Defocusing Effect Studies in MTF of CCD Cameras Based on PSF Measuring Technique

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ABSTRACT- Defocusing effects in modulation transfer function (MTF) measurement of charge coupled device (CCD) cameras is the main focus of current paper. We introduce measuring Point-spread function (PSF) in order to calculate the MTF and further more we will study the shape of MTF and its cut-off frequency by adjusting the lens focusing in different locations. A collimated white light LED by broadband spectra is used as source and our results shows that the cut-off frequency is related to defocusing.

KEYWORDS: CCD, Cut-off Frequency, Defocusing, MTF, PSF.

I. INTRODUCTION

Nowadays CCDs have found many applications in industry, science and etc. These useful devices can record images from various objects and scenes[1].

CCD cameras have two main parts: array detector and optics. Array detectors are one or two dimensional pixels sensitive to photons. Camera optics consists of a complex lens alongside the other optical parts like aperture and optical filter.

Image quality in imaging systems has major importance. Modulation Transfer Function (MTF) could be a good criterion in quality determination[2], [3].

In this paper Point-Spread Function (PSF) has been introduced to measure MTF of an imaging system also defocusing as an effective parameter in imaging quality, has been investigated. This method has at least two advantages over the others: convenience of the setup and the simplicity of calculation.

II. THEORETICAL BASIS

Optical Transfer Function (OTF) represents the evolution from object to image in an optical system. This function shows the evolution in frequency domain[4]. The relation between the object and its image is given by Equation (1).

$$I(\mu,\upsilon)=OTF(\mu,\upsilon)*O(\mu,\upsilon) \tag{1}$$

$I(\mu,\upsilon)$ And $O(\mu,\upsilon)$ are two Fourier transforms of the image and object intensity respectively. OTF consists of two parts, the modulation transfer function (MTF) and the phase transfer function (PTF):

$$OTF(\mu,\upsilon)=MTF(\mu,\upsilon)*e^{iPTF(\mu,\upsilon)} \tag{2}$$

Because of the 2-dimentional nature of image and object position, their transforms are also a 2-D function. For simplicity the normalized value of MTF will be presented.

Point-Spread Function (PSF) is a simple method to measure the MTF of an imaging system. Measurements based on Talbot effect[5], parallel Moiré[6], edge-spread function (ESF) and line-spread function(LSF) [7]–[9] are also used in MTF measurements. PSF is the response of the imaging system to a point source (Eq. 3).

$$i(x,y) = \int_{-\infty}^{+\infty} PSF(x-u, Y-v)\, o(u,v)\, du dv \quad (3)$$

According to Eq. 1 and Eq. 3, the OTF is the Fourier Transform of PSF ($\mathcal{F}$ represents the Fourier Transform).

$$OTF(\mu,\upsilon) = \mathcal{F}\{PSF(x,y)\} \quad (4)$$

The absolute value of the PSF's Fourier transform is MTF [7].

$$MTF(\mu,\upsilon) = Abs(\mathcal{F}\{PSF(x,y)\}) \quad (5)$$

LSF test uses a line-source object (or a slit in front of a point source) like one-dimensional delta function and ESF test uses an illuminated knife-edge source (a step function). As a result, the main differences between PSF and other methods are in illumination source and MTF calculation path (PSF is a 2-dimentional based technique but ESF and LSF are 1-dimentional techniques).

The main optical part of the imaging system consists of a complex lens. If the defocusing effect occurs (as an aberration), the point like image will spread to form a circular spot. The position of the focal plane will be found by minimizing the PSF in the image plane. In MTF and frequency domain, maximizing the cut-off frequency has the same result. In this paper we measured the cut-off frequencies in order to find the focal plane. In satellite cameras, the focal plane is an important parameter because camera optics must be set to be in the focal length to achieve the best image quality of distanced objects.

III. Experimental Measurements

The imaging system consists of a CCD manufactured by IMPREX (see Table 1) and a triplet lens with focal length of 40mm and diameter of 12.7mm. A white 3Watt LED were utilized in order to make a point source along with 3 doublet lenses and a 100µm pinhole. Beside these elements, a diaphragm is used to control the beam diameter. Using a fiber spectrophotometer, the spectrum of the light source was obtained (see Fig. 1).

Table 1 CCD model and properties used in experiment

Property	Value
Model	IPX-VGA120LMCN
Resolution	640 pixel x 480 pixel
Pixel size	7.4µm x 7.4µm
Max frame rate	120 frame/sec.
Shutter speed	1/100000 to 1/100 sec.

A. Experimental Setup

As mentioned earlier, 3 doublets were used along with a pinhole in order to construct a point source. Position of the doublets were also based on 4f technique[10] (see Fig. 4 and Fig. 5). The final parallel beam was projected to the imaging system with divergence less than 1′ and diameter of 12.7mm.

