

MTF Analysis and its Measurements for Digital Still Camera

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Abstract

MTF(Modulation Transfer Function) is one of the most important characteristics of digital still cameras. Imaging characteristics of 3-CCD digital still camera which has dual-green system are analyzed from the view point of MTF.

The designed MTF for 3-CCD camera in which the MTF values are higher than unity are compared with measured MTF. The measured MTFs by ISO's slanted edge method show the similar curve with calculated MTF. The measured MTFs using sinusoidal-wave chart show the low MTF value because of low-contrast chart.

Introduction

Image evaluation for digital still camera should cover many aspects. There are many factors to evaluate the image qualities of digital still cameras, such as resolution limit, MTF(Modulation Transfer Function), signal to noise ratio, color reproduction and so on.

The image qualities of digital still cameras are usually expressed as output image pixels and/or resolution limit. No proper measurement index of digital still camera exists.

MTF which shows the spatial frequency transfer characteristics is one of the most important qualities to assess the images. The total image quality concerning the sharpness of digital still camera can be suitably expressed by MTF curves.

There are many elements which affect the MTF characteristics of digital still cameras. The elements are the aberrations of taking lens, diffraction by lens aperture, optical low-pass filter, aperture of CCD sensing elements, amplifier of electronic circuit, digital interpolation filter, digital filter and so on. The total MTF for camera system is expressed by the multiplication of element MTF.

In this paer, the element MTFs of a dual-green 3-CCD digital still camera are analyzed and the designed total MTF are calculated. MTFs of the 3-CCD digital still camera are measured by (1) ISO(International Org-anization for Standardization)'s slanted edge method, (2)sinusoidal-wave chart method, (3) calculation from rectangular-wave chart method.

MTF Analysis of a Digital Still Camera

There are many elements which affect the MTF of a digital still camera. Figure 1 shows the image data flow and MTF elements affecting the image characteristics. For simplicity, MTF analysis are performed by one-dimensional expression.

The frequency components of digitized images are distributed under the Nyquist limit frequency, so the MTFs are discussed in this frequency region.

Lens System

Figure 2 shows the designed MTF of a lens system for 3-CCD digital still camera.[1] MTF based on the diffraction optics has been calculated. The lens system for the 3-CCD digital still camera includes the picture taking lens and relay lens.

MTF for green light region(G) has considerably high value at sampling frequency *Sp*. The images formed by green light mainly contribute to the sharpness of color images. The sampling frequency *Sp* of CCD image sensor for the dual-green 3-CCD digital still camera system becomes equal to the Nyquist frequency of synthesized image.

Optical Low-pass Filter

A digital still camera has an optical low-pass filter to avoid the aliasing. The plane parallel quarts plate using birefringence effect is usually used as an optical low-pass filter. The MTF curve of single quarts filter denotes as cosine function. Figure 3 shows the MTF curve for dual-green 3-CCD digital still camera system. The first zero frequency is selected as twice of sampling frequency *Sp*.

CCD Aperture

The light sensing on a CCD image element is performed by the area, not point. The MTF is degraded by this aperture effect. MTF curve for CCD aperture is defined by the light sensing distribution in the aperture. In the case of rectangular sensing distribution, MTF curve is given by

$$MTF_{CCDaperture} = \sin(Lap)/Lap$$

Lap: width of CCD aperture

Figure 4 shows the MTF curves based on the CCD aperture ratio. Recently the aperture ratio of CCD image sensor becomes almost 100%, because of micro-lens on the sensing area. The 200% aperture ratio occurs at green image of a dual-green 3-CCD digital still camera system, in the case of CCD sensor with 100% aperture ratio.

Interpolation

The synthesized green channel image for dual-green 3-CCD digital still camera becomes checkered pattern. We should fill up the pixel value by interpolation process. The interpolation is one of the digital filtering operation. This interpolation operation can change the MTF characteristics. Figure 5(a) shows the interpolation filters and Figure 5(b) shows the MTF curves. The usual interpolation by averaging the surrounding 4 pixels is shown as STD.

