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Adaptive Image Sharpening Method Using Edge Sharpness

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Abstract

This paper proposes a new method for automatic improvement in image quality through adjusting the image sharpness. This method does not need prior knowledge about image blur. To accomplish this work, the authors developed a new method for evaluating image sharpness without MTF. This is called image "edge sharpness" value. According to the subjective experiments, optimal edge sharpness value for image quality was obtained. Image sharpness can be optimally and automatically adjusted by altering the edge sharpness into optimal value. This method was applied to several images, obtained by scanning photographs, and experimental results were good.

1 Introduction

The targets of this method are mainly natural images obtained by scanning photographs or video equipments,etc. Sharpness is the most important factor on image quality. To improve image quality, the sharpness must be adjusted to an optimal value. For automatic image quality improvement, the following subjects need to be settled.

1. A method to evaluate image sharpness, and to express it as physical value.
2. Determining the optimal sharpness value that makes an image quality the best.
3. An algorithm to alter an image into one which has optimal sharpness.

To evaluate image sharpness, previous works usually used the modulation transfer function(MTF), or some other known blurring mechanism on the image [1][2][3]. However, when dealing with images obtained by scanning photographs, or from video equipments, MTFs are usually unknown. Therefore, in these cases, the image sharpness could not be evaluated.

In this paper, the image edge sharpness(ES) value is used to evaluate image sharpness. It is defined by average intensity of the high spatial frequency components in the edge area. By using this, it is possible to calculate image sharpness without MTF.

In the following section, the ES value is described. Then experimental results, obtained from comparison between the ES value and subjective image sharpness, are presented, along with quality. Section 5 shows the algorithm to alter an image into another image which has different edge sharpness value. Using this method, image sharpness can be optimally and automatically adjusted.

2 Edge Sharpness

In this section, the edge sharpness(ES) value is defined. It is considered that human visual system judges image sharpness mainly considering the edge area features. Therefore, attention is paid to the high spatial frequency components in the edge area. The ES value is defined by average intensity of the high spatial frequency components in the edge area.

Equation 1 shows the ES definition. In this equation, $f(x,y)$ is an input image, and ES_f is the edge sharpness value for image $f(x,y)$. The $E(f)$ is edge area in the input image, and $A_E(f)$ is amount of edge area $E(f)$. The $SS(u,v)$ is a high band-pass filter, which is the weighting function for spatial frequency with respect to subjective sharpness, and $ss(x,y)$ is inverse fourier transform of $SS(u,v)$. The numerator in Eq.1 represents integral high spatial frequency components in $E(f)$.

$$ES_f = \frac{\int\int_{E(f)} |f(x,y) \otimes ss(x,y)| dxdy}{A_E(f)} \quad (1)$$

Sharpness is a scale with human visual sensitivity. Therefore, the high band-pass filter $SS(u,v)$ must be defined considering visual sensitivity for spatial frequency.

The human visual system has band-pass spatial frequency characteristics [4]. The very high frequency components are not sensed in human visual acuity, so they do not influence image sharpness. Therefore, $SS(u,v)$ has a cut-off in high frequency side, which corresponds with the MTF for the human visual system.

In Reference[5], sharpness weighting function $Gr(u)$ was defined as a function of spatial frequency and MTF for the visual system. That is represented as:

$$Gr(u) = 2uR(u)H(u) \quad (2)$$

where u is spatial frequency, $R(u)$ is MTF for the human visual system, and $H(u)$ is MTF for the imaging device. The $SS(u,v)$ concept is to that for $Gr(u)$.

According to the concept, $ss(x,y)$ is defined as the difference of gaussian filter, for simplicity.

$$ss(x,y) = A\exp\frac{x^2+y^2}{2\pi\sigma_1^2} - B\exp\frac{x^2+y^2}{2\pi\sigma_2^2} \quad (3)$$

$$A = \frac{1}{2\pi\sigma_1^2}, B = \frac{1}{2\pi\sigma_2^2} \quad (4)$$

Constant values σ_1 and σ_2 were determined as follows. Any noticeable difference in a step edge was examined, by filtering the step edge image with gaussian-filters with several σ values. The σ_1 was obtained as the value just noticeable in a step edge. Moreover, the authors made sharpening experiments on the blurred step images with several filters. The σ_2 value was determined as being the best in the most natural sharpening result. Figure 1 shows 1 dimensional spatial frequency characteristics for $SS(u)$. Spatial frequency u is represented by [cycle/deg].

Equation 1 includes the edge area $A_E(f)$ and $E(f)$. Therefore, to implement the method, the edge detection filter is needed. In this paper, the sobel filter is used to detect the edge area.

