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Modified slanted-edge method to measure the modulation transfer function of camera

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ABSTRACT

The slanted-edge method specified in ISO Standard 12223, which experiences large errors in the camera modulation transfer function(MTF) due to tilt angle error in the knife-edge resulting in non-uniform sampling of the edge spread function. In order to resolve this problem, a modified slanted-edge method for camera MTF measurement is proposed. By applying a simple direct calculation of the Fourier transform of the derivative for the non-uniform sampling data, the camera super-sampled MTF results are obtained. Theoretical simulations for images with and without noise under different tilt angle errors are run using the proposed method. It is demonstrated that the MTF results are insensitive to tilt angle errors. To verify the accuracy of the proposed method, an experimental setup for camera MTF measurement is established. Measurement results show that the proposed method is superior to traditional methods, and improves the universality of the slanted knife-edge method for camera MTF measurement.

1. Introduction

With the development of optoelectronic technologies, cameras have been used increasingly more in space remote sensing, earth observations from space, environmental monitoring, urban construction, and more. As a means of evaluating imaging quality, modulation transfer function (MTF) can provide a comprehensive and objective metric for camera imaging performance [1,2,3].

The main methods for camera MTF measurements include the following: slit method [4,5], fringe target method [6], and knife-edge method [7–11]. The use of slit method requires very precise fabrication and alignment of the device in the radiation beam, a high radiation exposure to allow sufficient transmission through the narrow slit, and, in most case, a correction for the finite slit width [12]. The use of fringe target method requires precise width of stripes and obtains MTF of camera at specific spatial frequency. Compared to the slit method and the fringe target method, only one edge is needed for knife-edge method. As a result, knife edge greatly reduces the processing difficulty of the target plate, making it the most widely used method in camera MTF measurement. As in the straight knife-edge method, the edge should be parallel to the columns or rows of the detector. The edge spread function (ESF) can be obtained by averaging after summing. The line spread function (LSF) can be obtained from the differential of ESF. The MTF can be obtained by the fast Fourier transform (FFT) of the LSF. ESF under-sampling results from low quality images of straight knife-edge, which causes aliasing in the camera

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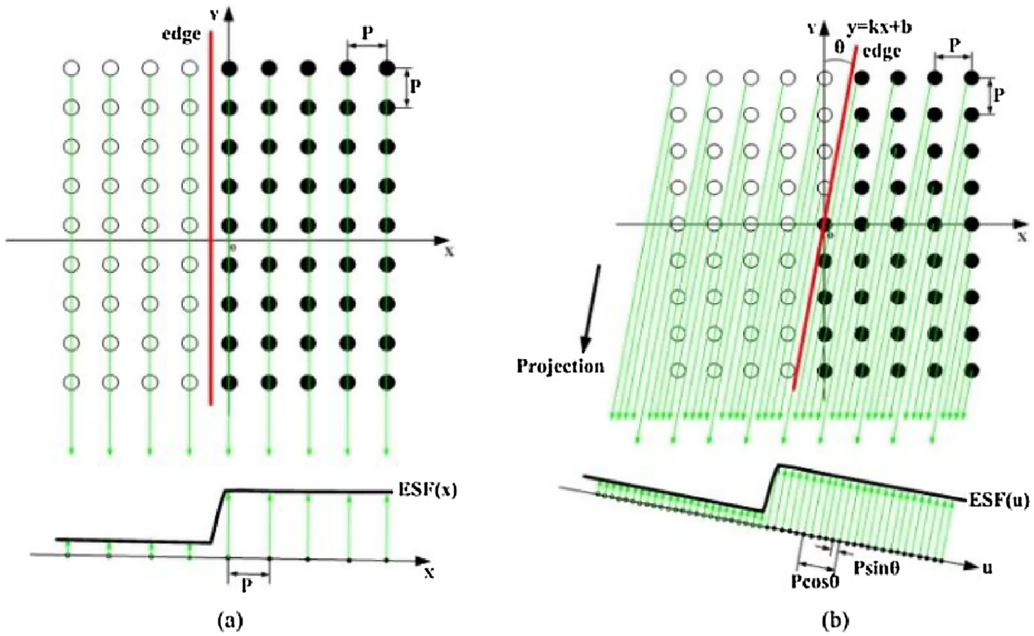

Fig. 1. (a) straight knife-edge method, (b) slanted knife-edge method.

MTF frequency spectrum [13–16]. To address this issue, the ISO12223 standard [17] specifies that the MTF measurement method must use the slanted knife-edge method. In this method, the detector pixels are tilted with respect to the knife edge to obtain the super-sampled MTF. The camera MTF can be obtained from the ESF resulting from the slanted knife edge. However, this method limits the slope of slanted knife-edge to an integer (4 is recommended), else the ESF is non-uniform sampled. Errors in the edge tilt angle lead to large errors in the MTF measurement of camera by use of FFT.

In this paper, we propose a non-uniform sampling of slanted knife-edge method for camera modulation transfer function measurement. By applying a simple direct calculation of the Fourier transform of the derivative for the non-uniform sampling data, the camera MTF results are obtained. The conventional slanted knife-edge method is presented in Section 2. In Section 3 the drawbacks of conventional slanted knife-edge method and a non–uniform sampling slanted knife-edge method for camera MTF measurement are discussed. In Section 4 theoretical simulations for images with and without noise under different tilt angle errors are run using the proposed method. It is demonstrated that the MTF results are insensitive to tilt angle errors. In Section 5 we establish an experimental setup based on both a stripes board and a knife-edge target for camera MTF measurements. The camera MTF results achieved by proposed method are compared with the fringe target method. Finally, we draw conclusion in Section 6.

2. Principle of slanted knife-edge method

The response function $ESF(x)$ of the camera to a straight knife-edge target can be expressed as the convolution of a step function $step(x)$ and a camera response function $h(x)$, namely:

$$ESF(x) = step(x) * h(x) \tag{1}$$

The straight knife-edge target is aligned with the column pixels of the imaging device. All intensity values of the pixels in the column are summed and averaged to obtain the edge function$ESF(x)$, as shown in Fig. 1(a).The pixels in the imaging device are square, with a side length P. As a result, the adjacent sampling point interval of the edge function is also P. ESF under-sampling results from the loss of image quality due to the camera lens, which causes aliasing in the camera MTF frequency spectrum. To resolve this problem, the straight knife-edge target is rotated an angle θ with respect to the pixel column of the imaging device, as shown in Fig. 1(b).

The slanted edge of knife-edge target can be expressed by line equation as follows:

$$y = k \cdot x + b \tag{2}$$

where is the slope of slanted edge, $k = {}^{1}\!/_{\tan\theta}$ and b is the inter section of the tilt edge and the y-axis. All sampling points are projected in the tilt direction of the knife-edge. Two adjacent pixels with an interval of p along a row correspond to sampling points with an interval of $p\cos\theta$ in the direction perpendicular to the knife-edge. An interval of p between two adjacent columns and rows corresponds to an interval of $p\sin\theta$ and $p\cos\theta$ from the knife edge, respectively. Compared