High-boost filtering

In order to boost the high frequency components of a digital image, the high-boost filtering operations are performed. Figure 6(a) shows block diagram of high-boost filter. The original image is filtered by a low-pass filter, and the high frequency components are computed as the difference between the original image and a low-pass filtered image.

The high-boost image can be attained by adding the multiplied high frequency components to low-pass filtered image. Figure 6(b) shows the MTF characteristics by changing the high-boost coefficients. For example, HC4 means the high frequency components being multiplied 4 times.

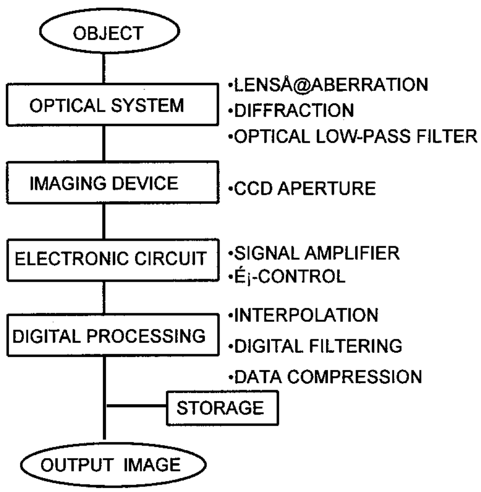

Figure 1. Image data flow and processing elements affecting the MTF characteristics of digital still camera.

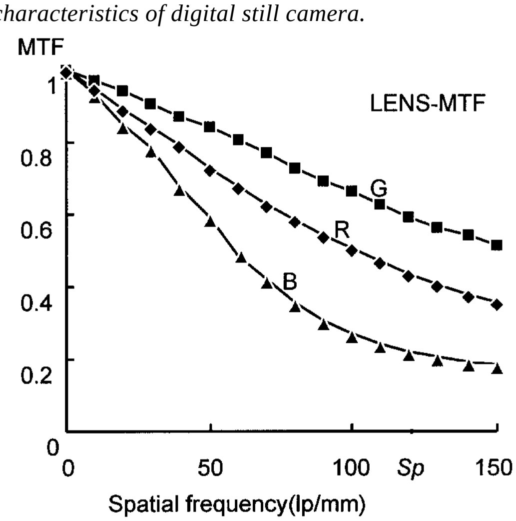

Figure 2. MTF of a lens system used for a dual green 3-CCD digital still camera. MTF for three primary colors are shown as R,G,B. Sp indicates the sampling frequency(119lp/mm) for CCD image sensors.

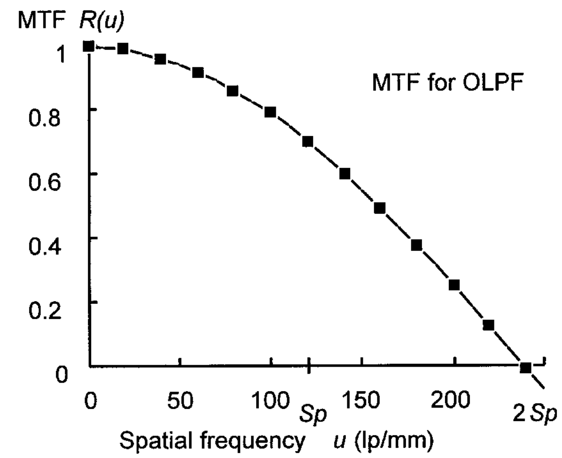

Figure 3. MTF curve of an optical low-pass filter for dual-green 3-CCD digital still camera. R(u) = cos((π*/2*)(*u/2Sp*))

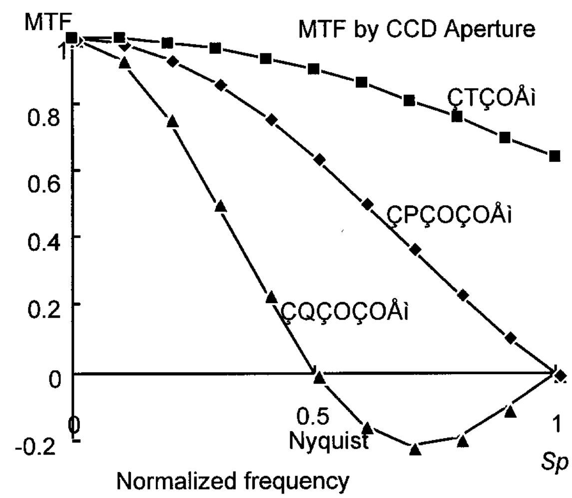

Figure 4. Degradation of MTF by the CCD aperture ratio. The sensing distribution is rectangular -form. The normalized frequency is used. Sampling frequency Sp = 1. Nyquist frequency = 0.5.

