

Adaptive Edge Sharpening by Multiple Gaussian Filters

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Abstract

The color image has different edge profiles depending on the local characteristics of the images. This paper discusses an adaptive image sharpening method depending on edge slopes of color images. First, the edge strengths of color image are measured by Gaussian derivative spatial filter for detecting the differential edge slopes. Secondly, the segmen -ted mask pattern is generated to characterize the measured edge strengths, such as hard, medium, soft, and gentle or flat. Finally, the color image is processed by switching the plural number of edge sharpening spatial filters according to the mask pattern. The edge sharpening spatial filters worked well without coloring the gray edges when applied to the luminance signal converted from RGB signals by linear matrix. In the gentle or flat areas, all the edge sharpening filters are suppressed not to enhance the flat area noises. Here the multiple second derivative filters such as Gaussian or Gabor with different σ are applied to restore the edge sharpness depending on the mask patterns. The proposed method resulted in the dramatic improvements in the reduction of flat areas' noise, and the image sharpness is recovered in smooth and in natural adaptive to the edge strengths.

Introduction

The color image has different edge profiles depending on the characteristics of the objects placed in the scene. In the most simple conventional edge enhancement method, a single sharpness filter such as digital Laplacian or un-sharp mask operator is applied to the entire image. The non-adaptive single sharpness filter is known to have the following drawbacks such as

- random noise in flat area is amplified with edge enhancement.
- dull edges are not well sharpened by a single spatial operator with small size
- coloring in the gray edges by un-balanced RGB responses

The random noise problem is most serious and may be avoided by setting a threshold value to make the filter non-sensitive to the weak edges or undercutting the edge enhancement signals less than threshold value.

However, the conventional operator such as digital Laplacian doesn't create the natural edge sharpness, because it shows local edge responses different from receptive field in human vision.

In the proposed method, multiple edge enhancement filters are applied to work adaptive to the different edge slopes and not to work in the flat areas avoiding the enhancement in the background noises. The coloring problem in grayish edges is resolved by applying the edge enhancement operators only to the luminance signal. The enhanced composite luminance signal works to recover the sharpness for component color signals through the inverse matrix operation.

Edge Sharpening Operator

A variety of simple cell receptive field models for human vision have been considered such as

- Gaussian Derivative (=Hermite Polynomial*Gaussian)
- Gabor(=Cosine·*Gaussian)
- DOG(Difference-Of-Gaussian
- DOOG(Difference-Of-Offset-Gaussian)
- DODOG (Difference-Of-Offset-DOGS)

Stork and Wilson 1, Yang 2, and Klein et al 3, disputed which is the better function, Gaussian derivative (GD) or Gabor 4 to minimize the joint space-spatial frequency uncertainty $\Delta x \Delta \omega$. Young 5 and others reported the GD is better than Gabor. Marr and Hildreth 6 operator using GD is well known and has been applied to detect zero-crossing image edges. Here we used GD-based operators.

The basic Gaussian distribution function in two dimensions is defined by

$$G(r) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right); \qquad r^2 = x^2 + y^2 \tag{1}$$

Its second derivative is given by

$$\begin{aligned} \nabla^2 G &= \partial^2 G(r)/\partial x^2 + \partial^2 G(r)/\partial y^2 \\ &= \frac{1}{\pi\sigma^4}\left(\frac{r^2}{2\sigma^2} - 1\right)\exp\left(-\frac{r^2}{2\sigma^2}\right) \end{aligned} \tag{2}$$

The edge signals are extracted from image f(x, y) by the two-dimensional convolution operation as follows.

$$\delta(x, y) = \nabla^2 G <*> f(x, y) \tag{3}$$

Where, symbol <*> denotes the convolution operation and the edge sharpness is measured by operating the pre-scan filter $\nabla^2 G_s$ with appropriate standard deviation σ_s.

Procedures

Fig.1 illustrates the sharpening process in the proposed system. First, the RGB image is transformed into luminance-chrominance image such as YCrCb, YIQ or HLS. The edge enhancement is applied only to the luminance Y image to keep the gray balance on the edges. In our proposal, the edge strengths are analyzed by the histogram of $\delta(x, y)$ and classified into multiple zones reflecting the edge profiles, such as, hard, medium, soft, and gentle or flat. Thus the zone mask $M(x, y)$ is generated to discriminate these edge types.

