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AN ANALYSIS REGARDING THE DECREASING OF THE IMAGE QUALITY WITH THE OPTICAL MISALIGNMENT

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Rezumat. *Performantele de informație vizuala achiziționate de o camera termala sunt determinate de doi parametri distincți, NETD (Noise equivalent temperature difference) si MTF (Modulation Transfer Function); valoarea fiecăruia dintre acești parametri este dependentă de caracteristicile si de metodologia de măsurare a componentelor de bază ale unei camere termale: obiectivul și matricea de detecție. Autorii analizează unele probleme legate de măsurarea NETD și a MTF în cazul în care variază distanța focală a obiectivului și apare o dezaliniere optică la montajul camerei termale. Experimentele realizate demonstrează că o distanță focală mai mare asigură un MTF mai bun, iar evaluarea NETD cu instrumentar electronic este mai adecvată.*

Abstract. *The performances of visual information acquired with a thermal camera are determined by two distinct parameters, NETD (Noise equivalent temperature difference) and MTF (Modulation Transfer Function) values of each of these parameters is dependent on the characteristics and the methodology for measuring the basic components of thermal camera: the lens and the starring detector. The authors analyze some problems related to measurement NETD and MTF where the focal lens is variable and optical misalignment occurs when mounting thermal camera. Experiments demonstrate that a longer focal distance provides a better MTF and NETD evaluation with electronic instruments is most appropriate.*

Keywords: Thermal camera, NETD, MTF, optical misalignment, lens focal

1. Introduction

It is known that, in the field of actual research of vision using thermal cameras, the most frequent question refers to the performance of the distance observation, as is shown in the paper [1, 2].

This performance is described by some main parameters, as Noise Equivalent Temperature Difference (NETD), Modulation Transfer Function (MTF), and Minimum Resolvable Temperature Difference (MRTD) [3].A thermal camera is commonly composed of an optical assembly, a FPA detector module (starring detector), and signal processing electronics.

The imaging process can be described as a functional flow diagram (fig. 1.) from scene (input information) to observer (output information).

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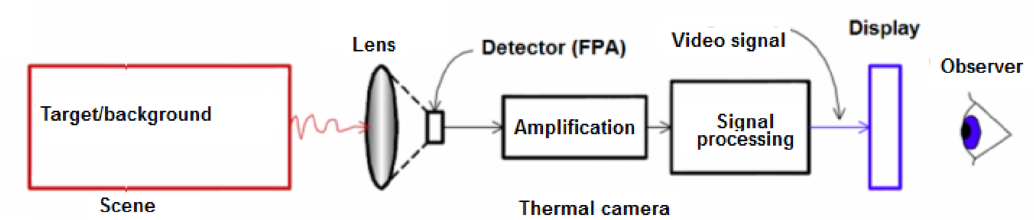

Fig. 1. The flow information between thermal camera components.

The lens gathers the scene radiance onto the detector array (FPA). The detector module converts the radiation (photons) into an electrical signal, which enters a signal processing unit. As it already was mentioned by authors in a previous article [2], the environment (the atmosphere with aerosols or thermal perturbations) and the main components of camera can deteriorates the final image.

An object is visible in an image because it has a different brightness than its surroundings (target contrast). The input to any thermal camera system is photon number N from the scene. The contrast of the object (i.e., the signal) must overcome the image noise. Noise increases with the signal level results when the image has been represented by a small number of individual particles. The signal-noise ratio (SNR) is defined as the contrast divided by the standard deviation of the noise [4]. The mathematics governing these variations is called counting statistics or Poisson statistics. That is, if there are *N* particles in each pixel on display, the mean is equal to *N* and the standard deviation is equal to $\sqrt{N}$. This makes the signal-to-noise ratio equal to $\sqrt{N}$. Detection is a noisy process. The noise V is composed of shot noise, spatial noise, and excess noise. There are additional noise sources, including readout amplifier noise and digital quantization noise. This is modelled as follows [4]:

$$V = V_{read} + V_{noise} \tag{1}$$

The noise equivalent temperature difference (NETD) is a widely used performance parameter that characterizes the sensitivity of thermal imaging sensors.

