Influence of Image Enhancement Processing on SFR of Digital Cameras

Yukio Okano
Sharp Corporation, Information Systems Labs.
Yamatokoriyama, Nara, JAPAN

Abstract

The SFR for digital still camera is affected by the non-linear image enhancement processing. We analyze the influence of the edge chart contrast on SFR characteristics. The SFR expressions depending on the chart image contrast are proposed. The resolution limit measurement method based on the slanted edge is also proposed.

Introduction

The sharpness of digital camera system is entirely expressed by the SFR(Spatial Frequency Response)[1] which equals to the total MTF(Modulation Transfer Function)[2] of the camera system. The SFR is calculated from slanted black-white (white-black) edge. The SFR can be considered as the linear function, when the filtering operations are performed in the linear manner. However, digital still camera system is suffering from non-linear image processing. One of the non-linear operation is image enhancement processing which compensate the sharpness of images degraded by the optical system, CCD aperture, interpolation process and so on.

In this paper, we analyze the SFR characteristics for image enhancement processing. It is found that the SFR curve changes in accordance with the image contrast of slanted edge image. We propose the SFR expression depending on the contrast of chart image.

The filtering processes of digital cameras are usually performed in the gamma=0.45 space, so the LSF(Line Spread Function) calculated from slanted edge becomes asymmetrical function. The influence of gamma correction on SFR is also considered.

The resolution limit measurement method based on the width of slanted LSF is proposed

Image Enhancement Processing

The image enhancement processing is divided into two steps. One is enhancement of high frequency components and another is noise reduction process. Figure 1 shows the block diagram of an image enhancement processing. This processing is usually performed in the luminance channel or green channel.

Enhancement of High-Frequency Components

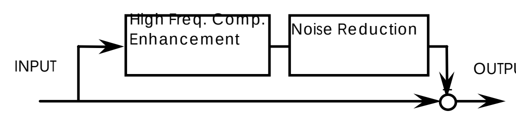
High-boost filter or Laplacian filter is used for image enhancement operation.[3] Figure 2 shows the filter kernel and frequency characteristics of a Laplacian filter.

The image enhancement filtering processes are based on mathematical calculation. As the pixel values of enhanced image are restricted from 0 to 255 in case of 8-bit image, overflow and underflow occurs for high contrast chart in image enhancement process. The SFR is affected by this non-linear mathematical process.

Noise Reduction

One of the noise reduction processes is the noise-slice which cuts off the low amplitude noise components. Figure 3 shows the input/output characteristics of the noise reduction process. This process is called " corring" in the field of video image processing.[4]

Figure 1: Schematic diagram of image enhancement process.



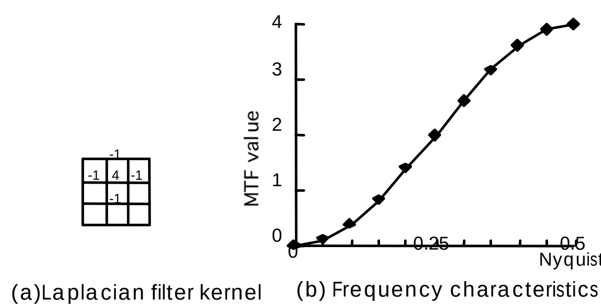
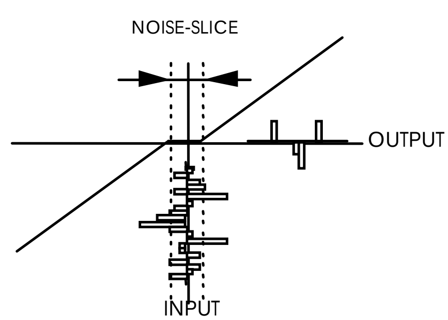


Figure 2: Laplacian filter kernel and its frequency characteristics

Figure 3: Input/Output characteristics for noise reduction



SFR for Image Enhancement Processing

The influence of non-linear image enhancement processing on SFRs is carried out by computer simulation. The pixel values for filtered chart image are limited to 8-bits.

