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Image Sharpening Using A Novel Unsharp Masking Algorithm

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Abstract- **Enhancement of contrast and sharpness of an image is required in many applications. Unsharp masking is a classical tool for sharpness enhancement. We propose a generalized unsharp masking algorithm using the exploratory data model as a unified framework. The proposed algorithm is designed to address three issues: 1) simultaneously enhancing contrast and sharpness by means of individual treatment of the model component and the residual, 2) reducing the halo effect by means of an edge-preserving filter, and 3) solving the out-of-range problem by means of log-ratio and tangent operations. We also present a study of the properties of the log-ratio operations and reveal a new connection between the Bregman divergence and the generalized linear systems. This connection not only provides a novel insight into the geometrical property of such systems, but also opens a new pathway for system development. We present a new system called the tangent system which is based upon a specific Bregman divergence. Experimental results, which are comparable to recently published results, show that the proposed algorithm is able to significantly improve the contrast and sharpness of an image. In the proposed algorithm, the user can adjust the two parameters controlling the contrast and sharpness to produce the desired results. This makes the proposed algorithm practically useful.**

Keywords- **Bregman divergence, exploratory data model, generalized linear system, image enhancement, unsharp masking.**

INTRODUCTION

Enhancing the sharpness and contrast of images has many practical applications. There has been continuous research into the development of new algorithms. In this section, we first briefly reviewpreviousworks which are directly related to our work. These related works include unsharp masking and its variants, histogram equalization, retinex and dehazing algorithms, and generalized linear systems. We then describe the motivation and contribution of this paper.

A. Related Works

1) Sharpness and Contrast Enhancement: The classical unsharp masking algorithm can be described by the equation $v = y + \gamma(x - y)$: where x is the input image, y is the result of a linear low-pass filter, and the gain $\gamma(\gamma > 0)$ is a real scaling factor. The signald=x-y is usually amplified ($\gamma > 1$) to increase the sharpness. However, the signal d contains 1) details of the image, 2) noise, and 3) over-shoots and under-shoots in areas of sharp edges due to the smoothing of edges. While the enhancement of noise is clearly undesirable, the enhancement of the under-shoot and over-shoot creates the visually unpleasant halo effect. Ideally, the algorithm should only enhance the image details. This requires that the filter is not sensitive to noise and does not smooth sharp edges. These issues have been studied by many researchers. For example, the cubic filter [1] and the edge-preserving filters [2]–[4] have been used to replace the linear low-pass filter. The former is less sensitive to noise and the latter does not smooth sharp edges. Adaptive gain control has also been studied [5]. Contrast is a basic perceptual attribute of an image [6]. It is difficult to see the details in a low contrast image. Adaptive histogram equalization [7], [8] is frequently used for contrast enhancement. The retinex algorithm, first proposed by Land [9], has been recently studied by many researchers for manipulating contrast, sharpness, and dynamic range of digital images. The retinex algorithm is based upon the imaging model in which the observed image is formed by the product of scene reflectance and illuminance. The task is to estimate the reflectance from the observation. Many algorithms use the assumption that the illuminance is spatially smooth. The illuminance is estimated by using a low-pass filter or multiresolution [10] or formulating the estimating problem as a constrained optimization

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problem [11]. To reduce the halo effect, edge-preserving filters such as: adaptive Gaussian filter [12], weighted least-squares based filters [13] and bilateral filters [11], [14] are used. Recently, novel algorithms for contrast enhancement in dehazing applications have been published [15], [16]. These algorithms are based upon a physical imaging model. Excellent results have been demonstrated. An important issue associated with the unsharp masking and retinex type of algorithm is that the result is usually out of the range of the image [12], [17]–[19]. For example, for an 8-bit image, the range is [0, 255]. A careful rescaling process is usually needed for each image. A histogram-based rescaling process and a number of internal scaling processes are used in the retinex algorithm presented in [19].