Designed Total MTF

MTF characteristics of total camera system is expressed as the multiplication of the element MTFs.

$$MTF_{total} = MTF_{lens} * MTF_{OPLF} * MTF_{CCDaperture} * MTF_{Interpolation} * MTF_{Filter}$$

Figure 7 shows one of designed total MTF for a dual-green 3-CCD digital still camera. The high-boost filter HC4 emphasize the middle frequency region. In this design, MTF for CCD aperture limits the high frequency components.

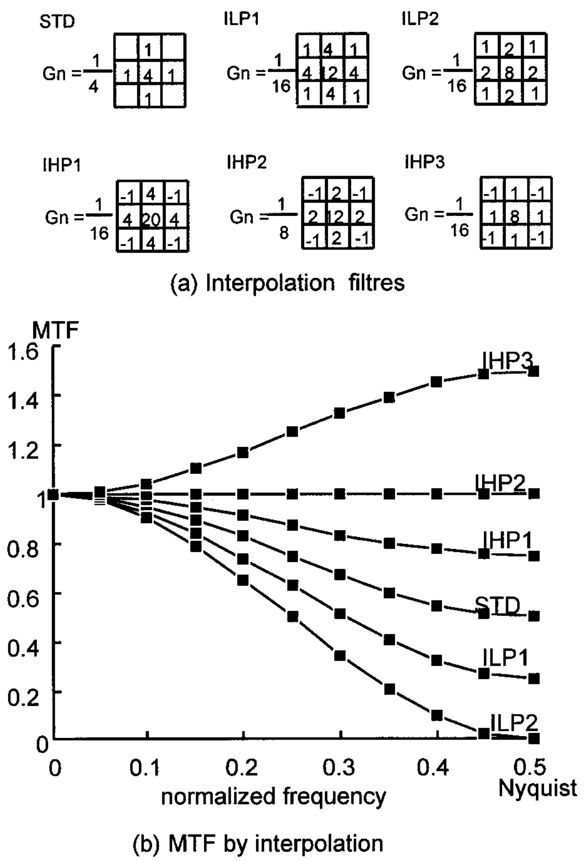

Figure 5. Variation of MTF by interpolation filters.

