation or edge detection.

The multichannel nature of the color images adds another degree of complexity to the enhancement problem; due to the inherent correlation that exists between the different components.

Early approaches to detect discontinuities in a multivalued image attempted to combine the response of single-valued edge detectors applied separately to each of the image components. The way these responses are combined is generally heuristic. A more theoretical way of looking at the problem of edge detection in multivalued images was presented in [1], and is adopted in this paper.

In the following, we propose a new scheme for image enhancement which allows a selective enhancement of image details. This is achieved by replacing the parameter λ by a data-dependent function f. Specifically, we propose to estimate the direction and the magnitude of the maximal change in the filter window. Then depending on the range of the magnitude of the change a rational function controls the amount of enhancement or smoothing to do along the direction of the edge. Therefore, midrange details are enhanced while small variations attributed to noise are smoothed.

2. UNSHARP MASKING

In the unsharp masking (UM) approach for image enhancement, a fraction of the high-pass filtered image is added to the original one to form the enhanced image [2]. The input/output relation for the unsharp masking filter can be written as follows:

$$x' = x + \lambda z \qquad (1)$$

where x, x' are the input, output images and λ a positive constant which controls the fraction of the high-pass filtered image z to be added to the input image; see Fig. 1.

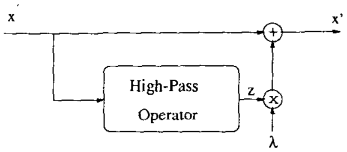

Figure 1: The unsharp masking structure.

This is a simple method, but it has two major drawbacks. First it enhances the noise present in the image. Second, it enhances too much the sharp transitions which leads to excessive overshoot on sharp edges.

Several modifications of the linear UM technique were presented in the literature, [3], [4], [5], trying to reduce the noise amplification. In some of these modifications the Laplacian was replaced by an operator which is less sensitive to noise [6] and in others [3] adaptive control of the fraction of details added to the image is used. The latter tries to avoid the noise amplification and the over shoot near sharp edges; by making λ very small whenever the existence of edges or noise is detected. Elsewhere, λ is larger than zero to enhance the midrange details. Similarly to this approach, the algorithm we propose avoids overshoot near sharp edges. Moreover, by allowing the control function f to take small negative values the noise is attenuated, see Fig.3. The proposed scheme is applied to color image enhancement by using an extension of the gradient to multivalued signals [1], which allows the detection of local changes in the color image.

3. PROPOSED ALGORITHM

In this paper we propose a method which combines a directional high-pass filter and a rational function to control the amount of enhancement based on the rate of change in the filter window, which allows the discrimination between true details and noise.

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The gradient of the multivalued images used in the rest of this paper was introduced in [1]. The idea is the following. Let $I(u_1, u_2) : R^2 \longrightarrow R^m$ be a multivalued image with components $x_i(u_1, u_2) \in R,\ i = 1, 2, ..., m$. For color images $m = 3$. Each pixel in the image is a vector in R^3, when the Euclidean distance $d(P, Q)$ between two pixels P and Q tends to zero, the difference $P(u_1^0, u_2^0) - Q(u_1^1, u_2^1)$ becomes the arc element

$$dI = \sum_{i=1}^{2} \frac{\partial I}{\partial u_i} du_i. \qquad (2)$$

and its square norm is

$$dI^2 = \sum_{i=1}^{2} \sum_{j=1}^{2} \frac{\partial I}{\partial u_i} \frac{\partial I}{\partial u_j} du_i du_j. \qquad (3)$$

This quadratic form is called the *first fundamental form* [1]. Let us denote $g_{ij} = \frac{\partial I}{\partial u_i} \frac{\partial I}{\partial u_j}$, then

$$dI^2 = \sum_{i=1}^{2} \sum_{j=1}^{2} g_{ij} du_i du_j = \begin{bmatrix} du_i \\ du_j \end{bmatrix}^T \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} du_i \\ du_j \end{bmatrix}. \qquad (4)$$

The first fundamental form allows the measurement of the local changes in the image. The extrema of the quadratic form (4) are obtained in the direction of the eigenvectors of the matrix $[g_{ij}]$, and the values attained there are corresponding to the eigenvalues. Thus, the eigenvectors provide the direction of maximal and minimal change at a given point in the image, and the eigenvalues are the corresponding rates of change. Let θ_+, θ_- denote the direction of maximal, respectively minimal change, and λ_+, λ_- denote the maximal, respectively the minimal rate of change.

In contrast to gray-level images ($m = 1$), the minimal rate of change λ_- may be different from zero. Thus, the strength of edges in the multivalued case can be measured by how λ_+ compares to λ_-. A function $f(\lambda_+ - \lambda_-)$ would be a good choice for detecting edges in the multivalued image. This function would have the property of reducing to $f(||\nabla I||^2)$ for the gray-level images. This, property is used in the following to illustrate the behavior of the proposed scheme, using simple examples.

