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Influence of lens defocus on the image quality in the process of the thermal imaging systems evaluation

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This paper presents some aspects regarding the effects of lens defocus on the image quality in case of the thermal imaging systems. Starting from the assumption that the thermal imaging systems are linear systems, the defocusing of the optical system (as a part of the thermal imaging systems) has a direct influence on the modulation transfer function and on the image quality also. The paper highlights that when it is desired to evaluate the superior limit performance of a thermal vision system, it is absolutely necessary to achieved the lens focusing by tracking both the edge spread function and the line spread function.

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1. Introduction

In the case of thermal imaging systems, the main sources of defocus are given by:

- changes in operational temperature. As the temperature changes, the elements and mounts change its dimensions and the refractive indices change [1, 2];
- focus procedure (due to inaccuracy in the measurement of the desired focus position and resolution in the positioning of the focus).

Linear systems theory provides a powerful set of tools with which we can analyse optical and electro-optical systems. The spatial impulse response of the system is Fourier transformed to yield the spatial-frequency optical transfer function [3 - 5]. Thermal imaging systems are systems made from optical and electronic subsystems, and assuming that they are linear systems, it can be argued that the modulation transfer function (MTF) for thermal imaging systems can be calculated as the product of the modulation transfer functions of each subsystem [6, 7].

The goal of this paper is to evaluate the image quality of the thermal imaging systems through the evaluation of the modulation transfer function. A defocusing of the optical system inevitably induces changes in the quality of the images provided by these systems, and the degree of influence is appreciated by determining the changes made to the MTF [1, 8].

In practice, the modulation transfer function is the most widely used criteria for the image quality evaluation of the electro-optics systems, generally with incoherent illumination and when image contrast is important. MTF provides more complete performance information than is available from simply specifying resolution, including information about system performance over a range of spatial frequencies [9 - 13].

For a thermal imaging system, the transfer modulation function is given by the Fourier transform of the line spread function or the edge spread function and is usually computed by these methods [9, 10,14].

Generally, the thermal imaging systems are divided into two categories: scanned imaging systems and focal plane array (FPA) imaging systems (the most used systems). In each case, the incident flux falling onto an individual detector produces a single output [16 - 19].

A square detector of size $d\ x\ d$ (the case of FPA imaging systems) performs spatial averaging of the scene irradiance that fall on it. The following equation is a fundamental MTF component for any imaging system with detectors:

$$MTF(\xi) = \left|\frac{\sin(\pi\xi d)}{(\pi\xi d)}\right| \quad (1)$$

where ξ is spatial frequency [3, 15].

It can be using this simple approach as a handy reality check, comparing a measured spot size to calculated MTF values.

2. Theoretical and experimental approach

The defocusing effects on the image quality in the process of the evaluation of thermal imaging systems was made starting from modulation transfer function testing. The main benefit of this method is that it is non-subjective and it is universal. The test engineer is not required to make judgments of the contrast or the resolution. Therefore, under the same conditions, the polychromatic

MTF of the lens can be directly compared to the polychromatic MTF of a design, or to another measurement instrument.

The MTF measurement methods are important tools for objectively evaluating the quality of images provided by any electro-optical system. Moreover, the MTF can be calculated from the design data of the electro-optical system, giving designers the ability to predict the performance of the system effectively.

Two methods of determining the MTF system will be discussed. One method consists in the measuring of the line spread function (LSF), and the second in measuring of the edge spread function (ESF). The LSF is defined as the radiation intensity distribution in the image of a line object of unit intensity [10, 20]. Similarly, the ESF represents the radiation intensity distribution in the image of a perfectly attenuating edge of unit intensity.

In practice, the MTF is usually determined along one dimension from the line spread function (LSF), as shown by Equation 2.

$$MTF(\xi) = \frac{\left|\int_{-\infty}^{\infty} LSF(x) e^{-i2\pi\xi x} dx\right|}{\left|\int_{-\infty}^{\infty} LSF(x) dx\right|} \tag{2}$$

where the ξ is the spatial fervency.

The LSF can be determined by the detector response to either a slit or gradient over the response to a sharp edge. The difficulty in aligning the narrow slit with the black body surface is often the deterrent in using this method, and the edge response is used instead.

The edge spread function (ESF) is the response of an imaging system to a sharp edge. Differentiating the ESF will produce the LSF, from which the MTF can be determined through use of Equation 2. The advantages of the edge method include high precision, particularly exceling at low spatial frequencies, along with its simplicity and speed of data acquisition. Its downfalls are based on the differentiation step, which enhances high frequency noise into the MTF measurements [12, 21 - 22].