Test Chart and its SFR

The digital test chart image which is slanted 5 degree is made on the Adobe's "Photoshop", as shown in Figure 4. The contrast of edges are varying 9 steps. This chart image is filtered by the digital 2*2 low-pass filter, which simulate the optical low-pass filter of a digital still camera.

The SFRs are calculated using the software "Image Analyzer 6.1.3" developed by ISO/TC42/WG18.[1] The calculated SFRs show the almost same curves for varying the edge contrast, as shown in Figure 5. SFR curves become zero at the Nyquist frequency for the effect of low-pass filter

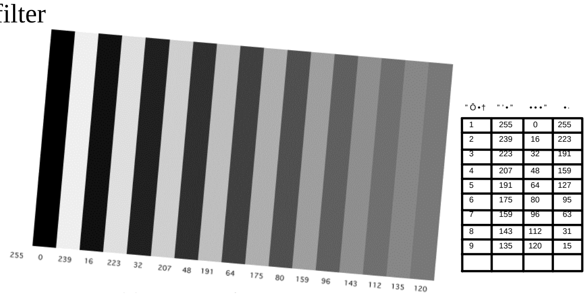


Figure 4: Edge chart

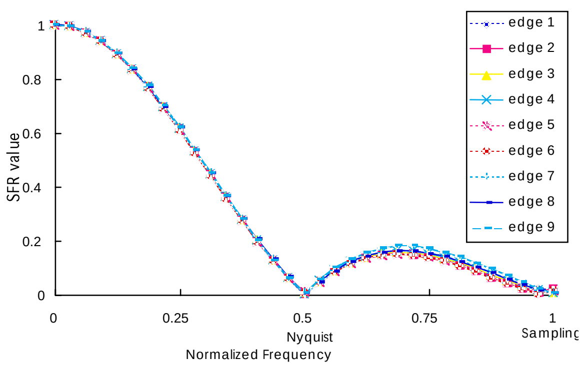


Figure 5: SFRs for the edge chart

SFRs by using Laplacian filter

The high frequency components separated by the Laplacian filter shown in Figure 2, are added to original chart image. The enhanced SFRs are shown in Figure 6.

In Figure 6, the SFRs for edges numbered 1 through 4 have lower peak value than edges 5-9 and do not become zero at the Nyquist frequency. As the pixel values for filtered image are restricted from 0 to 255 in mathematical calculation, the non-linear effect occurs for high contrast edges. The SFRs for edges 5-9 which correspond from medium to low edge contrast are same shape, because they do not suffer from the above non-linear effect.

It seems that the resolution limit becomes higher in high contrast edge1-3 by the Laplacian filtering. However, it only means that the high contrast edges contains high frequency components for the effect of the non-linear operations.

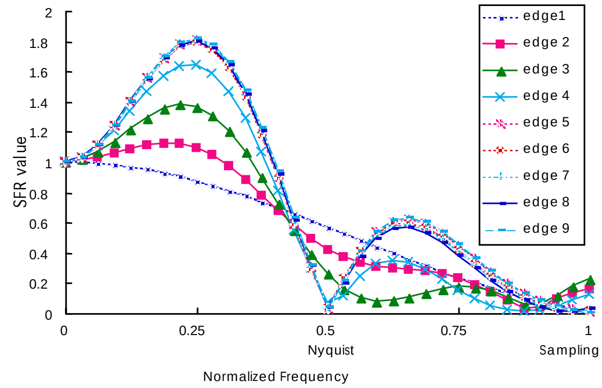


Figure 6: SFRs for Laplacian filter

SFRs for noise reduction processing

The high frequency components separated by the Laplacian filter are processed by the noise reduction, shown in Figure 3. The processed high frequency components are added to original chart images. The resultant SFRs for the edge images are shown in Figure 7.

The influence of noise reduction processing can be remarkably seen in the SFR for low contrast edges. The peak values for edges 7, 8, 9 becomes lower than Laplacian filtered SFRs shown in Figure 6. This fact means that the noise reduction process reduces the SFR values for low contrast edges.