The Modulation Transfer Function (MTF) is a quantitative measure of thermal camera capability to transfer contrasts from the object plan in the image plan depending on the aims of the lens and detector details. MTF is used to approximate the position of best focus.

2. The problematic

Two problems are import ants if there is misalignment between the optical lens and FPA:

a) Although NETD has been used for many years, there has always been some confusion and misunderstanding about how to measure it. Differences in opinion on how this measurement should be made can cause substantial variations in reported values of NETD measurements [5]; for example, subjective digital noise introduced by the display. The NETD will then calculated from the experimental data as follows [6,7]:

$$NETD = \frac{\Delta T}{S/N} \tag{2}$$

where $\Delta T = T_{target} - T_{background}$, and the SNR is the signal-to-noise ratio of the thermal camera.

b) The projection of the scene on the FPA detector is not perfect; since the optical elements create blur [8]. For a quantitative analysis it used a test thermal pattern as in figure 2., and the relation [3]:

$$MTF = MTF_{optics} \cdot MTF_{FPA} \cdot MTF_{display} \cdot MTF_{eye} \tag{3}$$

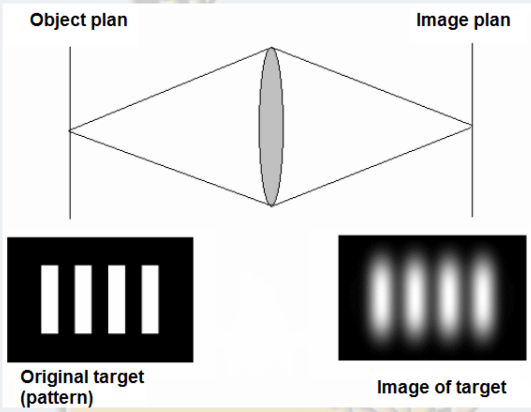

Fig. 2. Thermal pattern used in the thermal camera performance analysis.

The MTF value varies with the lens focal length and their aperture or F number (F#). The calculus of MTF values is based on the followings relations:

$$MTF_{FPA} = \left| \frac{\sin\left(\frac{\pi f}{f_{cutoff}}\right)}{\left(\frac{\pi f}{f_{cutoff}}\right)} \right| = \left| \operatorname{sinc}\left(\frac{\pi f}{f_{cutoff}}\right) \right| \tag{4}$$

where the spatial frequency *f* [cycles/mm], the cut-off frequency $c_{ut\text{-}off}$ [cycles/mm], the horizontal and vertical size of detector (d*H* and d*V*, respectively) is exprimed as:

$$f_{cutoff-H} = \frac{1}{dasH}\left[\frac{lp}{mrad}\right]; f_{cutoff-V} = \frac{1}{dasV}\left[\frac{lp}{mrad}\right];$$

$$dasH = \frac{dH}{f_{ob}}[mrad]; dasV = \frac{dV}{f_{ob}}[mrad]$$

$$MTF_{display}(f_H) = \left| \operatorname{sinc}\left(\pi \, FF_H \frac{d_{CCH}}{fl} f_H \right) \right| \quad (5)$$

where FF_H and FF_V –fill factors for detector on the horizontal, respectively vertical direction.

MTF_{optics} and MTF_{FPA} have the configuration in figure 3.