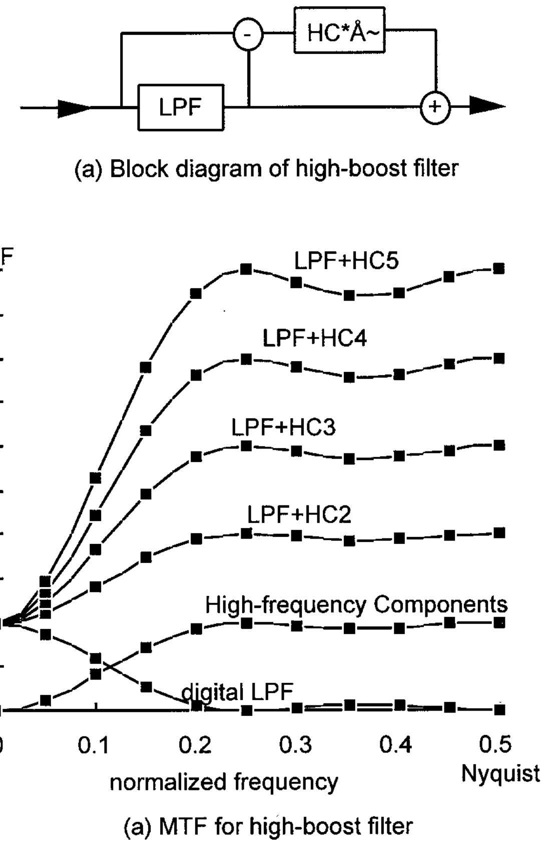

Figure 6. high-boost filtering

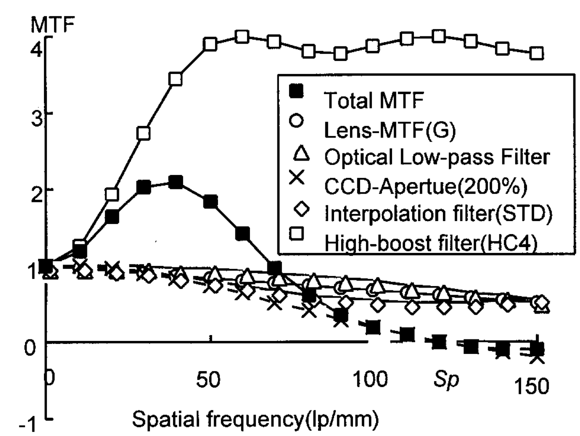

Figure 7. Example of designed total MTF for 3-CCD digital still camera

The interpolation filter and high-boost filter for the 3-CCD digital still camera are executed by software processing. Various types of MTFs can be achieved by changing the coefficients of high-boost filter. Figure 8 shows the total MTFs by changing the coefficients of high-boost filter.

MTF Measurements of a Digital Still Camera

MTFs for the 3-CCD digital still camera are measured. MTFs are calculated from the output digital image of test chart which is illuminated by the fluorescent light source. The MTF for gray channel are calculated. The gamma correction on the digital data is corrected by digitally before measurements.

MTF by Slanted Edge Method

MTF of the system is defined as the Fourier transform of a line spread function. A line spread function is given by the differentiation of black-white(or white-black) edge image.

The MTF measurement using slanted black-white edge has been shown in the ISO's working draft.[2] The higher sampling frequency can be attained by using slanted edge image in the digital image measurements. The measuring software "Image Analyzer 6.1.0(Plug-in for Adobe Photoshop)" was used.

Figure 9 shows the ISO's resolution chart. The slanted edge can be seen in Figure 9.

Figure 10(a) shows the enlarged image of the slanted edge in the case of high-boost filter HC4. Figure 10(b) shows the line spread which is differentiated digitally from the edge image shown in Figure 10(a). Figure10(c) and (d) show the intensity profiles of line images shown in Figure 10(a) and (b), respectively. Intensity profiles are calculated by using the software "NIH image ver.1.57".

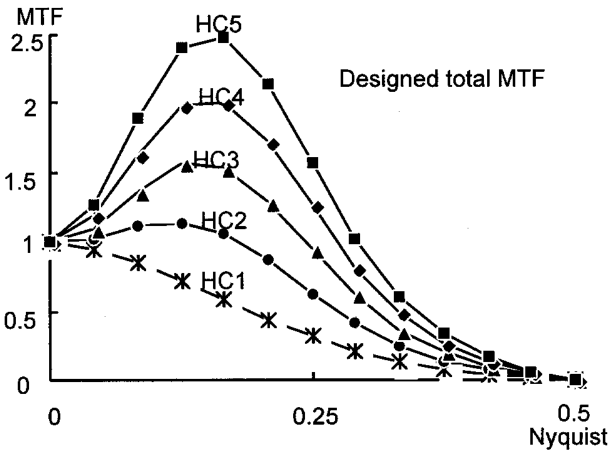

Figure 8. Variation of designed MTF by changing the coefficient of high-boost filter

Figure 11 shows the measured MTFs by varying the coefficient of high-boost filter. The normalized frequency is used in Figure 11, so the Nyquist frequency is O.5. The correspondent designed MTFs are shown in Figure 8.