Next, the multiple Gaussian derivative operators $\nabla^2 G$ with different σ_1, σ_2, and σ_3 are applied to Y image and the edge signals, hard edge $\delta_1(x, y)$, medium edge $\delta_2(x, y)$, or soft edge $\delta_3(x, y)$ are detected in response to the statistical distribution of the edge slopes in the image.

These edge signals are selectively activated by looking up the following zone mask $M(x, y)$ according to the edge types and resumed in the gentle or flat areas without edges.

$$M(x,y) = \begin{cases} 0 & \delta(x,y) = 0 \quad \text{for gentle or flat areas} \\ 1 & \delta(x,y) = \delta_1(x,y) \quad \text{for sharp edge} \\ 2 & \delta(x,y) = \delta_2(x,y) \quad \text{for medium edge} \\ 3 & \delta(x,y) = \delta_3(x,y) \quad \text{for soft edge} \end{cases} \qquad (4)$$

Thirdly, the Y image is sharpened by subtracting this edge adaptive Gaussian second derivative $\delta(x, y)$ from $f(x, y)$ as follows.

$$f'(x, y) = f(x, y) - \delta(x, y) \qquad (5)$$

Finally, the original Y image is replaced by sharpened luminance image Y' and converted into R'G'B' primary color image from luminance-chrominance image by inverse transform.