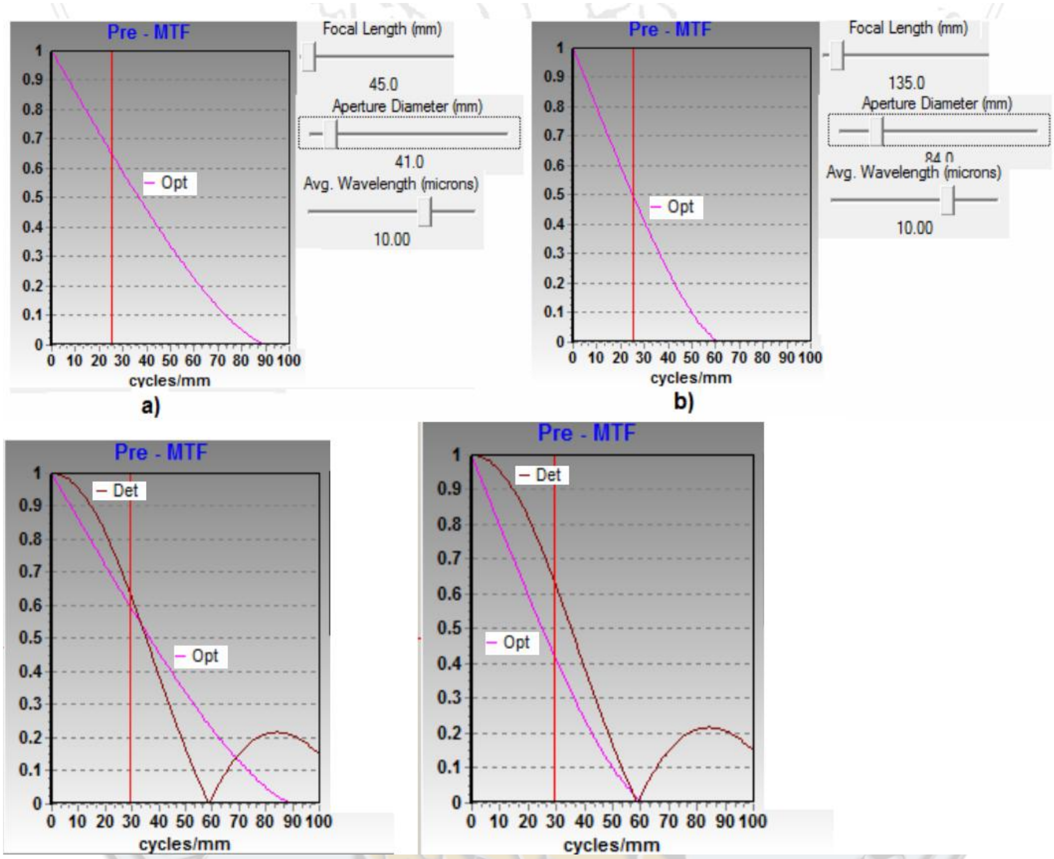

Fig. 3. MTF Diagram for the MTF realized with the Maviis 1.5 software (JCD Publishing).

where
$$MTF = \frac{\pi \cdot (V_1 - V_4)}{(V_1 + V_4) \cdot 4} \quad (6)$$

On the other hand, it is known that [3, 9]:

$$MRTD = \frac{3\left(\frac{NETD}{(\Delta f_R)^{1/2}} \right) f_T \left[\frac{\alpha}{\tau_d} \right]^{1/2} \beta^{1/2}}{MTF (t \cdot t_{frame})^{1/2}} \quad (7)$$

or [7]:

$$MRTD_f = \frac{K_f\, NETD}{MTF_f} \tag{8}$$

where: Δf_R -electronic frequency bandwidth, α- the field of view of the FPA starring, f-the spatial frequency of the target being observed, τ_d [s]– response time of the detector, t- the integration time of the observer eye, t_{frame} - the frame time.

So, it can write:

$$MTF(f) = const_1 \cdot \frac{NETD \cdot \sqrt{\alpha}}{MRTD(f)}\ ;\ NETD = \frac{const_2}{\sqrt{\alpha}}\ ;\ \alpha = \frac{1}{f_{ob} \cdot f} \tag{9}$$

For comparison of two MRTD as the same spatial frequency, in which one of the thermal camera has a certain optical misalignment, it can by written as:

$$\frac{MRTD(f)}{MRTD_{mis}(f)} = \frac{MTF_{mis}(f)}{MTF(f)} \cdot \frac{NETD}{NETD_{mis}} \tag{10}$$

3. Experiments and results

For the experimental determination a thermal camera with the following technical characteristics was used: the working spectral range 8÷12 µm, detection matrix with micro-bolometers and resolution of 640 x 480 detection items, the size of the detection item being 0.17 µm, the focal distance for the objective being of 45 and 135 mm and f number (F#) between f/1.1 (for 45 mm lens focal) and f/1.6 (for 135 mm lens focal). In laboratory conditions, in order to determine the MRTD function thermal patterns with 4 cycles/target, the ambient temperature was 24.7^0C, and the black body temperature was 29.7^0C (fig.4-6).