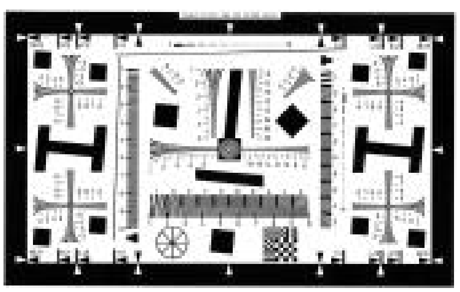

Figure 9. ISO's resolution chart

MTF by sinusoidal wave chart

MTF is also expressed as the spatial frequency response for sinusoidal-wave chart. Figure 12 shows the EIAJ's sinusoidal-wave chart .

MTF $R(u)$ is given by

$R(u)=(Bmax-Bmin)/ /(Bmax+Bmin)$

u : spatial frequency

$Bmax$: maximum value of a sinusoidal chart

$Bmin$: minimum value of a sinusoidal chart

The measured MTF for high-boost filter HC4 is shown in Figure 13. Designed MTF is also shown in Figure 13.

MTF by rectangular-wave chart

ISO chart has the rectangular-wave sweep chart. The MTF can be calculated from amplitude response $A(u)$ for rectangular-wave chart. The relation between MTF $R(u)$ and amplitude response $A(u)$ is given by

$R(u)=(/4)\{A(u)+A(3u)/3 - A(5u)/5 + ...\}$

The measured MTF by rectangular-wave chart for high-boost filter HC4 is also shown in Figure 13.

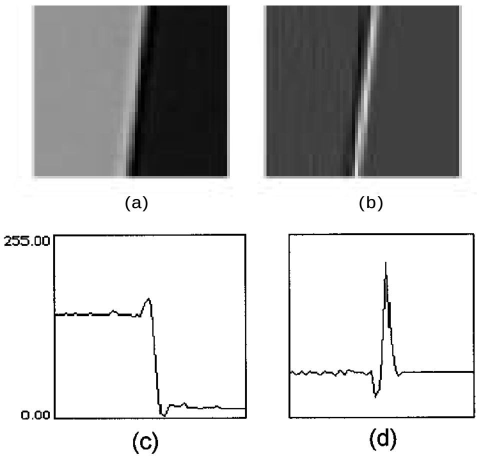

Figure 10. (a)Slanted edge image and (b)differentiated image. (c) and (d) are intensity profiles.

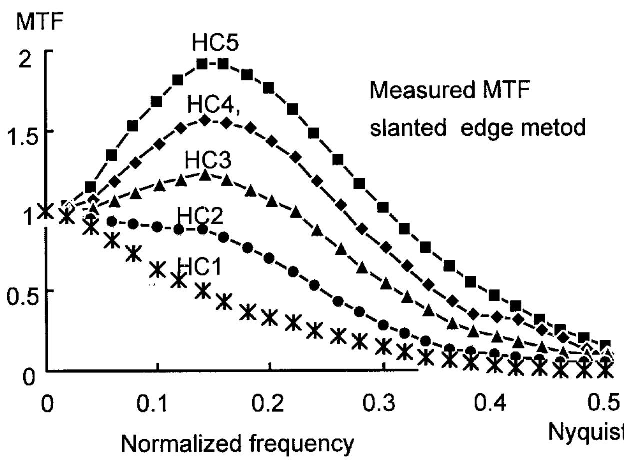

Figure 11. Measured MTF by slanted edge method varying the coefficients of high-boost filter.

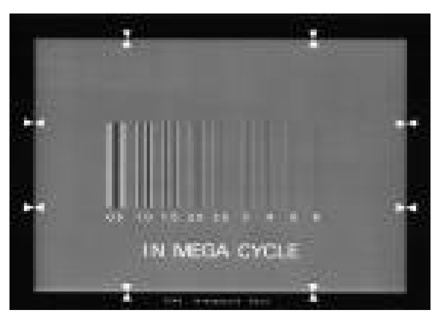

Figure 12. EIAJ's sinusoidal wave chart.

MTF by Low-Contrast Slanted Edge Method

MTFs for low-contrast slanted edge chart are measured. Figure 14(a) shows the chart image pattern. MTFs for varying the chart contrast are shown in Figure 14(b). The high-boost filter for the measurement has been HC4. The peak value of MTF curves decrease in accordance with the chart contrast.