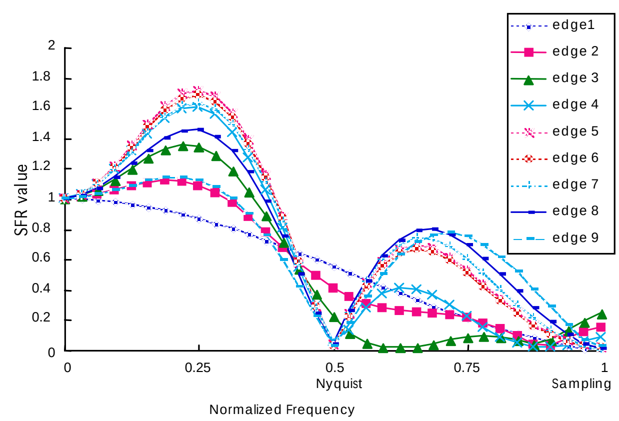


Figure 7: SFRs for Laplacian filter and noise reduction

SFR Expressions in accordance with Edge Image Contrast

The SFRs for digital still camera vary with the chart edge contrast because of non-linear image enhancement processing, as shown in Figure 7. The SFRs for linear system show same curves. However, SFRs depend on contrast of chart images for the non-linear system.

We propose the new SFR expressions which accord to the edge image contrast. The contrast is defined as,

$C_0=(I_{white}-I_{black})/I_{max}$

where C_0: SFR value for zero frequency
I_{white} :Pixel value for white edge
I_{black}: Pixel value for black edge
I_{max} :Maximum pixel value (=255 for 8bit image)

Figure 8 shows the new SFR expressions in accordance with edge image contrast. If it is necessary to evaluate the total system SFR to avoid the non-linear effect, medium contrast edge is adequate for measurement.

Effect of Gamma Correction on SFR

The gamma correction for output image from digital still camera sets to gamma=0.45, because the CRT display has the gamma=2.2.[5,6] When the image enhancement processing is carried out in the gamma=0.45 space, the effect on SFR is different from that of gamma=1 space. The SFR should be measured in the linear space, so the OECF (Opto Electronic Conversion Function)[7] is used in actual measurements.

Figure 9 shows two cases of the gamma correction for digital still camera. Figure 9(a) shows that the image enhancement processing is performed in the gamma=0.45 space. Figure 9(b) shows that the image enhancement is performed in the gamma=1 space. The SFRs in Figure 8 correspond the image enhancement being done in gamma=1 space.

The SFRs for Laplacian filter and noise reduction filter in gamma=0.45 space is shown in Figure 10. The SFRs for edge 5-9 do not become zero at the Nyquist frequency. The effect of image enhancement processing in the gamma=0.45 space is different from gamma=1 space.

ESF and LSF in Gamma Correction

The ESF(Edge Spread Function) and LSF(Line Spread Function) for a medium contrast slanted edge (edge number 5) are calculated, at two gamma correction cases shown in Figure 9. The intensity profiles of ESFs and LSFs are shown in Figure 11. Figure 11(b)-(c) show that the Laplacian filtering is applied in gamma 0.45 space, and Figure 11(f)-(i) show the Laplacian filtering in linear space. The vertical axis is pixel value and the horizontal axis is length.

If the image enhancement processing (Laplacian filtering) is carried out in gamma=0.45 space, the filtering effect for white portion and for black portion becomes not symmetry, as seen in Figure 11(c). The LSF which is calculated from differentiation of ESF becomes asymmetric function by the filtering in gamma=0.45 space. The resultant LSF become asymmetric function, as shown in figure 11(e). However, when the filtering is performed in linear space, the LSF is symmetric functions, as shown in Figure 11(f)-(i).

The SFR derived from LSF is affected by the image enhancement processing in the gamma 0.45 space.