The MTF measurements of the thermal imaging systems are achieved by applying only a single image for each level of defocusing (see the Fig. 1).

The edge spread function (ESF) represents the convolution of the point spread function (PSF) with unit-step function [*step (x)*], resulting the following equation:

$$g(x, y) \equiv ESF(x) = PSF(x, y) ** step(x) \cdot 1(y) \tag{3}$$

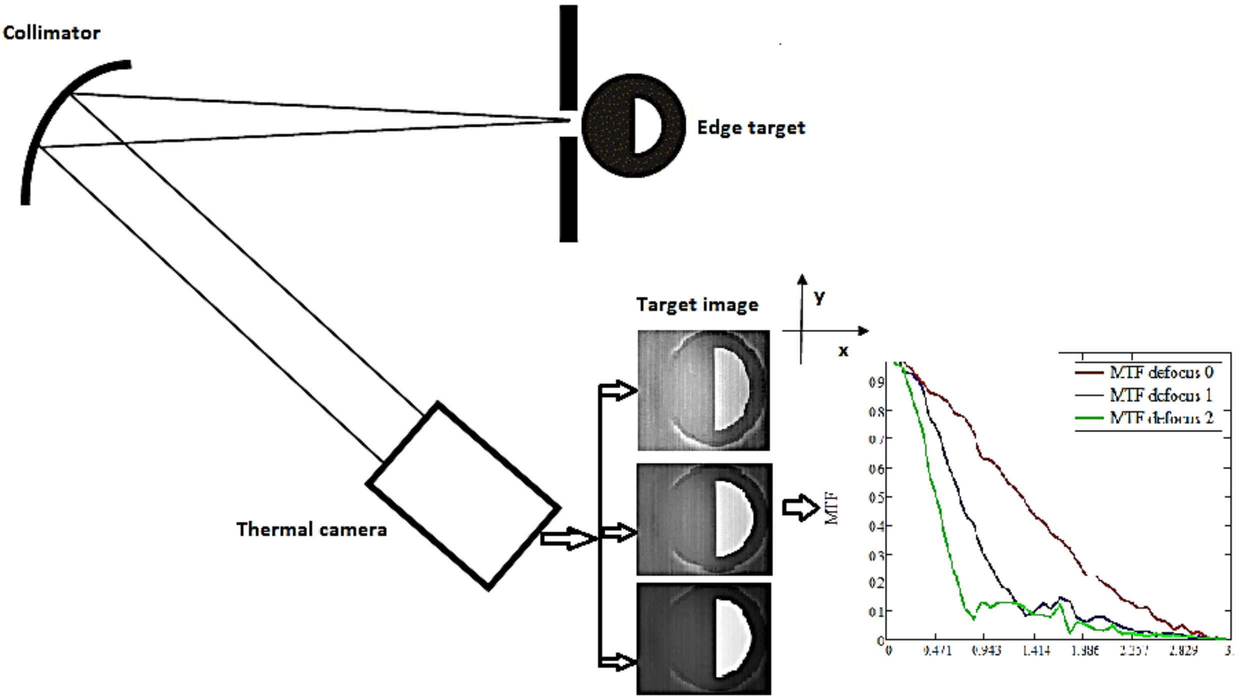

Fig. 1. The schematic method of the MTF measurement

The *y* convolution of the PSF with a constant produces an LSF.

We can understand the ESF in terms of a superposition of LSFs [23 - 24]. Each vertical strip in the open part of the aperture produces a LSF at its corresponding location in the image plane. These displaced LSFs overlap in the horizontal direction and sum to form the ESF. We can write this process as [3 - 4]:

$$ESF(x) \approx \sum_{i=1}^{\infty} LSF(x - x_i) \tag{4}$$

In the limit of small displacements, the summation becomes an integral. To convert ESF data to the MTF, we first take the spatial derivative of the ESF data to invert the integral in equation (5) [3 - 4].

$$\frac{d}{dx}\{EFS(x)\} = \frac{d}{dx}\int_{-\infty}^{x} LSF(x')dx' = LSF(x) \quad (5)$$

We can obtain any one-dimensional profile of MTF by re-orienting the edge target.

