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SOME CONTRIBUTIONS TO THE IMAGE ANALYSIS IN AMBIENT PERTURBATIONS BY USING AN INTEGRATED VIDEO SENSORS SYSTEM

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Abstract. *The paper presents a fast evaluation method for the true performances of an integrated video sensors system. The principle of the proposed method is based on the analysis of main index of the images acquired using mechanical vibrations simulations. It is assumed that the assessment of an EO/IR sensor system performance can be known in poor mechanical ambient conditions, where the mechanical vibrations have an essential contribution. It has been hypothesized (proven during the work) that the modulation transfer function for two integrated video sensor systems (more neatly mounted or less precise) differ slightly in laboratory conditions, but there are significant differences in severe ambient conditions*

Keywords: Atmospheric turbulence, mechanical random vibrations, histogram, image quality, Electro-Optical/Infra-Red system, image simulation, Modulation Transfer Function

1. Introduction

An integrated video sensors system is an Electro-Optical/Infrared (EO/IR) system which aims to provide the detection, the recognition or the identification (as performance index) of an object of interest during the day or the night, sometime fusing the information from the images acquired by each of their afferent subsystems. The most commonly used sensors are CCD cameras / CMOS (EO) and thermal cameras (IR).

The detection of an object of interest is very much influenced by mechanical vibration from ambient, as shown in the graphic simulation from fig.1 using MAVIISS 1.5 [1] and NVThermIP 2009 software [2].

For the case of two EO/IR systems with the same architecture and the same performances of its components, but in which one system has a less accurate montage, the index of the picture quality is different (for example the Modulation Transfer Function, abr.MTF); as a consequence, the observation distances differ substantially if both systems are disturbed from the ambient (Figure 1).

It is very important to assess the effectiveness of an EO/IR system in different conditions of use, especially in those conditions where the possible threats are present and the ambient limits their operability.

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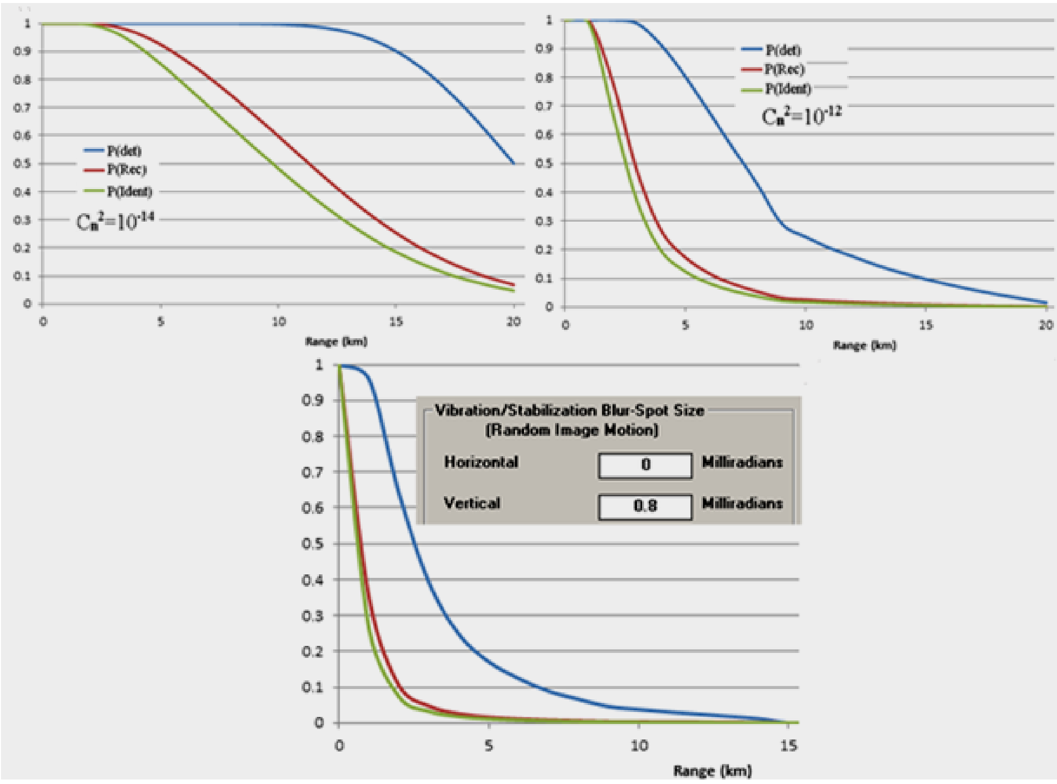


Fig. 1. The observation distances (detection, recognition, identification) in undisturbed ambient (a), disturbed ambient only by the maximum variation ambient turbulence (b) and disturbed ambient only by random vertical mechanical vibrations with 0.8 mrad angular amplitude (c).

