

## Measurement on Modulation Transfer Function Under Different Contrasts

Li Wen-juan\*, Liang Chuan, Jiang Wei, Wang Chi-zhong

School of Electrical and Electronic Engineering, Harbin University of Science & Technology 450#Box No.52  
XueFu Road. Harbin, P.R, C hina, 86-451-8639-1640

\*Corresponding author, e-mail: lwenjuan@163.com

### Abstract

Aiming at the effect of environment to MTF measurement, the MTF measurement at different contrasts is presented. In order to get different contrasts, two integrating spheres are used to illuminate the face and back of the test target uniformly. The target luminance and background luminance of the test target are regulated by luminance control parts conveniently. The MTF measurement system is designed and developed. Many experimental results of show that the luminance differences between the values by the system and those by L88 standard level luminance meter are within  $\pm 0.3 \text{ cd/m}^2$  so that the MTF measurement precision can be ensured. MTFs of Sony camera and Cannon camera at different contrasts are measured. The measurement values imply that MTFs at different contrasts can evaluate the imaging quality fully and objectively. This study provides an effective method to assess the imaging quality of visible imaging systems.

**Keywords:** modulation transfer function, contrast, imaging quality, imaging system

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### 1. Introduction

The development of modern optical theory demonstrates that under the linear spatially invariant condition the optical system can be regarded as a filter with different space frequencies. Its imaging properties and evaluation of imaging quality are denoted by the ratio of image spectrum to object spectrum. These frequency characteristics are called as the optical transfer function (OTF) [1]. The magnitude of OTF is recognized as the modulation transfer function (MTF). The phase angle of OTF is the phase transfer function (PTF). PTF can show the shift of image to the ideal point, but cannot influence the image definition. Therefore MTF is adopted to evaluate the imaging quality not only in the optical system but also in the optoelectronic system [2-5].

The MTF is able to reflect the resolvable ability of the CCD camera to the different spatial frequencies. Nevertheless, the effect of environmental lightness on MTF is not taken into account. This causes the only MTF assessment not to be objective and effective. In this paper, MTFs at different contrasts are presented. The method achieving different contrasts is stated. The MTF measurement system is designed and developed. The imaging quality of CCD camera is evaluated by MTFs under different contrasts.

### 2. Measurement Principle and System

#### 2.1. Measurement Principle

Under the non-coherent illumination, if the intensity distribution of the object point imaging through the optical system is  $h(u, v)$ , the normalized intensity distribution is called the point spread function represented with  $PSF(u, v)$  as follows

$$PSF(u, v) = \frac{h(u, v)}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} h(u, v) du dv} . \quad (1)$$

The area with the same point spread function  $PSF(u, v)$  is the isoplanatic region, i.e. the region with space invariant condition.

When the imaging system satisfies the linear condition, the amount of light  $i(u', v')$  at one point of its image plane can be regarded as the superposition of the amount of light formed on the image plane  $(u', v')$  by the amount of light  $o(u, v)$  at each point of the object plane. The imaging process is represented as

$$i(u', v') = \iint_{\sigma} o(u, v)h(u, v, u', v')dudv \quad (2)$$

where  $\sigma$  is the distribution range of the amount of light of the object in the object plane;  $h(u, v, u', v')$  is the distribution of the amount of light formed on the image plane through the optical system by the object point on the object plane  $(u, v)$ , which amount of light is the unit value.

In the isoplanatic area when the optical system meets the linear condition, Equation 2 is rewritten as

$$i(u', v') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} o(u, v)PSF(u' - u, v' - v)dudv . \quad (3)$$

Equation 6 represents that the intensity distribution of the image plane is the convolution of the intensity distribution on the object plane and the point spread function.

According to the convolution theorem in the Fourier transform, it can be derived by Equation 3 as

$$I(r, s) = O(r, s)OTF(r, s) . \quad (4)$$

Here,  $O(r, s)$  and  $I(r, s)$  are the Fourier transform of the intensity distribution  $o(u, v)$  on the object plane and the intensity distribution  $i(u, v)$  on the image plane, respectively.  $r$  and  $s$  are the spatial frequencies of the frequency domain along the two axes directions.  $OTF(r, s)$  is the optical transfer function and it is the two-dimensional Fourier transform of the point spread function  $PSF(u, v)$ , that is

$$OTF(r, s) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} PSF(u, v) \exp[-2\pi j(ru + sv)]dudv \quad (5)$$

The amplitude of Equation 5 is the MTF of the optical system. This provides the theoretical basis for measuring MTF [6-7].

## 2.2. Measurement System

Based on the above technique MTF measuring system is designed. Figure1 illustrates the schematic diagram of the system. This system is consisted of three parts: the lighting part, target and imaging part, and the control part.

