Multi-Scale Image Sharpening with Noise Reduction

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Abstract

The color image has various edge profiles. In the conventional single kernel sharpness filter has the drawbacks of exhausting background noises or insensitivity to the dull edges. In the previous paper,[1] we proposed an adaptive image sharpening method to the edge profiles. This paper, reports its advanced model, which has both sharpening and smoothing functions. In addition, the paper assesses the edge sharpness factors by introducing the indices, such as ***ES*** (Edge Sharpness), ***FS*** (Spatial Frequency Sharpness), and ***Nf*** (Flat Area Noise). The improved model makes the flat area noises intentionally ***smoothed*** with preserving the enhanced edges. A pre-scanning spatial filter generates the ***edge map*** to classify the edge types into hard, medium, soft, and flat zones. The multiple ***GD*** (Gaussian Derivative) operators with different deviations are selectively applied to the corresponding edge zones by looking up the ***edge map***. Here the smoothing filters are applied only to the flat zones to reduce the background noises. In comparison with the single kernel filter method, the proposed model worked excellent to sharpen the different edge slopes naturally together with dramatically reducing the background noises.

Introduction

The color image has different edge profiles depending on the characteristics of the objects placed in the scene. In the conventional edge enhancement methods, such as Laplacian or unsharp masking, a single filter is applied to the entire image. The non-adaptive single sharpness filter is known to have the following drawbacks such as

[1] Background noises in flat area are amplified with edge enhancement.

[2] Dull edges are not well sharpened by a fixed single filter

In the unsharp masking approach, a fraction of the high-pass filtered version of the image is added to the original image. It is simple, but enhances the noise and/or digitization effects resulting in visually unpleasant image. While the noise can be suppressed with low-pass filters associated with the blurring of the edges. Ramponi et al proposed a nonlinear unsharp masking method[2], which combines the features of both high-pass and low-pass filters. Inoue and Tajima reported an adaptive image sharpening method,[3] which estimates the edge sharpness by high band-pass filter based on DOG function.

However, these methods don't suppress the flat area noises sufficiently. Also, the conventional Laplacian filters don't create the natural sharpness, because they have local edge responses different from the receptive field in human vision.

In the proposed method, multiple edge enhancement filters are applied to work adaptive to the different edge slopes and to work ***intentionally smoothing*** the background noises in the flat areas avoiding the enhancement.

Edge Sharpening Operator

A variety of simple cell receptive field models for human vision have been considered such as ***GD*** (Gaussian Derivative), ***Gabor***, ***DOG***, ***DOOG***, ***DODOG***, and so on.

Stork and Wilson, Yang, and Klein et al, disputed which one, Gaussian derivative (***GD***) or Gabor[4] could 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] applied ***GD*** to detect zero-crossing edges.

Here we also applied ***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

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

Figure 1 shows the 3D shape of ***GD*** spatial filter and its cross sectional view.

The effective field spreads to $r_2 \cong \pm 4\sigma$ from center. Hence $M \cong 8\sigma + 1$ will be sufficient to reflect the receptive field. For example, $7\times7(\sigma=0.7) \sim 13\times13(\sigma=1.5)$ matrices may be applied to describe the GD filters.