3 Subjective Image Sharpness and Edge Sharpness

In order to examine the relationship between ES values and subjective sharpness, the authors carried out experiments using several natural images. In Table 1, the experimental conditions are presented. 48 images, which were 8 pictures and 6 different sharpness levels for each picture, were observed. The ES value was calculated considering translating luminance to L^* (CIE 1976 $L^*a^*b^*$). The five-grade scale method was used in this experiment. The grades are given in Table 2.

Table 1: Viewing conditions

display	N7832-23(NEC) 20inch
display size	1280*1024 pixel
viewing distance	0.5 m
u_{max}	15.96 cpd
picture size	512*512 pixel
number of pictures	8*6 grade
gray level	8 bit
number of observers	10

Table 2: Sharpness grades for subjective evaluation

Grade	Sharpness
5	sharp
4	slight by sharp
3	normal
2	slight by blurred
1	blurred

Experimental results are shown in Fig.2, and Fig.3. The correlation coefficient was $R = 0.793$. The experiments confirmed that the ES value showed a good linear relation with subjective image sharpness.

4 Subjective Image Quality and Edge Sharpness

Subjective image sharpness does not have a monotonic relation with subjective image quality. Therefore, the authors also examined the relationship between subjective image quality and the ES value. Experimental conditions were same as for the previous experiment (Table 1). Evaluating grades are shown in Table 3.

Figure 4 shows the relationship between image quality and ES values. These results showed that, if the ES value was within a particular range, the image quality was judged to be good. Therefore, there should be an optimal ES value that optimizes the image quality(Fig.4). The optimal ES value ($ES_{opt} = 2.63$) was obtained from the experiment.

Table 3: Quality grades for subjective evaluation

Grade	Quality
3	better
2	normal
1	worse
+1	the best

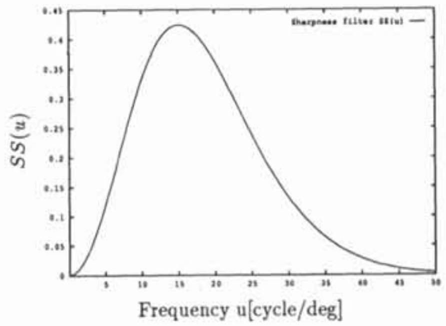

Figure 1: Spatial frequency characteristics for $SS(u)$

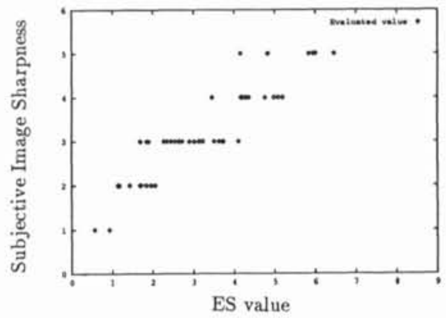

Figure 2: Relation between ES value and subjective image sharpness(observer A)

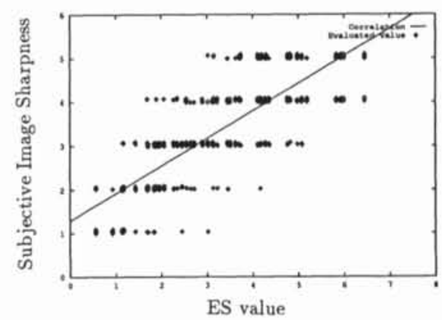

Figure 3: Relation between ES value and subjective image sharpness(all data plotted)

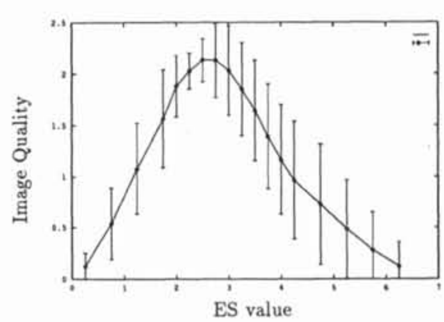

Figure 4: Relation between ES value and subjective image quality, where error bars indicate $\pm\sigma$

5 Sharpness Alteration Algorithm

An algorithm for use in altering an image into another image, which has a different ES value, is proposed in this section. In order to adjust ES value, a method to control the image high spatial frequency components is used. It is represented by Eq.5

$$fs = f + k(f \otimes ss), \tag{5}$$

where f is an original image $f(x, y)$, fs is an image whose sharpness is altered. ss is a high pass filter, and k is a coefficient(enhancement or reduction ratio). It shows that, if $k > 0$, a sharpened image is obtained, and, if $k < 0$, a blurred image is obtained. The authors use $ss(x, y)$ in Eq.3 as ss.