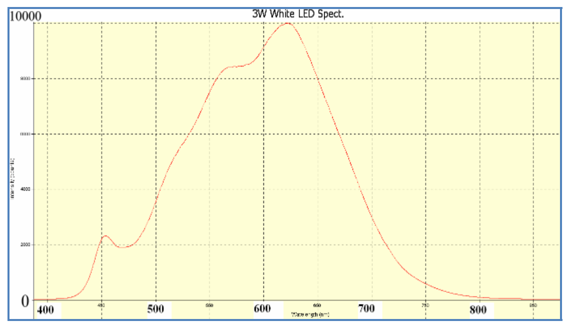

Fig. 1 The 3W LED spectrum in visible band (Counts/nm).

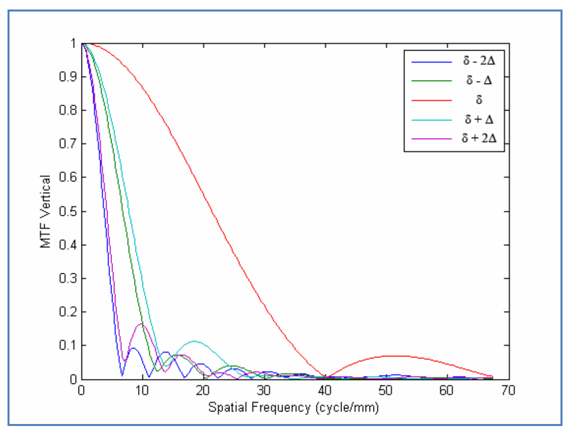

Fig. 2 Vertical MTF Vs. spatial frequency in five positions.

B. Data Acquisition

After collimating the beam, defocusing effect is investigated for five different camera optics positions: δ - 2Δ, δ - Δ, δ, δ + Δ and δ + 2Δ. Each position was separated $\frac{1}{3}$ mm from the previous one (δ is the distance between best focus position and focal plane, $\Delta = \frac{1}{3}$ mm). In each position, light intensity is adjusted in order to prevent CCD from saturation. Among these five positions, the first and the last possessed the highest defocusing and the third exhibited the best focus.

C. Image Processing

For each camera optics position, the average of 10 still images was analyzed using Matlab software. Discrete Fourier Transform calculated using FFT technique and the absolute normalized value was reported as the total MTF of the system. Data output was set in a way that the center of 2-D MTF was the zero frequency. Normalized vertical and horizontal MTF was plotted for each position (see Figs. 3 and 2).

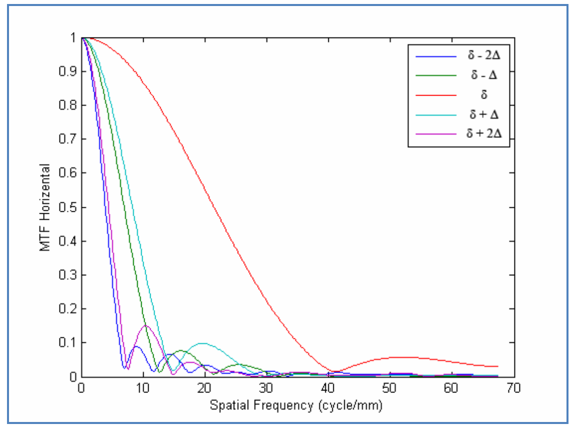

Fig. 3 Horizontal MTF Vs. spatial frequency in five positions.