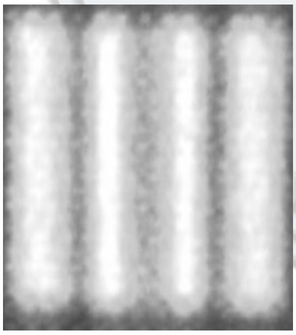

Fig. 4. Example of image acquired with thermal contrast ΔT = 10 °C

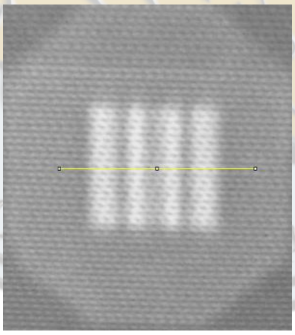

Fig. 5. Example of image acquired with thermal contrast ΔT=5 °C

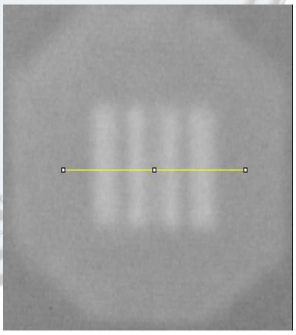

Fig. 6. Example of image acquired with thermal contrast ΔT=2 °C

The procedure used to evaluate NETD was based on standard ASTM E 1543-00 [6].

The results are presented in figures 7-19.

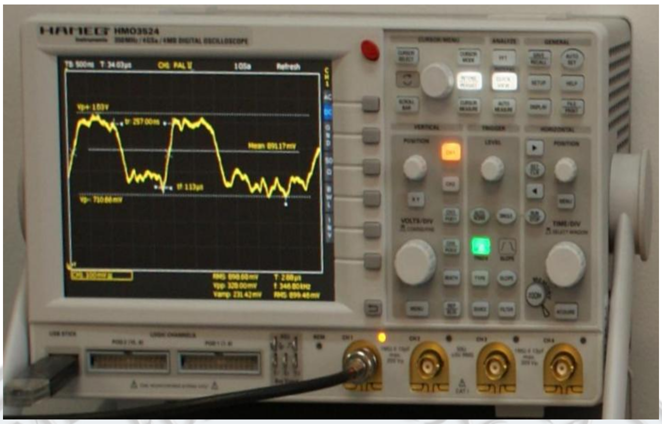

Fig. 7. Visual images signal and noise on the oscilloscope.

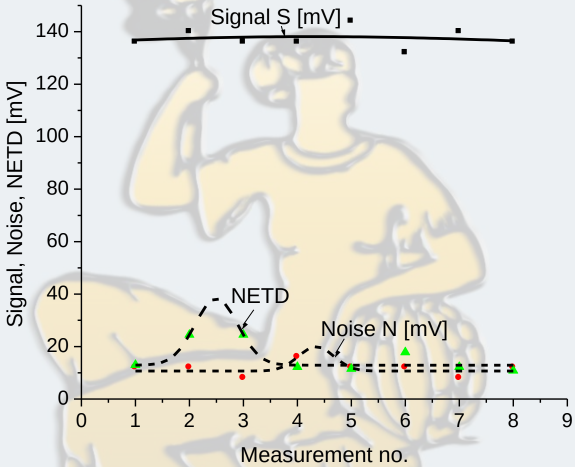

Fig. 8. Variation of the NETD excluding subjective (digital) noise.

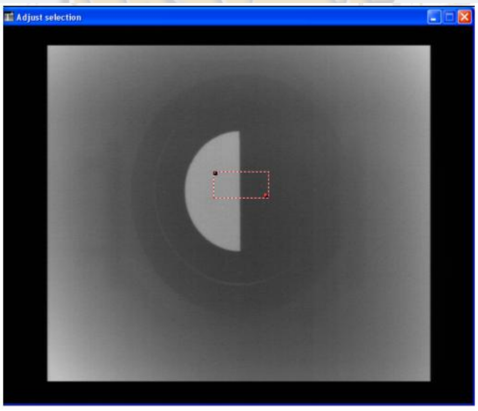

Fig. 9. Original Image for measurement MTF (aligned focal lens 135 mm) with DT 1500 tester thermal camera and related software from Inframet.