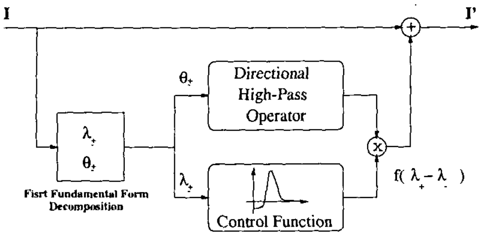

Figure 2: Structure of the proposed scheme.

The input/output relation of our algorithm can be written as:

$$I' = I + f(\lambda_+ - \lambda_-) \times HP_{\theta_+}, \qquad (5)$$

where I, I' are the input and output images to the filter, HP_{θ_+} the high-pass filter applied along the direction of maximal rate of change, and f the nonlinear control function.

3.1. The nonlinear control function

The control function f has to be simple and must obey several restrictions, in order to enhance true details and reduce noise.

i) It has to attenuate signal variations which are smaller than a certain threshold D. This will allow us to smooth selectively the signal variations which are attributed to noise corruption.

Let $g = (\lambda_+ - \lambda_-)$ be the magnitude of the multivalued gradient and $\Delta = \frac{g}{D}$.

$$f(\Delta) \leq 0, \text{ for } \Delta \leq 1, \qquad (6)$$

The threshold D determines the gradient magnitude beyond which changes in the image are considered to be true details. It is estimated from the gradient magnitude of changes in a smooth area of the corrupted image. Where the only changes can be attributed to noise corruption.

ii) The mid-range details which are the signal transitions having magnitude larger than D must be enhanced:

$$f(\Delta) > 0, \text{ for } \Delta > 1, \qquad (7)$$

iii) To avoid the excessive overshoot over sharp edges:

$$\lim_{\Delta \to +\infty} f(\Delta) = 0, \qquad (8)$$

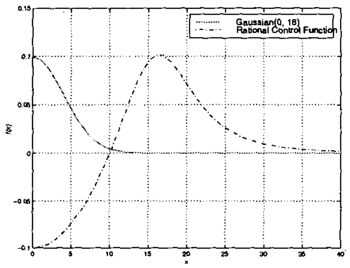

Figure 3: Plot of the control function.

Thus the ideal control function would have the shape shown in Fig.3. A simple function verifying all these conditions can be formulated as a rational function which is the ratio of two polynomial functions.

Rational functions have been recently proposed to represent the input/output relation in a nonlinear signal processing system [7][8]. The motivation for their introduction was to overcome the limitations which are typical of the polynomial approach, namely the need for a large number of parameters when the order of the nonlinearity is high and the poor ability of the polynomial to extrapolate beyond its domain of validity. Recently, rational functions were proposed as a new class of nonlinear signal processing techniques used in various tasks, such as restoration [9], noise filtering [10], enhancement [11], [12] and interpolation [13],[14].

$$f(\Delta) = \frac{\Delta^m - b}{c\Delta^n + h}, \qquad (9)$$

where, Δ is the thresholded output of the edge sensing operator.

By properly choosing $\{b, c, h, m, n\} \in R_+^*$; we can make this function verify all the previous conditions:

i) Noise smoothing:

$$f(\Delta) = 0, \quad \text{for } \Delta = 1 \quad \Rightarrow b = 1, \qquad (10)$$

$$\text{thus } f(\Delta) \leq 0, \quad \text{for } \Delta \leq 1, \qquad (11)$$

ii) Detail enhancing:

$$f(\Delta) > 0, \text{ for } \Delta > 1, \text{ verified for } b = 1; \qquad (12)$$

iii) Overshoot elimination:

$$\lim_{\Delta \to +\infty} f(\Delta) = 0 \Rightarrow n > m. \qquad (13)$$

We choose in our simulations $m = 2$ and $n = 4$.
Therefore the modified unsharp masking scheme we propose is characterized by,

$$I' = I + \frac{(\Delta^m - 1)}{c\Delta^n + h} \times HP_{\theta_+}, \qquad (14)$$

where, I, I' are the input, output images, HP_{θ_+} is the high-pass filter applied along the direction of maximal change θ_+.

The parameter h is determined by the amount of noise smoothing desired, since in smooth regions $\Delta \sim 0$ and $f(\Delta) \sim \frac{-1}{h} \times HP_{\theta_+}$. While c is determined by the amount of enhancement desired of true details, where $\Delta > 1$ thus $f(\Delta) \sim \frac{\Delta^m}{c\Delta^n} \times HP_{\theta_+}$.