3. Results and discussions

The experiments regarding the effects of defocusing on evaluation of thermal imaging systems were done on a FLIR SC4000 equipped an objective with 100 mm focal, and the measurement was done at 1°C temperature difference between target and background. The temperature in the measuring area was 25°C and the humidity was 60%.

For determining LSF and ESF, three captured images of the same rectangular pattern were used at the same camera calibration and temperature difference between pattern and background but with different focusing levels (Fig. 2). Defocusing of the lens was achieved by manually rotating the objective of the camera.

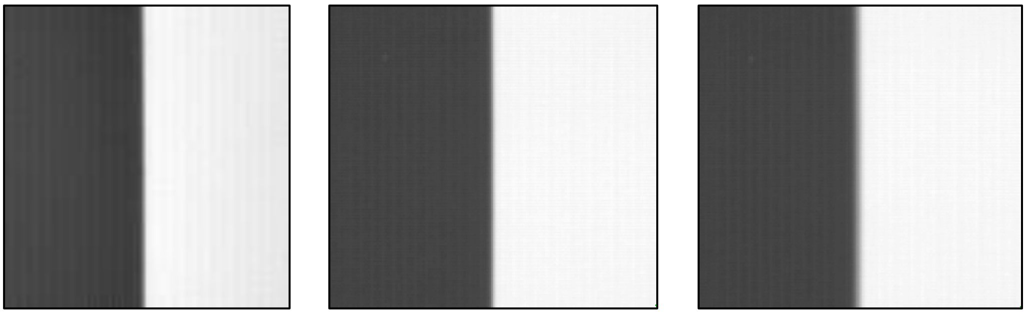

Fig. 2. The image of the target for three levels of focus

Apparently, following the line of separation between the two signal areas (black and white), coming from both the radiation source (black body) and background (pattern), no obvious contour differences are observed due to the existence of a defocus.

Analysing the graphs for the LSF (Fig. 3) and ESF (Fig. 4) corresponding to these three frames presented in Fig. 2, obvious differences are observed for the three focusing levels.

When a precise assessment of the performance parameters of thermal imaging equipment is desired, it is very important to set the correct focus of the equipment, otherwise the measurement results will be affected in value.

To achieve true performance, focus adjustment must be done in real time to minimize the area under the LSF function chart (Fig. 3).

From the graph shown in Fig. 4, it is seen that the slope of the ESF graph is affected by the focus of the thermal imaging equipment lens. Given that the MTF depends directly on ESF and LSF, these differences will be felt very much in MTFs.

By evaluating the modulation transfer function for the three cases, different results are obtained (Fig. 5). So, at a 50% MTF value, a limit spatial frequency of 1.25 lp/mrad is obtained for the optimal focusing and 0.667 lp/mrad, respectively, and 0.417 lp/mrad for the two levels of defocus. It is noted that the optimal focus of the lens allows for a much better MTF than the other cases.