1. Lighting Part Design. In order to get different contrasts, a new technique, which two integrating spheres are used to illuminate the test target respectively [8], is proposed. The test target wheel is inserted between them. A round hole is opened at two integrating spheres close to the target surface. Thereby a uniform illumination to the target is achieved. As shown in Figure 1, target integrating sphere and background integrating sphere are used as target illumination and background illumination respectively. The diameter of target integrating sphere is 150mm. There is an opening on the right of the target integrating sphere which diameter is 25 mm. The diameter of background integrating sphere is 200mm and has two openings. The left opening, whose diameter is also 25mm, coincides with the right opening of the target integrating sphere. The diameter of the right opening is 50mm. At this opening the collimating system is introduced so that the test targets with different contrasts are provided to imaging system under test.

The visible beam that the light source sends out is collimated by the collimating system, filtered by the filter, and arrives at the light splitting system where the beam is divided into two bunches. The reflected beam goes through the 1# attenuator and the focus lens, falls into target integrating sphere; the transmissive beam is reflected by the mirror, passes the 2# attenuator and the focus lens, and illuminates background integrating sphere. In order to prevent the beam of the first radiation from directly reflecting to the exit the light baffle is installed in the entrance of each integrating sphere.

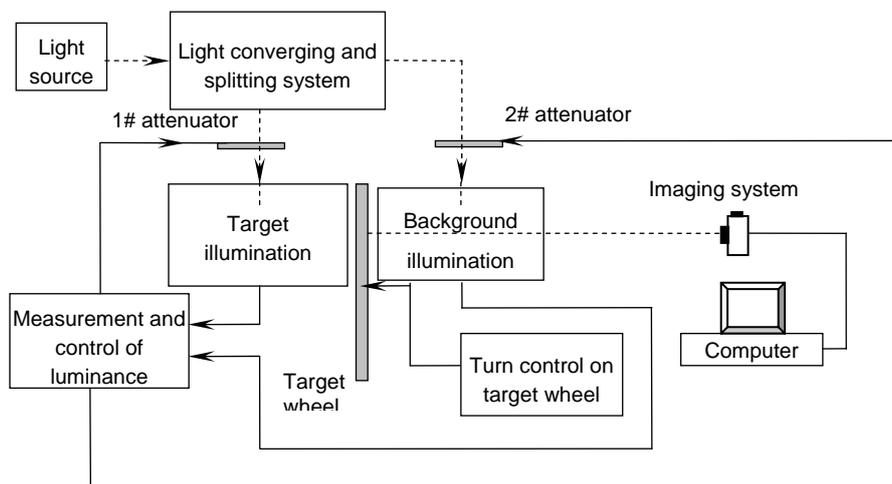


Figure 1. Diagram of MTF measurement system

2. Target and Imaging System. Different targets are on the round target wheel. There are solid target, hollow target, and point pattern. The solid target is used to calibrate the brightness of the background. But the hollow target is adopted to calibrate get brightness. The point pattern is often selected to measure MTF.

According to the general requirements, the focal length of the imaging system is selected as  $f=500\text{mm}$  and the diameter is 120mm. Considering the need to shorten the volume of the system, the telephoto lens structure is referenced [9].

**3. Control System** This part is the key to the whole system, its control is good or bad directly determines that the system can work. It is mainly to control the rotation of the target wheel; it is used to measure, display, and regulate the target luminance and background luminance; it is also to compute and display the contrast of the test target.

The purpose to control the target wheel is to provide different patterns for the imaging system. The peripheral of the target wheel are made as the gear structure so that it can mesh with a pinion, which is driven by a step motor.

The detection of the target luminance and background luminance of the test target are completed by the silicon photodiodes mounted in the target and background integrating spheres, as well as the latter converting circuits respectively. The silicon photodiode receives the light energy, transforms it into the current signal, then the operation amplifier with high performance is used as the current to voltage converting circuit and transforms the signal into the voltage signal. The voltage signals are amplified by the proportional amplifier, transformed by A/D conversion, and sent to the personal computer in order to be processed, transformed and displayed. At the same time the contrast of the test target is also computed and displayed.

The target luminance and background luminance of the test target are regulated by the beam coming into the target integrating sphere and background integrating sphere respectively. The beam is changed by adjusting the attenuators near the entrance of each integrating sphere. The attenuators are made of the metal board with an involute slit. The step motor drives the attenuator turn together. Thereby regulating the beam falling into the integrating sphere can control the target luminance or the background luminance.

### 3. Results and Analysis

Depending on the above design, the MTF measurement system is developed. CCD cameras are selected as the imaging system. Many experiments are done on this system to the CCD cameras.