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

$$\delta(x,y) = -\nabla^2 G(x,y) \otimes f(x,y) \tag{3}$$

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

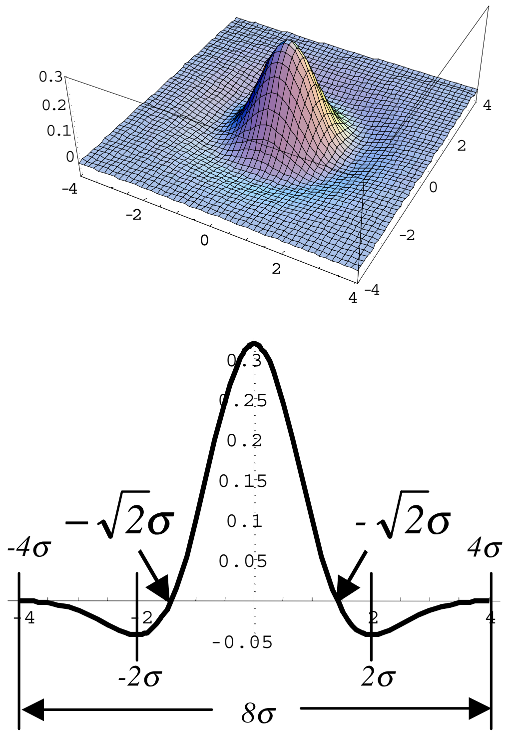

Figure 1. GD operator based on human visual field response

Multi-Scale Filtering by Edge Segmentation

Figure 2 illustrates the sharpening process in the proposed system. First, the RGB image is transformed into luminance -chrominance image such as YCrCb or YIQ. The edge enhancement is applied only to the luminance *Y* image to keep the gray balance on the edges. The edge strengths are analyzed by the histogram of $\delta(x, y)$ by a pre-scanning sharp ***GD*** filter and classified into multiple zones reflecting the edge profiles, such as, ***hard***, ***medium***, ***soft***, and ***flat***. Thus the ***edge map*** is generated to discriminate these edge types. The multi-scale Gaussian derivative operators $-\nabla^2 G$ with different σ_1, σ_2 and σ_3 are selectively applied to Y image by looking up the ***edge map***.

Thus, the luminance *Y* image is sharpened by adding this edge adaptive ***GD*** signal $\delta(x, y)$ to image $f(x, y)$ as follows.

$$f'(x, y)=f(x, y)+ \delta(x, y) \quad (4)$$

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

Experimental Results

Figure 3 shows an example of sharpened images by the proposed adaptive method in comparison with non-adaptive single kernel method in the close-up views:

As clearly viewed, the flat area noises are enhanced together with the edges in the conventional method, but are dramatically reduced in our method. Watching carefully, the proposed method provides with better background than the original by noise reduction smoothing filter and natural sharpening effects adaptive to the edge slopes in the image.