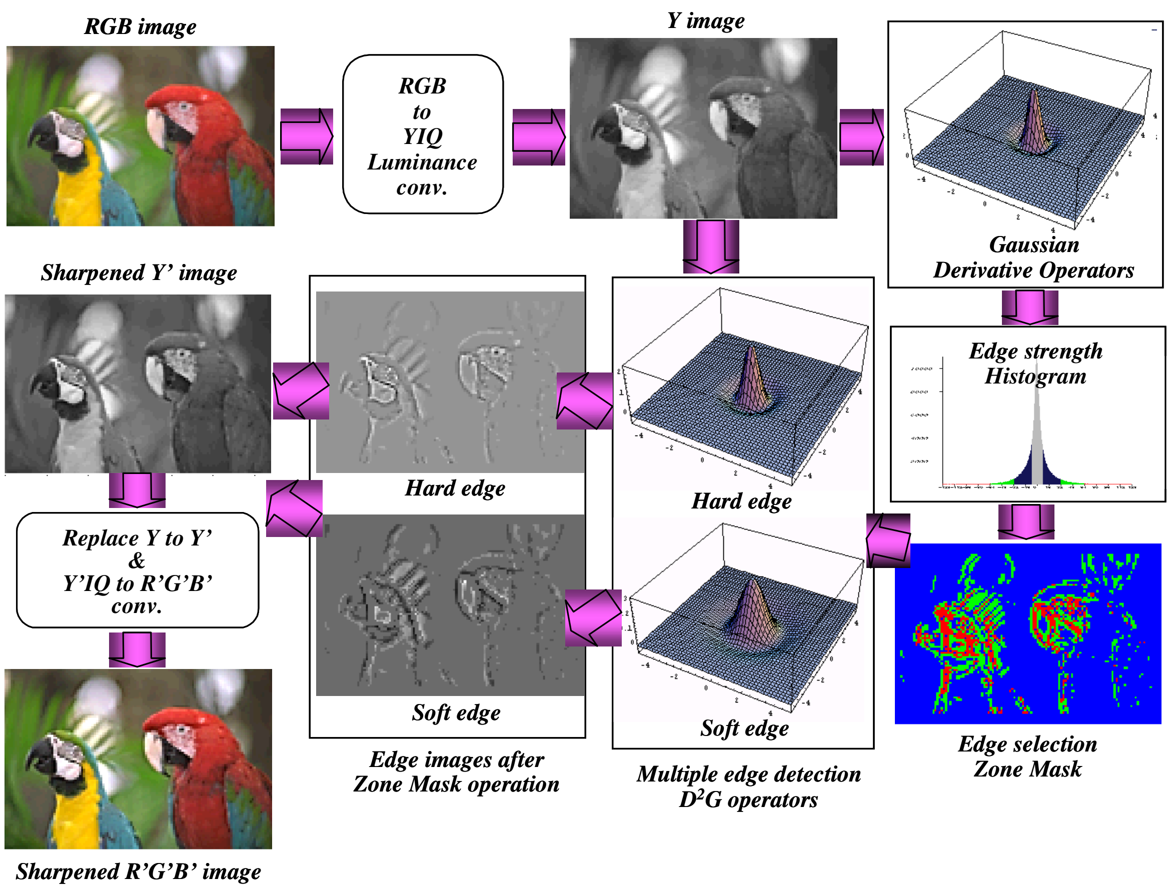

Figure 1. Overview of Sharpness Improvement Procedures

(a) original image *(b) conventional non-adaptive **GD*** *(c) proposed adaptive **GD***

Figure 2. Comparison of sharpened images

Experimental Results

Fig.2 shows an example of sharpened images by the proposed adaptive method in comparison with non-adaptive method :
(a) original (b) non-adaptive Gaussian derivative
(c) proposed adaptive Gaussian derivative

As clearly viewed in the image (b), the flat area noises are also enhanced together with the edges, but are dramatically reduced in (c), because the enhancement operations are suppressed in the areas with gentle or flat slopes. Moreover, the proposed method provides with smoothed and natural sharpening effects adaptive to the hard, medium, and soft edge slopes in the image.

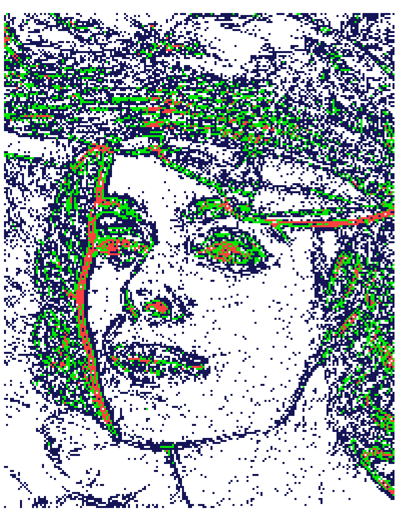

Figure 3. Zone mask image for switching the filters

Fig. 3 is the corresponding zone mask image used for switching the three types of edge sharpening filters, and Fig. 4 shows the histogram of measured edge strengths.

Here, the red, green, and dark blue colors represent the hard, medium, and soft edge zones, respectively. While, the gentle or flat slope areas are shown in white color for the zone mask image in Fig.3 and in gray zone for the histogram in Fig.4.

Fig. 5 illustrates an example of sharpened image profiles in a typical scan line including various types of edge strengths. In this sample, ***non-adaptive single GD*** method used a single second Gaussian derivative filter with small σ designed to response to the sharp hard edges, while the proposed ***adaptive multiple GDs*** method applied said three types of second Gaussian derivatives adaptively to the selected edge types. The enhanced image profiles include two different edge zones, that is, (1) mixed edge zone and (2) gentle or flat slope zone. In the proposed method, these different edge slopes are very well sharpened adaptive to the edge strengths without amplifying the background noises, while a single filter method works every where uniformly to enhance all the gradients including unwanted noises.

Discussion and Conclusions

An image sharpening ***adaptive filtering*** method is proposed.

Multiple Gaussian derivative operators have been applied adaptive to the edge strength and resulted in natural sharpness improvements without enhancing the background noises. Here the edge enhancement operators are applied only to the luminance signal. The same process may be applied to RGB tri- color signals simultaneously. However, the edge responses to R, G, and B channel are different one another, then the shears in color for achromatic grayish edges may cause unacceptable artifacts. Because the statistical distributions of edge slopes depend on the image contents, the specifications of pre-scanning GD filter and edge sharpening GD filters should be designed dependent of the given image. The standard deviation σ and the weighting coefficients of GD operators are to be determined by taking the digital matrix sizes into consideration. In our experiments, the sizes of GD filters have been set around 9 x 9 or 11 x 11 pixels in practice, and the second derivative filter coefficients have been adjusted for their sum to be equal to zero.