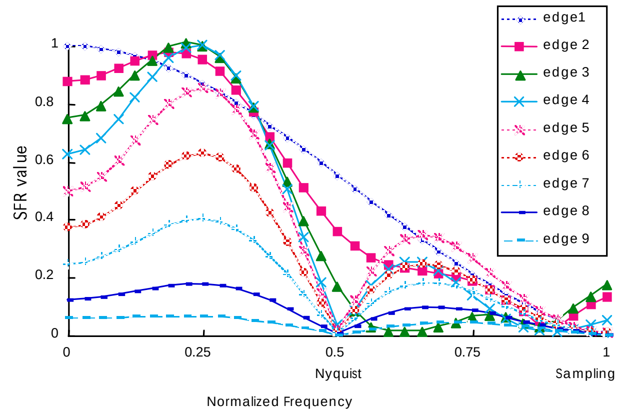


Figure 8: SFR expressions in accordance with edge contrast

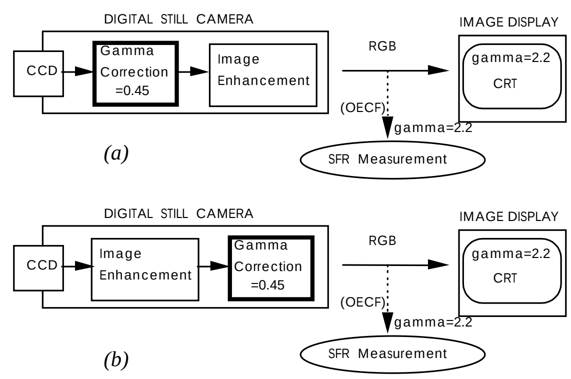


Figure 9: Two types of gamma correction for digital camera

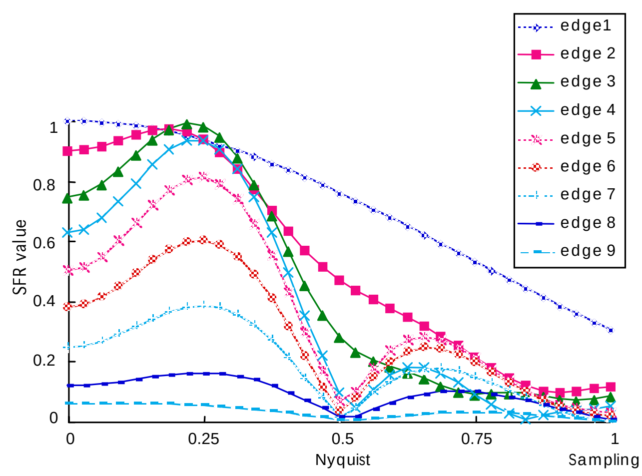


Figure 10: SFRs in case that Laplacian filter and noise reduction are made in gamma=0.45 space

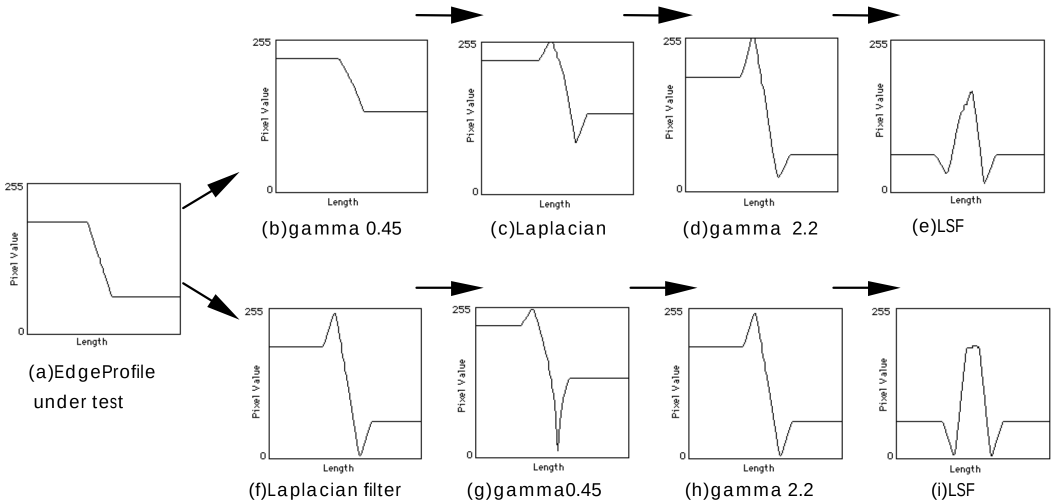


Figure 11: ESF and LSF in gamma correction

LSF from Slanted Edge

The horizontal ESF can be measured in vertical direction, by the use of slanted edge with 2-dimensional pixel array. Because the supersampled ESF for horizontal direction can be interpolated by the phase shifted vertical pixels.