One way of assessing the effectiveness of the EO/IR system, estimated in a previous paper [3] is to measure the quality of the acquired image by this system and simulate it in terms of atmospheric turbulence or low transmission as sever ambient. Another way is to simulate the acquired image in terms of mechanical vibrations of the EO/IR system, because the severity of testing in this case is much higher than in the turbulent variations (Figure 2). So, concerning the figure 2, the IR system used has a focal distance f=500[mm], aperture diameter D=125[mm], medium wavelength (λ) =4[μm]; the turbulence coefficient for the second image (b) is $C_n^2=10^{-15}[m^{2/3}]$ and for the third image (c) is $C_n^2=10^{-12}[m^{2/3}]$, the amplitude (σ) of the vibrations is 0.06 [mrad].

The quality picture indexes that estimates the performance of an EO/IR system can be quantified, usually, by the Modulation Transfer Function (MTF) values, the blur diagram and by the histogram distribution, too [4-16].For example, for two pictures with different contrasts and, consequently, different histograms, the histogram for high visibility covers a greater range of shades of grey, which means that the picture has good contrast.

The MTF analysis allows, in addition, the determination of the conditions of growth and optimization of the image quality, as can be seen in fig.3-5 (relating to the characteristics of the types of sensors EO / IR).

a) b) c)

Fig. 2. Some comparative pictures concerning the influence of environmental severity: a) picture of a scene in atmosphere without turbulence; b) the previous picture, simulated with extreme turbulence ($C_n^2=10^{-12}[m^{2/3}]$) and c) picture of the scene simulated with mechanical random vibration amplitude, order pixel size EO system user (18μm)

It can be seen that (fig.3-5), by increasing the quality of the optical lens there are not spectacular results, but rather, by increasing the number of detection elements (the MTF of the lens is more powerful than the MTF of the detection matrix).

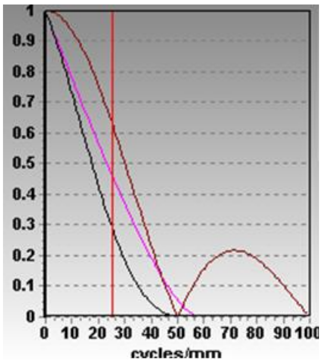


Fig. 3. Initial MTF of the EO/IR system.

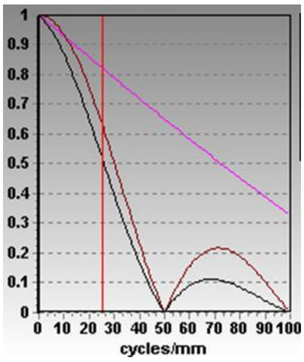


Fig. 4. The MTF can be higher by the lens optical corrections.

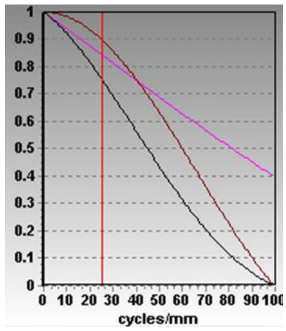


Fig. 5. The MTF can be higher by increasing the number of detection elements (pixels).

A way to determine the MTF values is the histogram analysis. Between the MTF and histogram are many connexions. By means of the histogram analysis it can obtain more information about fringes, besides the image contrast [4, 5].

2. The problematic

Two information types are important in the analysis of this paper:

a) For two systems EO / IR with the same components and features, but with different accuracies of execution, if these systems can be differentiated by analysing the acquired image quality of each system; to note that it is not known which of the two systems is deficient as execution;

b)For any EO / IR system, if the system behavior can be estimated for different severe ambient conditions.

The vibrations and the relative displacement produce a blurred image (fig. 6-7). The mechanical vibration affects the ability to resolve details. If the amplitude of the vibrations is low, the images do not appear to have blurred edges; on the contrary, if the amplitude is comparable with the image detail, the vibration influence becomes significant. It can be seen as the mechanical random vibrations were significantly higher importance than the turbulence (fig. 8).