The classification of edge strengths are based on the histogram of the edge signals and also dependent of the image contents. At present, the segmentation of edge strengths to make the zone mask is based on cut and try or simple division in the min-max range. The automatic generation of optimal zone mask is a future work and is under development. As well, the use of multiple pre-scanning GD filters is now under investigation for the better measurements and classification of edge strengths.

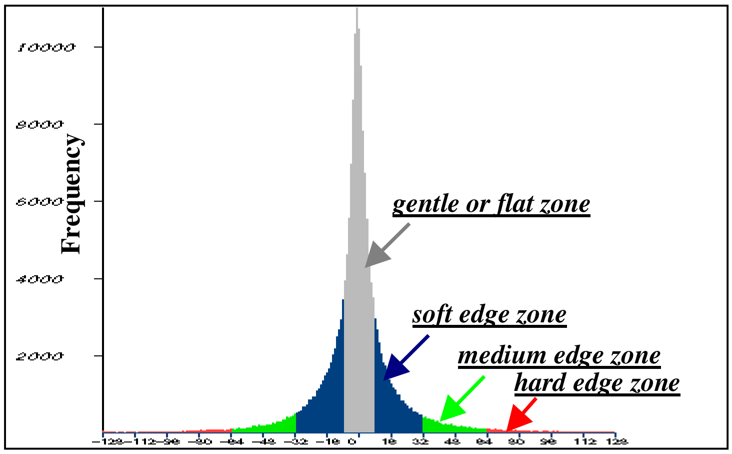

Figure 4. Histogram of edge strengths

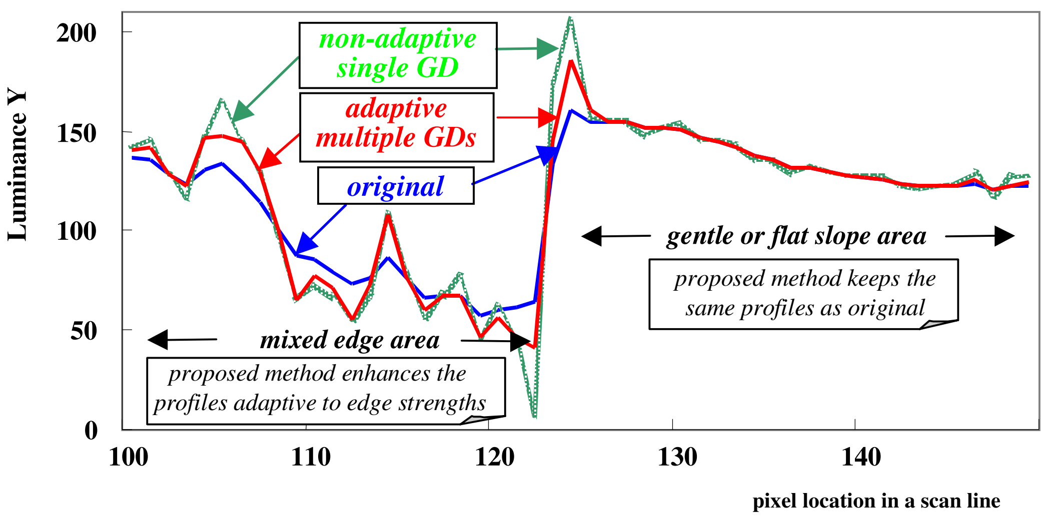

Figure 5. Typical edge profiles in a scan line aftersharpening

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Biography

Hiroaki Kotera received his B.S degree from Nagoya Institute of Technology in 1963 and Doctorate from University of Tokyo in 1987. In 1963, he joined Matsushita Electric Industrial Co. Since 1973, he has been working in digital color image processing at Matsushita Research Institute Tokyo, Inc. In 1996, he moved to Chiba University. He is a professor at Dept of Information and Image Sciences. He received Johann Gutenberg prize from SID in 1995.