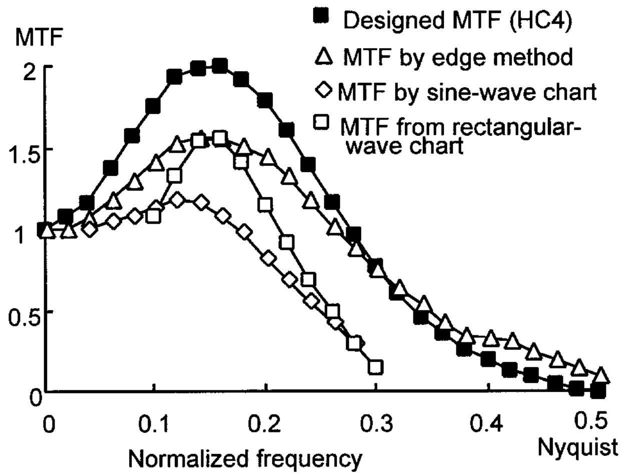

Figure 13. Measured MTFs in the case of the high-boost filter HC4.

Discussions and Conclusions

MTF for a digital still camera is analyzed and measured. MTF curves measured by using ISO's high-contrast slanted edge method are similar to the designed MTF, as shown in Figure 11. The peak MTF value for using high-boost filter is lower than designed MTF. The measured MTF for sinusoidal-wave chart has lowest peak value, as shown in Figure 13. The measured MTF for rectangular-wave chart has same peak value for slanted edge method.

MTF curve depends on its measuring method. In the case of MTF for high-boost filtering, MTF for sinusoidal-wave chart is lower than that of slanted edge method. One of reason is that the MTF is changed by the chart contrast. The MTF for EIAJ's low-contrast sinusoidal-wave chart is similar curve to the MTF for low-contrast slanted edge chart.

MTF characteristics should be considered in the linear region, but there are many non-linear operations which affect the MTF characteristics of digital still camera. The operations are image compression, noise-suppression, non-linear gamma correction, overflow and under flow of the image data, and so on.MTF curves depend on the chart contrast, because of non linear operations.

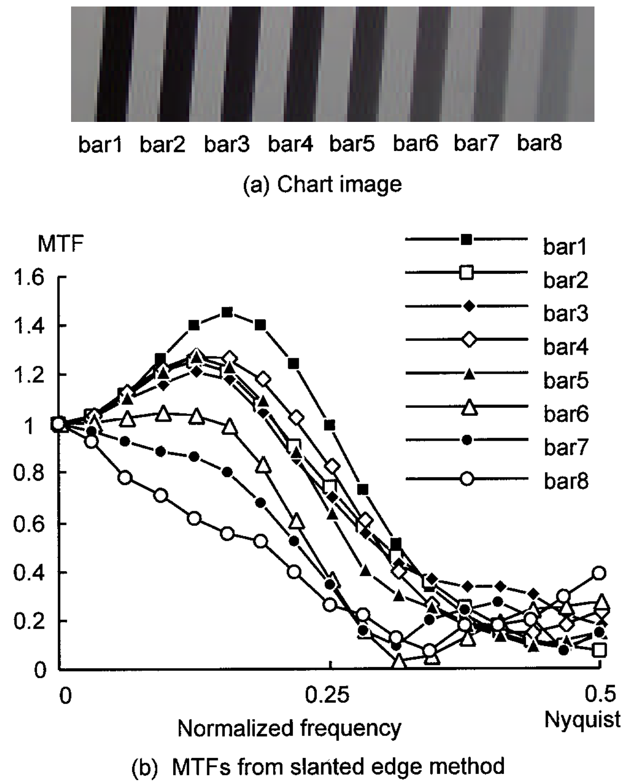

Figure 14. MTF variation by changing the chart contrast

References

1. Y.Okano, Y.Morimoto and T.Ishida, *IS&T's 48th Annual Conference Proceedings*, 428-431(1995).
2. ISO/TC42, WG18, WORKING DRAFT #7.0, ISO12233, Item188 (July 15,1995).