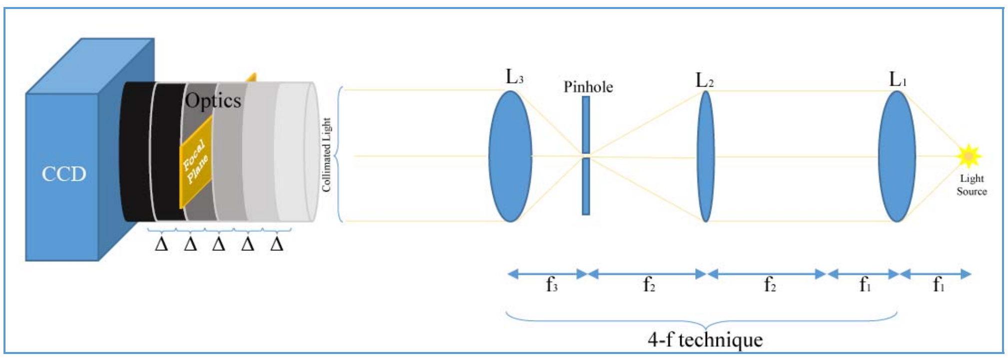

Fig. 4 Simple schematic of experimental setup: colimator (right) and CCD camera

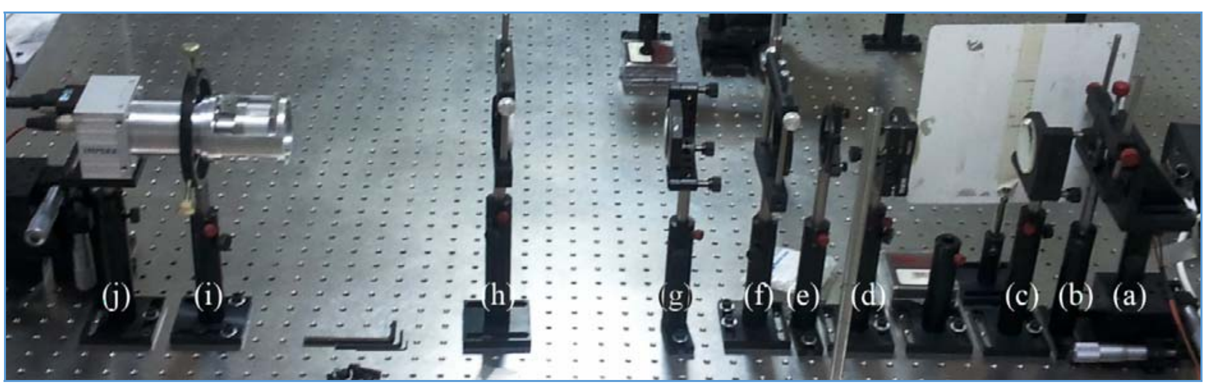

Fig. 5 Experimental setup: (a) light source, (b) aperture, (c) first doublet, (d) second doublet, (e) pin hole, (f) beam diameter aperture, (g) third doublet, (h) intensity filter, (i) camera optics, (j) CCD connected to lens holder.

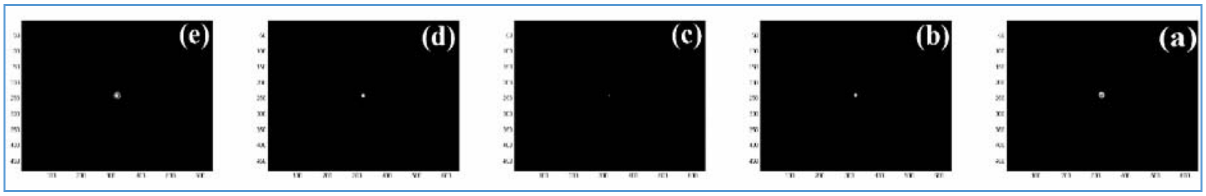

Fig. 6 Image in pos = : (a) δ-2Δ, (b) δ-Δ, (c) δ, (d) δ+Δ, (e) δ+2Δ (black=min., white=max.).

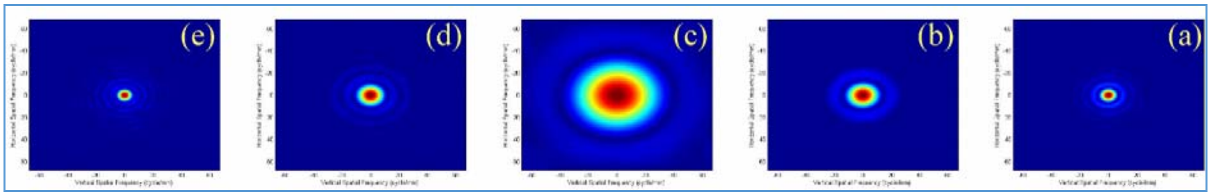

Fig. 7 Two Dimentional total MTF in pos = : (a) δ-2Δ, (b) δ-Δ, (c) δ, (d) δ+Δ, (e) δ+2Δ (blue=min. , red=max.).

IV. Conclusion

In an Imaging system like a camera, the calculated MTF (Eq. 5) is belong to all of imaging parts like lens, CCD, electronic parts, etc. Lens misalignment like defocusing deal with MTF of lens and will change the total MTF of system. In this paper we obtained MTF by measuring PSF and defocusing effect studied on total MTF of an imaging system. As presented earlier in Figs. 3 and 2, each camera optics is indicated by Δ and δ corresponds to that position. In pos = δ (which is shown by the red line) corresponds to the cut-off frequency of about 41 cycle/mm. Other positions δ+Δ and δ-Δ have cut-off frequency of about 12 cycle/mm. The δ+2Δ and δ-2Δ have cut-off frequency of about 7 cycle/mm. Therefore the best focusing situation could be achieved by maximizing the cut-off frequency (equivalent to placing the object in the infinity).

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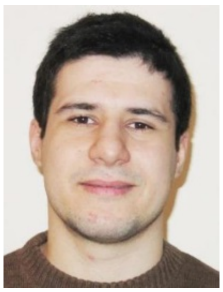

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