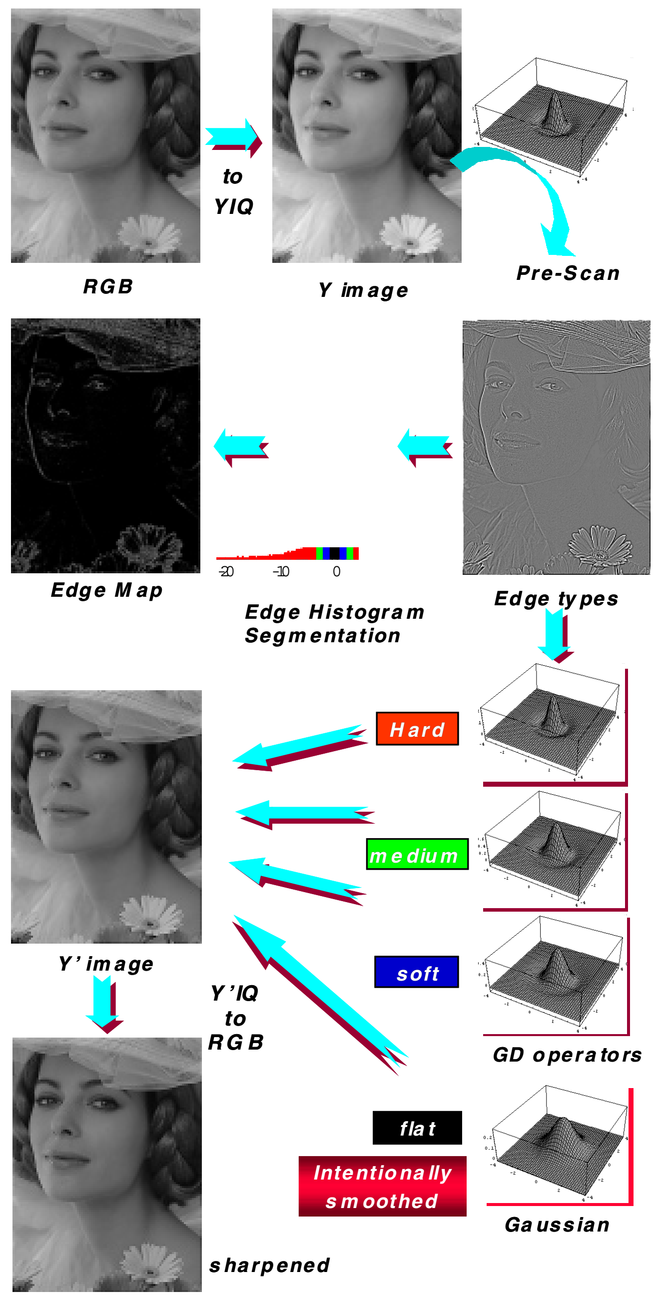

Figure 2. Multi-scale adaptive image sharpening process.

Figure 4 illustrates a comparison in the sharpened edge profiles along the scan line. The ***edge map*** shows the corresponding three edge types classified by the red, green, blue, and black colors representing the hard, medium, soft edge zones, and flat areas respectively. While, the lower figure shows how the proposed multi-scale GD filters work adaptive to the edge slopes. As clearly shown in these profiles, the proposed method has both the sharpening and smoothing effects. The red line is smoother than the original in the most left and right sides of the scan line, but well responding to the edge slopes in middle parts. On the contrary, the dotted line by causes the unwanted enhancement of background small noise in the flat area.

Fig.5 shows another comparison in the sharpened images. In this sample, the ***non-adaptive*** method used a single ***GD*** filter with σ=0.6 designed to response to the sharp edges, while the proposed ***adaptive*** method applied the same ***GD*** filter with σ=0.6 for pre-scanning and used three types of ***GD*** filters with σ=0.6, 0.7, and 0.8 for hard, medium and soft edges. The normal Gaussian smoothing filter with σ=1.0 was applied to the flat area. The center house with triangle roof in original image (a) includes sharp edges, while the next building to the right has smooth wall as shown in the edge map image (b). In the close up image (c) sharpened by the ***single GD filter***, the wall area of right building looks too much rugged or uneven due to the ***non-adaptive*** enhancement. On the contrary, the proposed method reproduced the wall area of right building very smoothly while sharpening the center house as shown in the close up (d). The smoothing filter in the proposed ***adaptive*** method dramatically improved the image quality in the flat areas as compared with ***non-adaptive*** method.

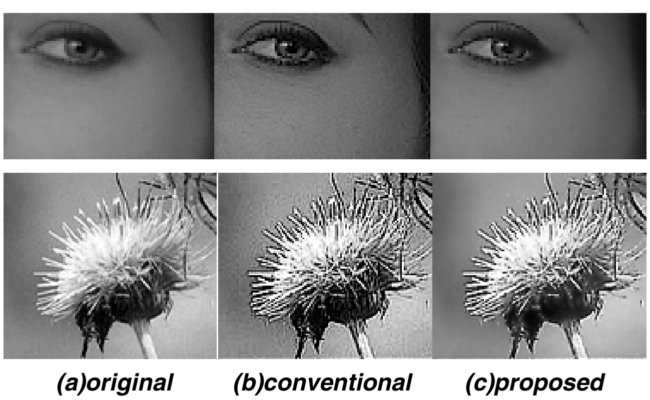

Figure 3. Comparison of sharpening effects in close up

Sharpness Factor

To estimate the sharpening effects, any sharpness index is necessary. Inoue and Tajima introduced the edge sharpness index ***ES*** to measure the strength of edge components after sharpening by