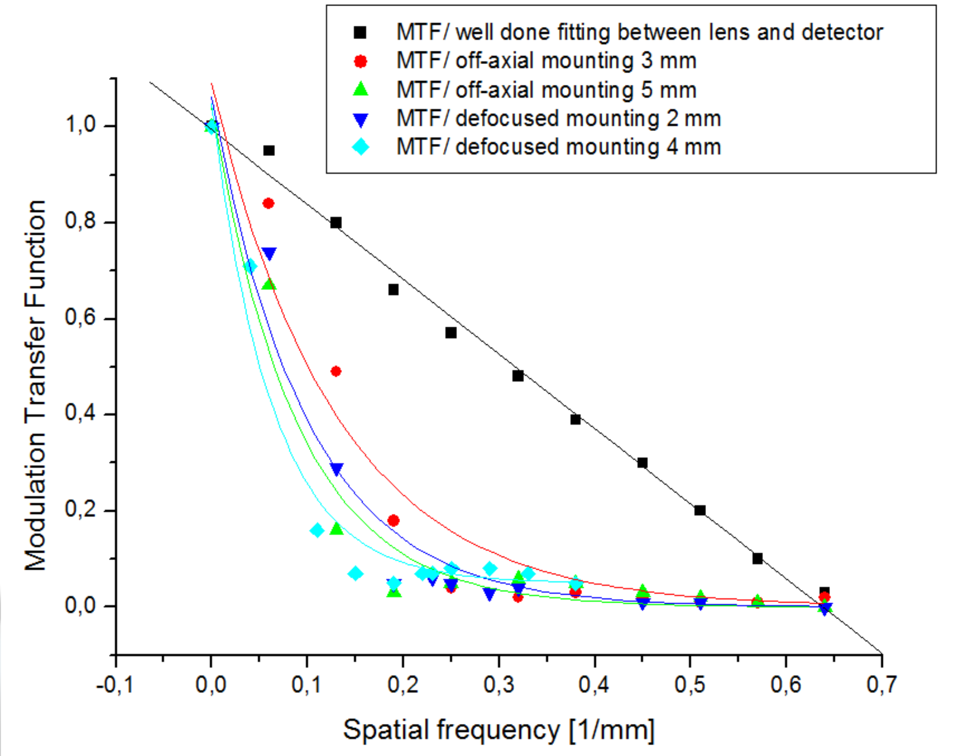

Fig. 10. The diagram MTF vs. spatial frequency. The loss of image quality in different cases of a lens misalignment with 45 mm focal length.

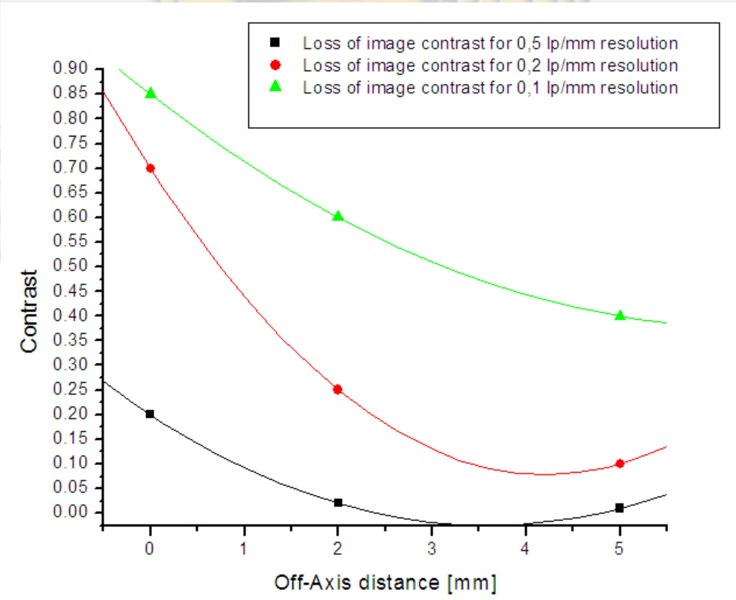

Fig. 11. The diagram contrast vs. off-axis distance.