4. EXPERIMENTAL RESULTS

Fig. 4, compares the action of the proposed operator on one-dimensional ideal steps of different amplitude to those of the linear UM and the mean filter. The enhancement threshold here is $D = 25$. Thus the first step is clearly attenuated and the second which is considered as a true detail is enhanced. Whereas, the mean filter attenuates both steps and the linear UM enhances both of them.

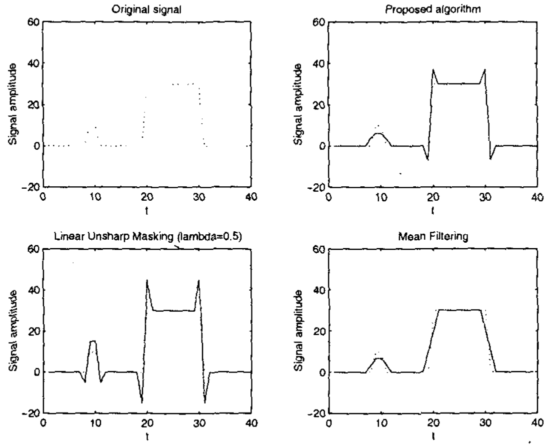

Figure 4: Comparison of the action of different algorithms on step signals of different amplitude.

The same operator is applied to enhance a one-dimensional step of amplitude 50 corrupted with zero-mean Gaussian noise of variance 1, see Fig.5.

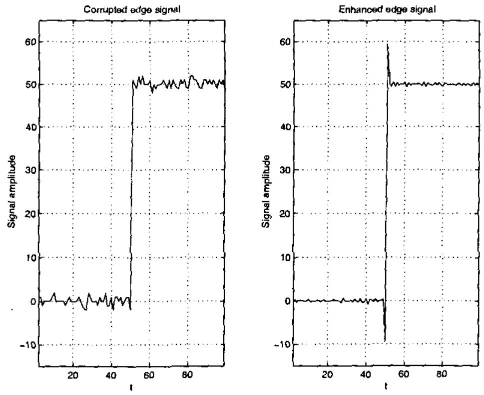

Figure 5: Noisy One-dimensional step edge and its processed version with the proposed operator.

In the case of one dimensional signals the proposed approach reduces to the one in [11].

To assess the performance of the proposed algorithm in enhancing color images, color image "Lenna of size 480x512 is corrupted by a zero-mean Gaussian noise with variance 400. A magnified region of the processed images using the directional UM algorithm and the conventional unsharp masking method are presented for visual evaluation. It can be seen that the image processed by our algorithm presents sharper edges and smoother flat areas, Fig.7; while noise is enhanced by the linear UM scheme see Fig.8.

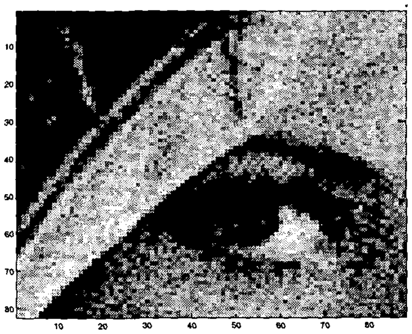

Figure 6: Corrupted Image.

5. CONCLUSIONS

A new approach for multivariate image enhancement was proposed. The enhancement is performed selectively to overcome the problems relative to the linear unsharp masking technique. The proposed approach enhances true details, limits the overshoot near sharp edges and attenuates noise in flat areas. The selective enhancement is achieved by the use of the multivariate gradient operator [1] and a nonlinear control function.

Future work will focus on a more robust estimation of the parameters of the control function based on the local statistics of the noise and the image details.

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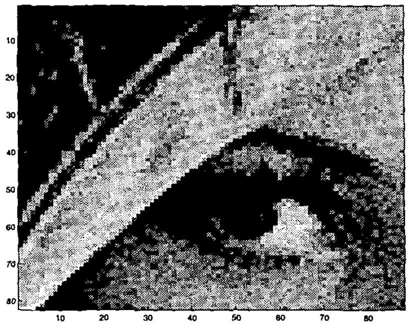

Figure 7: Processed image with the proposed algorithm.

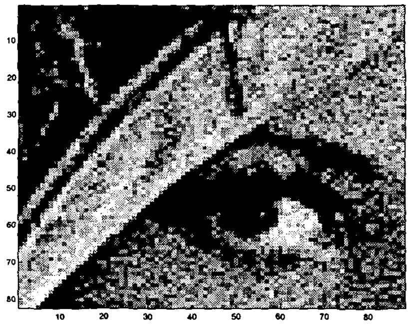

Figure 8: Processed image with the linear unsharp masking.