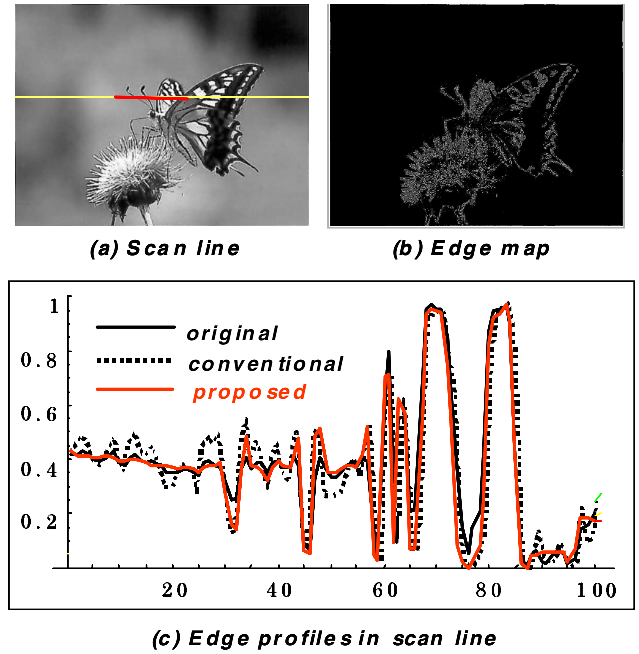

Figure 4. Comparison of edge profiles along the scan line

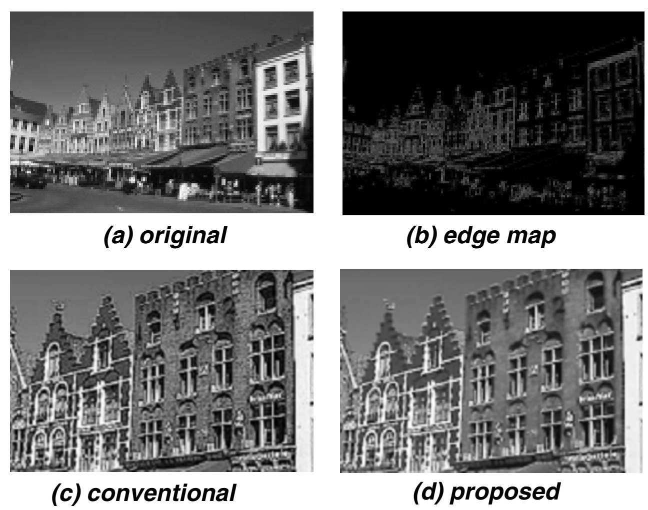

Figure 5. Comparison of sharpening effects

Edge Sharpness: ES

$$ES = \frac{\iint_E \left| g(x,y) \otimes s_{filt}(x,y) \right| dxdy}{A_E} \tag{5}$$

s_{filt} : sharpening filter, A_E : amount of Edge Area

ES is an effective index to measure the enhanced edge components existing in the edge areas.

In addition, we newly introduced the following indices to assess the sharpened image quality taking the other visual factors into consideration.

Frequency Sharpness: FS

$$FS = \frac{\int \left\{ \left| G_{sharp}(f) \right| - \left| G_{org}(f) \right| \right\} V(f) df}{\int \left| G_{org}(f) \right| V(f) df} \quad (6)$$

FS means the enhanced Fourier spectra after sharpening measured in 1-D diagonal spatial frequency *f cycle/deg*.

$\left| G_{org}(f) \right|$ and, $\left| G_{sharp}(f) \right|$ denote the Fourier spectra of original and sharpened images, and *V(f)* means visual transfer function in spatial frequency domain.

Mean Square Error: MSE

$$MSE = \iint \left\{ g_{sharp}(x,y) - g_{org}(x,y) \right\}^2 dxdy \quad (7)$$

MSE means well-known mean square error between the original and the sharpened images.

Noise in flat area: N_f

$$N_f = \iint E_{flat}(x,y) \left\{ g_{sharp}(x,y) - g_{org}(x,y) \right\}^2 dxdy \quad (8)$$

$$\begin{cases} = 1 & \text{for flat area} \\ = 0 & \text{for edge area} \end{cases}$$

N_f reflects the noise power in the flat areas except edge areas and signifies very important quality assessment measure.