The loss of image contrast with off-axis distance of a 45 mm focal length.

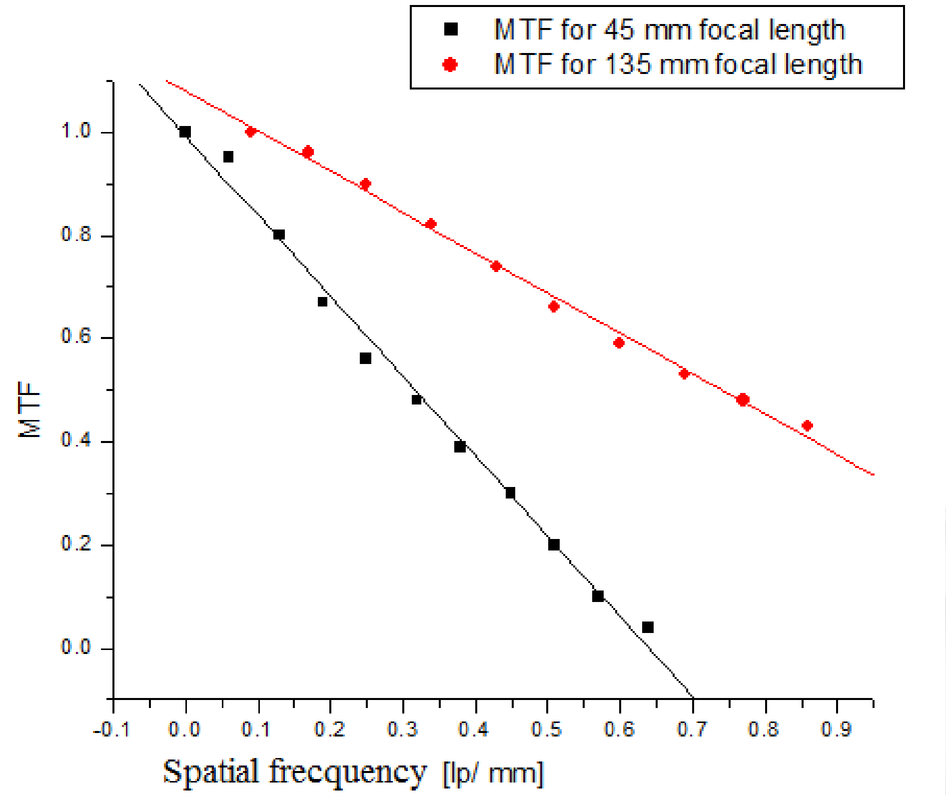

Fig. 12. The diagram MTF vs. spatial frequency. Comparison between MTF diagrams for lenses with 45 mm and 135 mm focal lengths, with well alignment done. One can see, for example, that for a same resolution of 0,5 lp/mm, a 3.3 times improvement of contrast using a lens with a focal length 3 times greater, can be obtained.

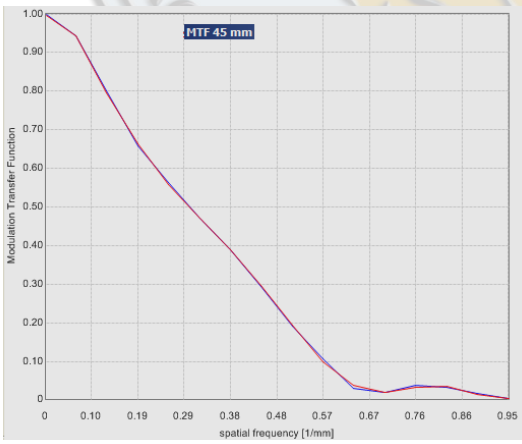

Fig. 13. MTF aligned focal lens 45 mm.