The LSF can be attained by differentiation of the ESF. If we differentiate the slanted vertical edge, the super sampled horizontal LSF can be seen in the vertical direction. The 1-pixel shift for horizontal direction relates to the slanted angle. For example, when the slanted angle is 10 degree, 1 pixel for horizontal direction is equal to supersampled 5.7 pixels for vertical direction.

The supersampled LSF has many sample points, so we can get the accurate shape of LSF.

Resolution limit from Slanted LSF

Assume that the resolution limit *reso* is

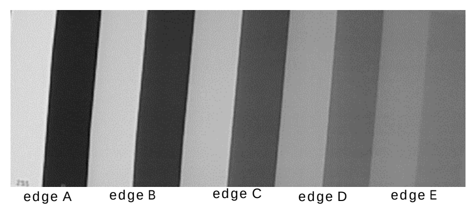
reso=spl/hw

spl is sampling period measured to horizontal direction.
hw is width between the half of average pixel value of LSF.
In this definition, *reso*=0.5 is equal to Nyquist frequency.
The sampling period *spl* is calculated from slanted angle.

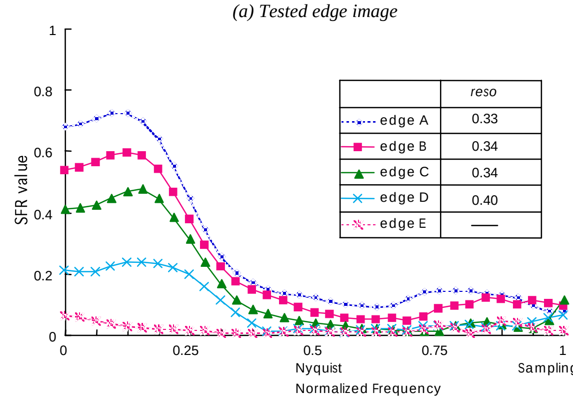
The resolution limit *reso* for the image enhanced system correspond to Figure 10 is evaluated. Table 1 shows resolution limit *reso* from slanted LSF. The slanted angle is estimated from the center points of 4 supersampled vertical LSF. The edge 4-8 have almost same value but edge 1-3 have higher value for the sake of non-linear processing.

Table 1 Resolution Limit from slanted LSF

	edge1	edge2	edge3	edge4	edge5	edge6	edge7	edge8	edge9
reso	0.81	0.52	0.48	0.46	0.46	0.45	0.45	0.46	---



(a) Tested edge image



(b) SFR and Resolution limit

Figure 12: Edge image and SFR for a marketed digital still camera

Experimental Measurements

The SFR and the resolution limit from slanted edge for a marketed digital still camera are measured. Figure 12(a) shows the slanted edge image and Figure 12(b) shows the SFR and resolution limit. The SFR values for medium frequency (around 0.15) is higher than the value of zero frequency, so it is clear that this camera utilizes the image enhancement processing technology.

The resolution limit *reso* for medium contrast edges (edge A-C) have almost same value, but have lower value than for low contrast edge D. The measurement for low contrast edge has the problem of accuracy 0for calculation.

Conclusions

SFR is useful index to express the sharpness of digital camera system. However, SFRs are affected by non-linear image processing and gamma correction.

(1).SFRs express the spatial frequency characteristics of processed slanted edge.
(2).SFR curves vary with the edge chart contrast.
(3).Gamma correction affects the SFR characteristics.
(4).Medium contrast edge chart is adequate for measuring the SFR

We propose

(1). SFR expression in accordance with edge image contrast.
(2).Resolution limit measurement method based on the slanted LSF.

References

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