#### 3.1. Luminance Calibration

In order to validate the accuracy of the luminance measure and control parts, many groups of measurements have been respectively made under the different target luminance and background luminance using the developed system. Meanwhile, calibration has been done with L88 luminance meter, which is the first level luminance meter and checked by National Institute of Metrology P. R. China. Two groups of the experimental data are shown in Table 1.

Table 1. Experimental data of target luminance and background luminance

| Variable             | Display value by the system( $\text{cd}/\text{m}^2$ ) | Display value by L88( $\text{cd}/\text{m}^2$ ) | Difference ( $\text{cd}/\text{m}^2$ ) |
|----------------------|---|--|---------------------------------------|
| Target luminance     | 14.3  | 14.5   | -0.2                                  |
|                      | 20.2  | 20.3   | -0.1                                  |
|                      | 32.3  | 32.2   | 0.1                                   |
|                      | 39.6  | 39.4   | 0.2                                   |
|                      | 43.0  | 42.9   | 0.1                                   |
|                      | 47.3  | 47.2   | 0.1                                   |
| Background luminance | 12.9  | 12.7   | 0.2                                   |
|                      | 15.4  | 15.2   | 0.2                                   |
|                      | 22.6  | 22.7   | -0.1                                  |
|                      | 31.2  | 31.1   | 0.1                                   |
|                      | 43.1  | 43.3   | -0.2                                  |
|                      | 47.8  | 48.1   | -0.3                                  |

It can be seen that results of many group measurements indicate that the luminance differences between the results using this system and the values by L88 are within  $\pm 0.3 \text{ cd}/\text{m}^2$ . Thereby the accuracy and repetition of the luminance in this system are validated.

#### 3.2. MTF Measurement

Under the premise to ensure the accuracy of luminance measurements, the target wheel is adjusted to the point pattern.

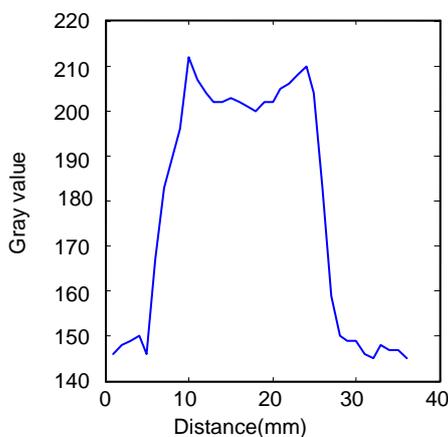


Figure 2. Intensity distribution of point image with DSC-F707 camera

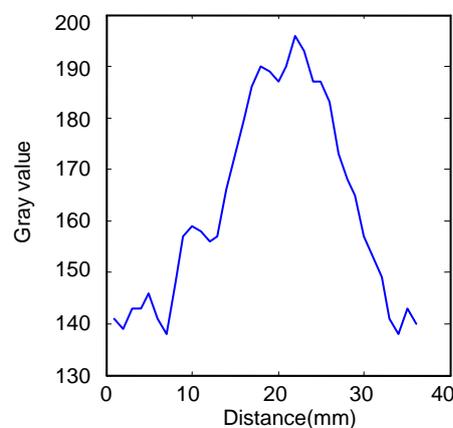


Figure 3. Intensity distribution of point image with Canon A75 camera

Then point images are taken under different contrasts by Sony DSC-F707 camera and Canon A75 camera, respectively. Sony DSC-F707 has 500 megapixels, while Canon A75 has 380 megapixels. The measurements are completed at an ambient temperature of 26.6 ° C, relative humidity of 56%.

By image processing, the intensity distribution curves of point images are achieved. Figure 2 and Figure 3 give a kind of curves. The point images are stored by Sony DSC-F707 camera and Canon A75 camera respectively when the contrast is 1.35.

PSF can be obtained from intensity distribution curves. After discretized and transformed by two-dimensional Fourier transform, the amplitude of PSF is calculated. MTF of the camera is received by normalization.

In terms of the above ways, MTFs of Sony camera and Canon camera are solved. Figure 4 and Figure 5 exhibits MTFs at different contrast 1.068, 1.181, and 1.350, respectively.