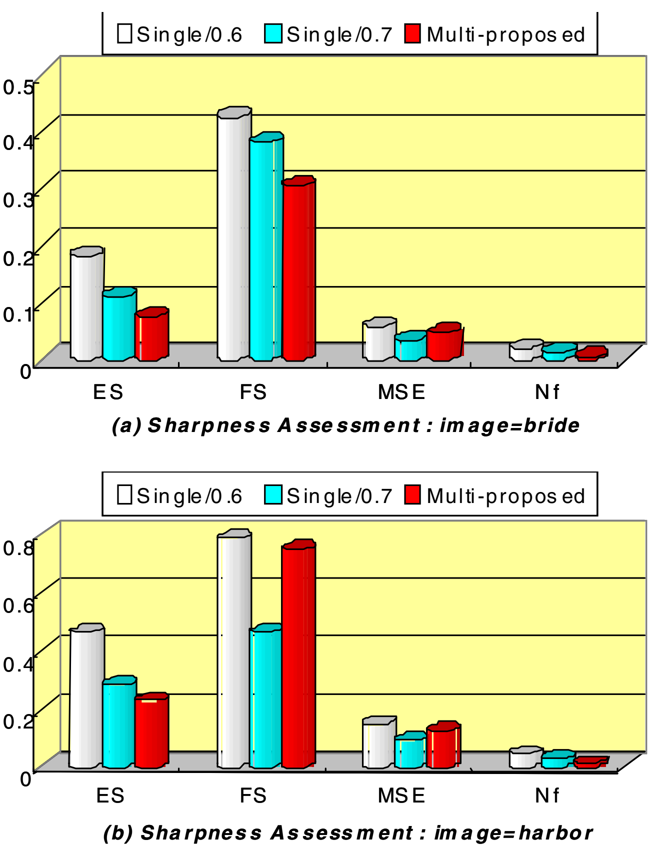

Figure 6. Comparison of sharpness factors

Figure 6 shows the measured sharpness factor for standard test images "bride" and "harbor" after sharpening. The result in the proposed method is compared with the single kernel filtering method processed by two different σ=0.6 and σ=0.7. The ***ES*** values by these two single kernel methods are larger than our method, because they works to enhance all the edge components in the image uniformly, while the proposed model operate the multiple filters, adaptive to the edge types not to enhance all the edges unnecessarily. On the other hand, as shown by the ***FS*** value, the proposed method behaves to lift up the spatial frequency components in the visible range as same as the single kernel method for the image "harbor" including much edge areas.

Figure 7 illustrates a comparison of the flat area noise for typical standard test images. It is clear the noise powers are dramatically reduced in the proposed method.

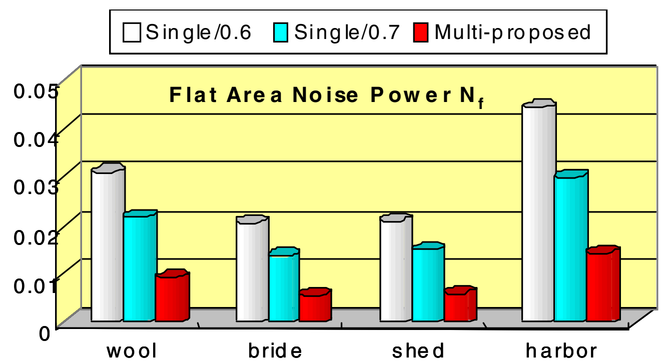

Figure 7. Comparison of flat area noises

Conclusions

A multi-scale ***adaptive*** image sharpening method with noise smoother was proposed. Multiple Gaussian derivative filters resulted in natural image sharpening adaptive to the edge profiles and at the same time Gaussian smoothing filter applied to the flat areas reduced the background noises dramatically. The classification of edge strengths are based on the histogram of the edge signals dependent of the image contents. At present, the segmentation of edge types to make the ***edge map*** is determined empirically by referencing to the normalized standard deviation σ. The advanced way to generate the better ***edge map*** is under development. Future works on the subjective sharpness quality assessments are also under planning based on psychophysical experiments.

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Biography

Hiroaki Kotera received his B.S degree from Nagoya Institute of Technology and Doctorate from University of Tokyo. He joined Matsushita Electric Industrial Co in 1963. 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 and journal awards from IS&T in 1993, from IIEEJ in 1990 and 2000.