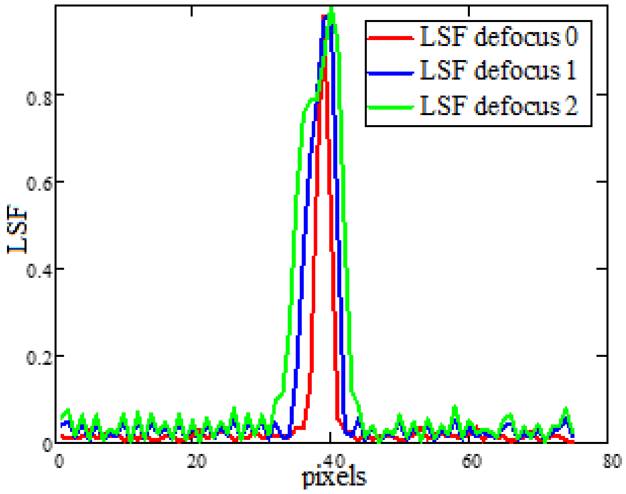

Fig. 3. The LSF graphs for analysed pattern

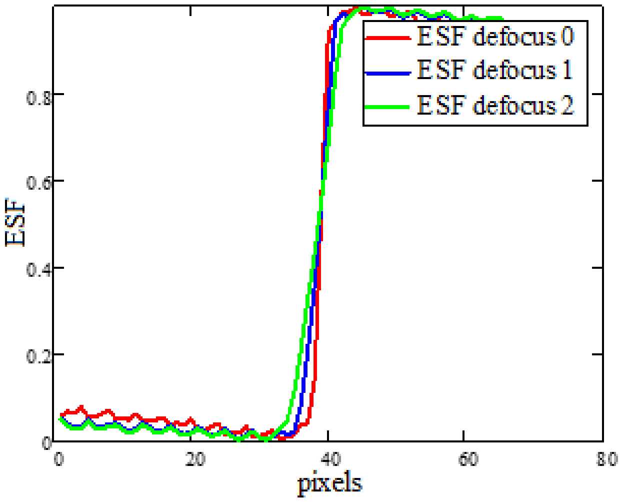

Fig. 4. The ESF graphs for analysed pattern

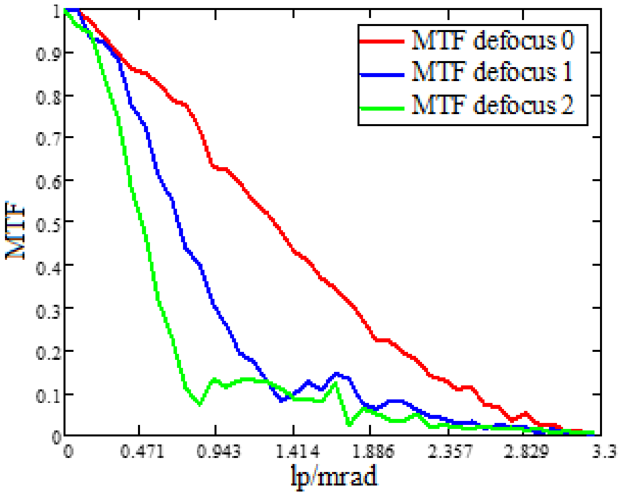

Fig. 5. MTF for different levels of defocus

Additionally, the uniformity of the image is also affected by the degree of focus of the lens of the thermal imaging equipment. The variations in uniformity for a focused lens are shown in Fig. 6, and for the same lens, but defocused, are shown in Fig. 7.

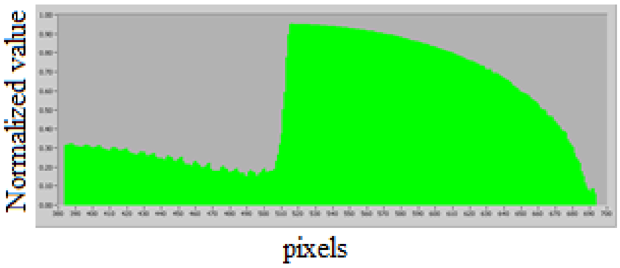

Fig. 6. Uniformity of a focused lens

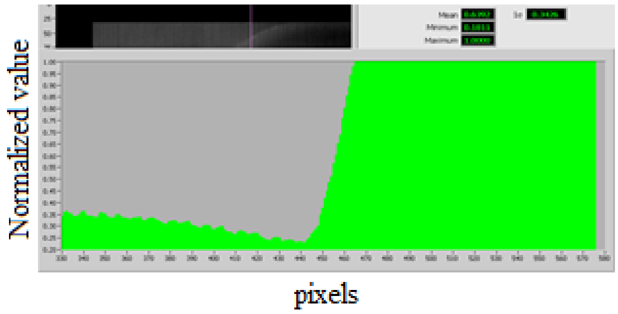

Fig. 7. Uniformity of a defocused lens

Analysing the measurements made, a uniformity standard deviation of about 20% results. This deviation is not noticeable by the user on the screen of the equipment, and an evaluation of the image quality provided by the thermal imaging system without taking into account the effects of defocusing may affects the process itself.

4. Conclusions

In the evaluating process of the thermal imaging systems performance parameters, setting an optimal level of focus plays an important role. In laboratory, the optimal focusing level is determined by evaluating the modulation transfer function, based on the Line Spread Function (LSF) and Edge Spread Function (ESF) methods.

Our experiments highlight that a small defocus, with an optical path difference of up to λ / 4, does not produce significant changes in image quality.

For the other situation, the position of the focal plane will be found by minimizing the LSF in the image plane. In MTF and frequency domain, maximizing the cut-off frequency has the same result.

Also, we could conclude that the low-resolution optical systems are more tolerant at defocusing than are the high-resolution systems.

In keeping with the theoretical predictions, it was found that a given amount of defocus reduced contrast transfer more at high spatial frequencies than at low ones.

It can also be concluded that a well corrected optical system of aberrations but defocused could produce a phase shift of 180 degrees in the image plane and the image to be bright where it should be dark but still visible due to contrast.

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