2) Generalized Linear System and the Log-Ratio Approach:

In his classic book, Marr [20] has pointed out that to develop an effective computer vision technique one must consider: 1) why the particular operations are used, 2) how the signal can be represented, 3) what implementation structure can be used. Myers [21] has also pointed out that there is no reason to persist with particular operations such as the usual addition and multiplication, if via abstract analysis, more easily implemented and more generalized or abstract versions of mathematical operations can be created for digital signal processing. Consequently, abstract analysis may show new ways of creating systems with desirable properties. Following these ideas, the generalized linear system, shown in Fig. 1, is developed. The generalized addition and scalar multiplication operations denoted by $\otimes$ and $\oplus$ are defined as follows:

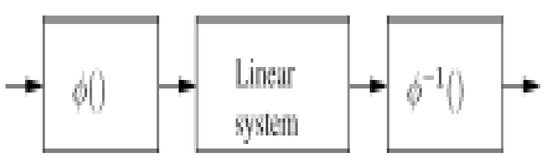

Fig. 1. Block diagram of a generalized linear system, where Ø()is usually a nonlinear function.

$$x \oplus y = \phi^{-1}[\phi(x) + \phi(y)] \quad (1)$$

$$\alpha \otimes x = \phi^{-1}[\alpha\phi(x)] \quad (2)$$

where and are signal samples, is usually a real scalar, and is a nonlinear function. The log-ratio approach [17] was proposed to systematically tackle the out of range problem in image restoration. The logratio can be understood from a generalized linear system point of view, since its operations are implicitly defined by using (1) and (2). A remarkable property of the log-ratio approach is that the gray scale set is closed under the new operations. Deng [22] used the log-ratio in a generalized linear system context for image enhancement. In their review papers, Cahill and Deng [23] and Pinoli [24] compared the log-ratio with other generalized linear system-based image processing techniques such as the multiplicative homomorphic filters [25] and the logarithmic image processing (LIP) model [18], [26].

PROPOSED ALGORITHM

A. Dealing With Color Images

We first convert a color image from the RGB color space to the HSI or the LAB color space. The chrominance components such as the H and S components are not processed. After the luminance component is processed, the inverse conversion is performed. An enhanced color image in its RGB color space is obtained. The rationale for only processing the luminance component is to avoid a potential problem of altering the white balance of the image when the RGB components are processed individually.

B. Enhancement of the Detail Signal

The Root Signal and the Detail Signal: Let us denote the median filtering operation as a function y=f(x) which maps the input x to the output y . An IMF operation can be represented as $y_{k+1}=f(y_k)$ where k=1 ,2….is the iteration index and . The signal is usually called the root signal of

TABLE IV

key components of some generalized linear system motivated by the bregman divergence. the domain of the lip model is$(-\infty, M)$. in this table, it is normalized by M to simplify notation

	Domain	$D_F(x,y)$	$\phi(x)$	$x \oplus y$	$\alpha \otimes x, (\alpha \in R)$
Log-ratio	$(0,1)$	$-x\log\frac{x}{y} - (1-x)\log\frac{1-x}{1-y}$	$\log\frac{1-x}{x}$	$\frac{1}{1+\frac{1-x}{x}\frac{1-y}{y}}$	$\frac{1}{1+\left(\frac{1-x}{x}\right)^\alpha}$
LIP	$(-\infty,1)$	$(1-x)\log\frac{1-x}{1-y} - [(1-x)-(1-y)]$	$-\log(1-x)$	$x+y-xy$	$1-(1-x)^\alpha$
MHS	$(0,\infty)$	$x\log\frac{x}{y} - (x-y)$	$-\log(x)$	xy	x^α
Tangent	$(-1,1)$	$\frac{1-xy}{\sqrt{1-y^2}} - \sqrt{1-x^2}$	$\frac{x}{\sqrt{1-x^2}}$	$\frac{\phi(x)+\phi(y)}{\sqrt{1+(\phi(x)+\phi(y))^2}}$	$\frac{\alpha\phi(x)}{\sqrt{1+(\alpha\phi(x))^2}}$