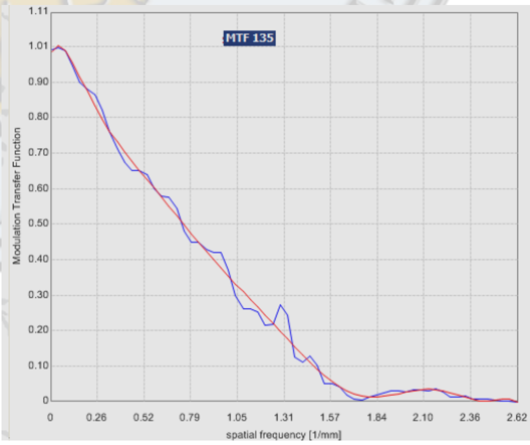

Fig. 14. MTF aligned focal lens 135 mm.

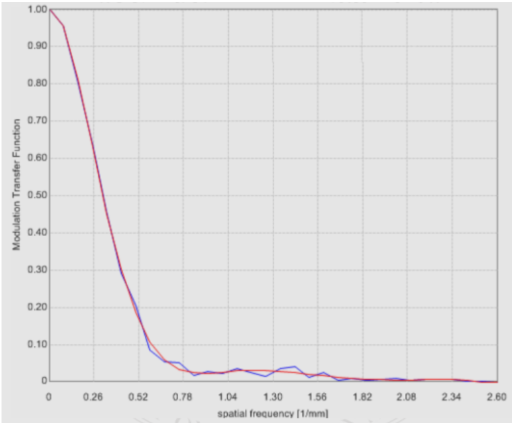

Fig. 15. MTF with misaligned 2 mm focal lens 135 mm.

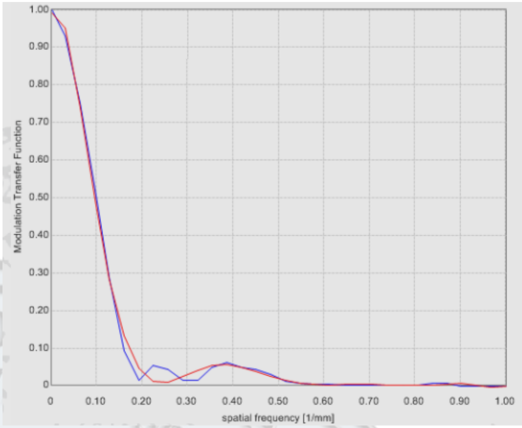

Fig. 16. MTF with misaligned 2 mm focal lens 45 mm.

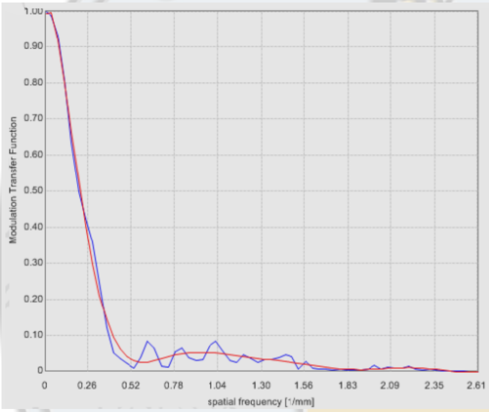

Fig. 18. MTF with misaligned 5 mm focal lens 135 mm.

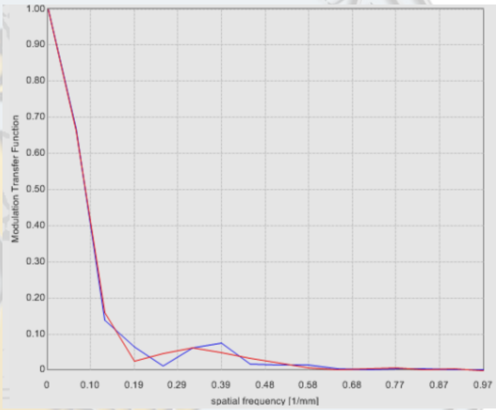

Fig. 19. MTF with misaligned 5 mm focal lens 45 mm.

4. Conclusions

A better MTF and NETD evaluation with electronic instruments is most appropriate;

A significant decrease in MTF is obtained at low level variations of optical misalignement;

4.3 The MTF decreases with decreasing lens focal.

R E F E R E N C E S

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