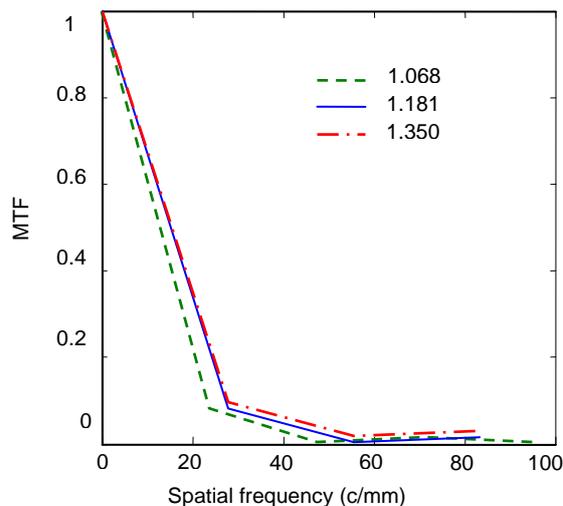


Figure 4. MTFs of Sony camera

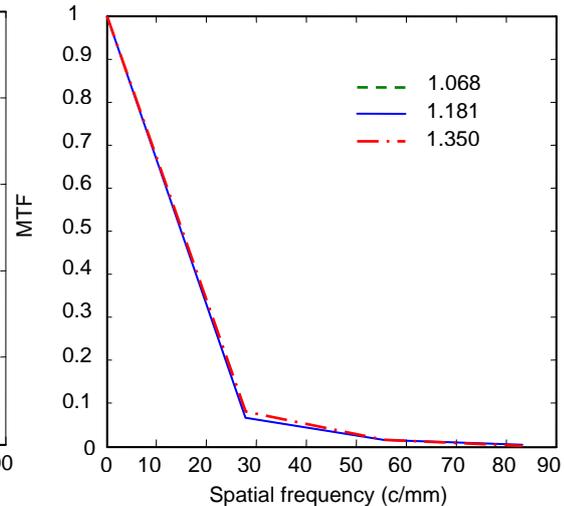


Figure 5. MTFs of Canon camera

Because the values of contrast are less in measuring MTF, Sony camera can distinguish MTFs and Cannon camera cannot separate those at contrasts of 1.068 and 1.181. However, from the overall MTF curves of Sony camera and Cannon camera reflect the following trends: the resolution of the camera increases with increasing contrasts of the test target at a certain MTF; the change of the area enclosed by MTF curve and the spatial frequency axis is the same as that of the resolution. These illustrate that the resolution at the high contrast is better than that of low contrast for a camera.

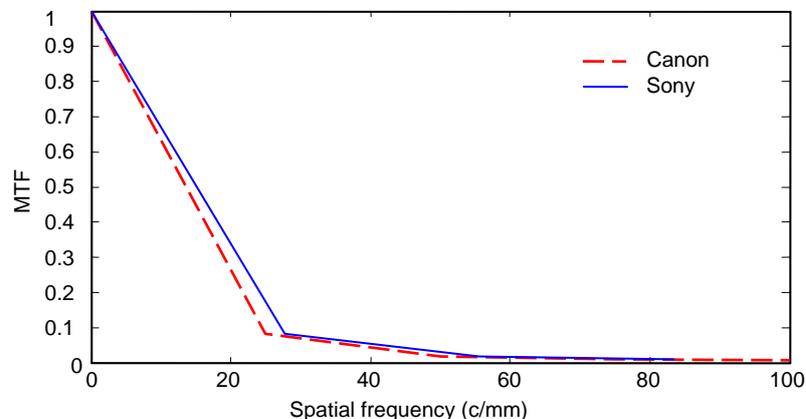


Figure 6. MTF comparison between Canon camera and Sony camera

In order to compare the imaging quality of Sony camera with that of Canon camera, mtf's are drawn in Figure 6 at the same contrast.

MTF values of Sony camera are greater than those of Canon camera whether in low frequency or in high frequency; the area enclosed by MTF curve and the spatial frequency of Sony camera axis is more than that of Cannon camera. All of which confirms that the imaging quality of Sony camera is superior to that of Cannon camera. This result corresponds with the known quality.

#### 4. Conclusion

On the basis of stating the MTF measurement principle with the point pattern, the MTF measurement system is designed and developed. In order to get different contrasts, two integrating spheres are used to illuminate the face and back of the test target uniformly. The target luminance and background luminance of the test target are regulated by luminance control parts. The contrast can be adjusted conveniently. The luminance can be regulated in the range  $0.3 \text{ cd/m}^2$  to  $200 \text{ cd/m}^2$ . This can satisfy the requirement of the contrast in MTF test. The error of measuring the luminance using this system is within  $\pm 0.3 \text{ cd/m}^2$ , therefore the measurement precision can be ensured in MTF test. The MTFs of Sony camera and Cannon camera are measured by this system. The experimental results show that MTFs at different contrasts can demonstrate the imaging quality fully and objectively. This study provides an effective system to measure MTFs of the imaging system so that its imaging quality can be evaluated quantitatively.

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