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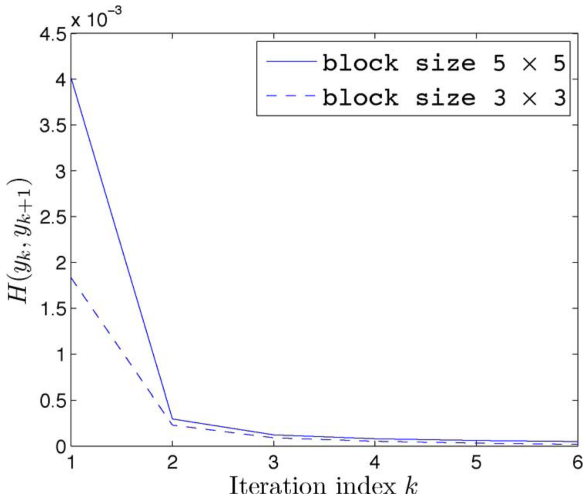

Fig. 2. Mean squared difference of images between two iterations H(y_k,y_{k+1}) =(1/N)$\|y_k - y_{k-1}\|$ where M is the number of pixels in the image. Results using two settings of the median filter and using the "cameraman" image are shown.

the filtering process if $y_{n+1} = y_n$. It is convenient to define a root signal y_n as follows:

n=min k, subjected to H(y_k,y_{k+1})<δ (3)

where H(y_k,y_{k+1}) is a suitable measure of the difference between the two images and is a user defined threshold. For natural images, it is usually the case that the mean squared difference, H(y_k,y_{k+1})=(1/N) $\|y_k - y_{k-1}\|$ defined as (N is the number of pixels), is a monotonic decreasing function of . An example is shown in Fig. 2.It can be easily seen that the definition of the root signal dependsupon the threshold. For example, it is possible to set a large value to such that is the root signal. Indeed, after about five iterations the difference changes only very slightly. As such, we can regard or as the root signal. Of course, the number of iterations, the size and the shape of the filter mask have certain impacts on the root signal. The properties of the root signal has been extensively studied [33].Here we use an example to illustrate the advantage of the proposed algorithm over the classical unsharp masking algorithm.

The original signal is shown in Fig. 3, which is the 100th row of the "cameraman" image. The root signal is produced by an IMF filter with a (3x 3) mask and three iterations. The signal is produced by a linear low-pass filter with a uniform mask of (5x5). The gain for both algorithms is three. Comparing the enhanced signals (last row in the figure), we can clearly see that while the result for the classical unsharp masking algorithm suffers from the out of range problem and halo effect (under-shoot and over-shoot), the result of the proposed algorithm is free of such problems.

2) Adaptive Gain Control: We can see from Fig. 3 that to enhance the detail signal the gain must be greater than one. Using a universal gain for the whole image does not lead to good results, because to enhance the small details a relatively large gain is required. However, a large gain can lead to the saturation of the detailed signal whose values are larger than a certain threshold. Saturation is undesirable because different amplitudes of the detail signal are mapped to the same amplitude of either 1 or 0. This leads to loss of information. Therefore, the gain must be adaptively controlled.

In the following, we only describe the gain control algorithm for using with the log-ratio operations. Similar algorithm can be easily developed for using with the tangent operations. To control the gain, we first perform a linear mapping of the detail signal to a new signal C

C=2d-1

such that the dynamic range of C is(-1,1). A simple idea is to set the gain as a function of the signal C and to gradually decrease the gain from its maximum value when to its minimum value γ_{max} when$|C| < T$. More specifically, we propose the following adaptive gain control function

$$\gamma(c) = \alpha + \beta\exp(-c^\eta)$$

where η is a parameter that controls the rate of decreasing. The two parameters α and β are obtained by solving the equations:

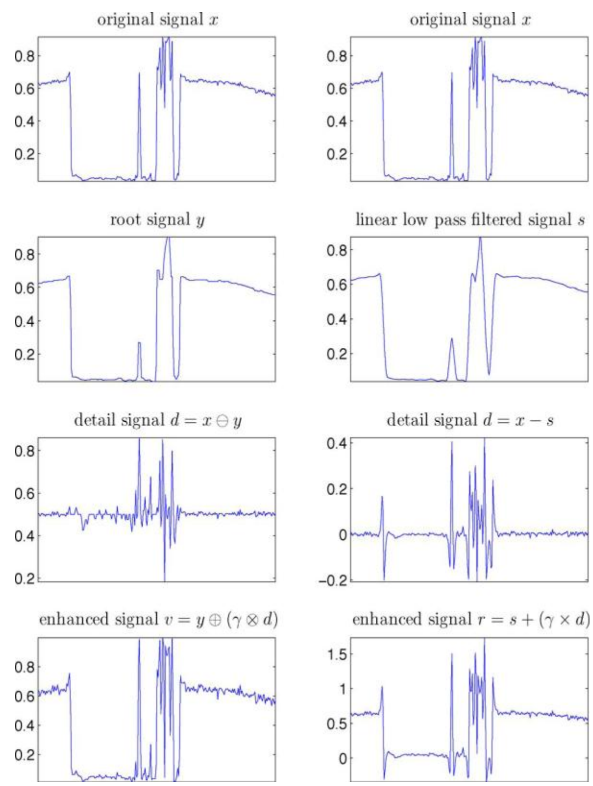

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Fig. 3. Illustration of the difference between the proposed generalized unsharp masking algorithm (left panel) and the classical unsharp masking algorithm (right panel). Comparing the two enhanced signal shown in the bottom row of the figure, we can clear see that while the classical unsharp masking algorithm (right) produces over- and under-shoots around sharp edges (halo-effects), the proposed algorithm (left) is almost free of these effects.

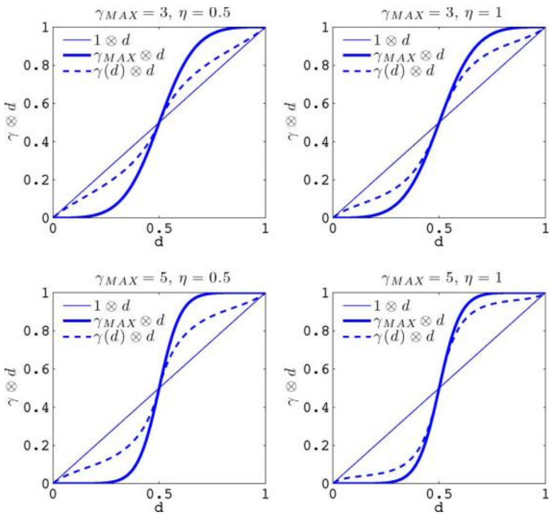

Fig. 4. Illustrations of adaptive gain control for four combinations of γ_{Max} and η. The results of using a fixed gain $\gamma = \gamma_{MAX}$ are also shown.

RESULTS AND COMPARISON

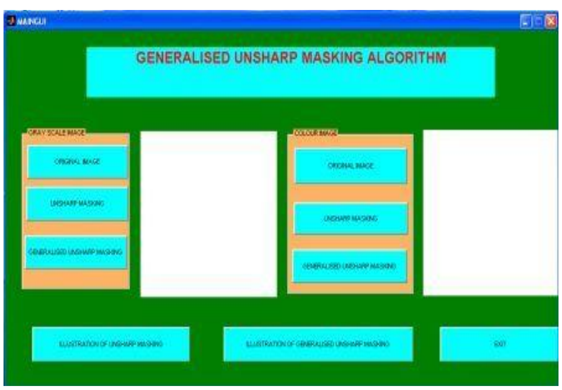

Fig.5.Generalized unsharp masking algorithm GUI

Fig.6.Original gray level image

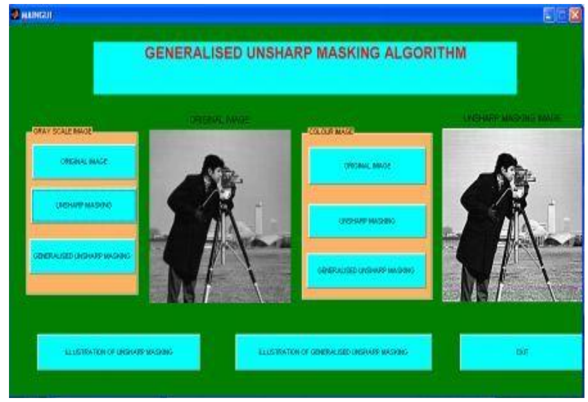

Fig.7. gray level Unsharp Masking

Fig.8.Generalized Unsharp Masking

Fig.9.Original color image corresponding unsharp masking

Fig.10.comparision of generalized unsharp masking and unsharp masking images

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