Therefore, using Eq.1 and Eq.5, the edge sharpness of altered image ES_{f_s} is represented in Eq.6.

$$\begin{aligned} ES_{f_s} &= \frac{\int\int_{E(f_s)} |(f + k(f \otimes ss)) \otimes ss| dxdy}{A_E(f_s)} \\ &= \frac{\int\int_{E(f_s)} |f \otimes ss + k(f \otimes ss) \otimes ss| dxdy}{A_E(f_s)} \end{aligned} \tag{6}$$

The desired enhancement(or reduction) degree(coefficient k) for the high frequency components is obtained by solving Eq.6 iteratively. In order to solve it faster, the following approximation Eq.7 is adopted.

$$\begin{aligned} & \int\int_{E(f_s)} |f \otimes ss + k(f \otimes ss) \otimes ss| dxdy \\ \approx & \int\int_{E(f_s)} |f \otimes ss| dxdy \\ & + k \int\int_{E(f_s)} |f \otimes ss \otimes ss| dxdy \end{aligned} \tag{7}$$

Therefore, k is calculated by Eq.8.

$$k \approx k_a = \frac{ES_{f_s} \cdot A_E(fs) - \int\int_{E(f_s)} |f \otimes ss| dxdy}{\int\int_{E(f_s)} |f \otimes ss \otimes ss| dxdy} \tag{8}$$

Equation 7 shows that, if $k > 0$, $k > k_a$, and, if $k < 0$, $k < k_a$. This rule keeps the image from deteriorating in quality due to too much enhancement(or reduction). Based on results obtained from several experiments, it was shown that the difference between k and k_a was too small to have much influence on actual image sharpness.

To calculate first $k(= k_0)$, $E(fs) = E(f)$, and $A_E(fs) = A_E(f)$ are assumed. Then k_0 is given by:

$$k_0 = \frac{(ES_{f_s} - ES_f) \cdot A_E(f)}{\int\int_{E(f)} |f \otimes ss \otimes ss| dxdy}. \tag{9}$$

In Fig.5, the processing flow chart is shown. First, calculate k_0 by Eq.9, and obtain sharpness altered image $f_1(x, y)$ by using k_0. Next, detect the edge area for f_1, $E(f_1)$, and the new $k = k_1$ is calculated by using Eq.8. After the iteration, the desired k values is obtained. Applying the k to Eq.5, the image edge sharpness ES_f can be converted to ES_{f_s}.

By using this algorithm, the ES value for an image can be adjusted to the optimal ES_{opt}. Consequently, the image quality is automatically improved.

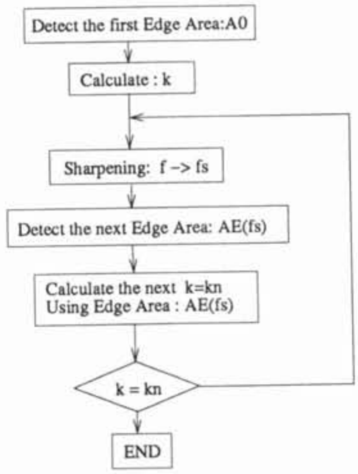

Figure 5: Processing flow for the adaptive image sharpening

6 Experiments

This new image improving method was applied to several images, that were obtained by scanning photographs. Table 4 shows the experimental results, where ES_0 and Q_0 are ES and quality for input images, ES_n and Q_n are those for output images. k is the enhancement coefficient. From the table, it is shown the ES values were closely adjusted to the optimal value, and every image quality was improved. It is also shown that enhancement ratios were varied with changes in original image sharpness.

Table 4: Simulation results: adjusted to $ES = 2.63$

Image	ES_0	Q_0	k	ES_n	Q_n
A	5.94	1.0	−0.98	2.87	1.9
B	1.16	1.6	4.04	2.57	1.8
C	1.70	2.1	1.18	2.58	2.2
D	1.71	1.7	1.73	2.58	2.6
E	1.13	0.9	3.57	2.57	2.3
F	0.56	0.9	6.88	2.60	2.0
G	1.18	0.5	3.23	2.58	2.2
H	0.93	0.2	6.47	2.54	2.0

Images from Fig.6 to Fig.9 show other experimental results. It is shown that input images with different sharpness (Fig.6 and Fig8) were altered to similar images with optimal sharpness (Fig.7 and Fig9).

Figure 6: Input image 1: Not sharp image

Figure 7: After adaptive sharpening for image 1(enhanced high frequency)

Figure 8: Input image 2: Sharp image(too sharp)

Figure 9: After adaptive sharpening for image 2(reduced high frequency)

7 Conclusion

An adaptive image sharpening method was proposed that evaluates sharpness only from input images, and alters that to the optimal sharpness. Although the optimal ES value may be varied with differing output devices, viewing conditions, and individuals, it is easy to estimate the value from several images.

The advantage of the method is that it is an automatic improvement, and that it does not need prior knowledge about image blur. The experimental results for natural images were quite good, and the advantages were confirmed. This method is a simple and effective method, and can be useful for various imaging systems.

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