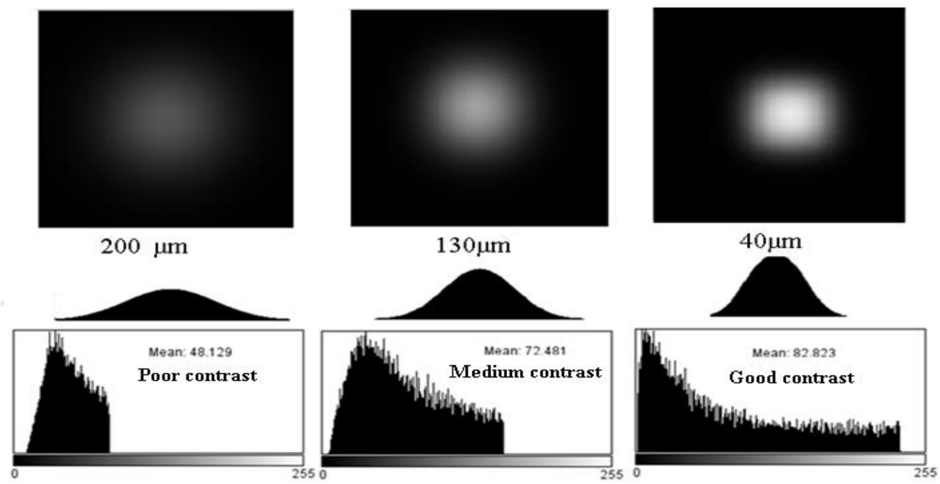


Fig. 6. The simulation of the mechanical random vibrations (for 3 different amplitudes: 200 µm; 130 µm and 40 µm; the size of the pixel of a matrix detection has 40 µm. It is presented, too, the afferent histograms of the three spots (the diffusion leads to blurring of the pictures).

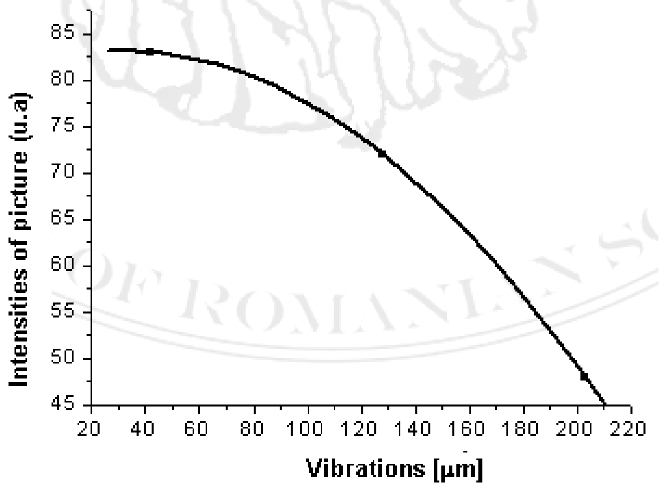


Fig. 7. The variation of average pixel intensity of the pictures from Figure 1.5 vs. the vibration amplitude; it can see that as the amplitude is higher, as the signal intensity (expressed in arbitrary units u.a. and given by the sharpness of the picture) is smaller.

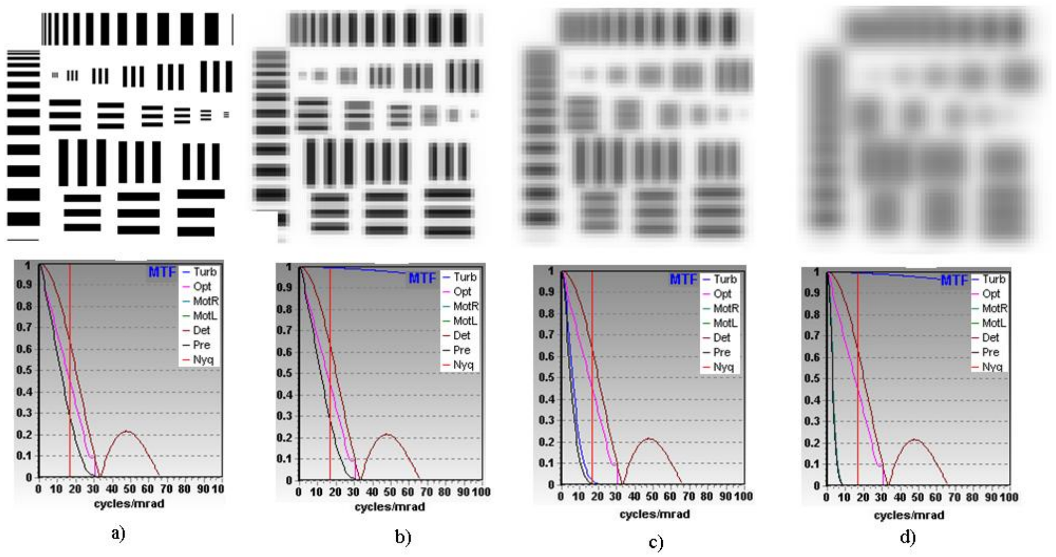


Fig. 8. The imagine of the USAF patterns (with the MTF afferent values) acquired using an IR system in normal ambient (a), with atmospheric turbulence (b and c) and only with mechanical random vibrations (d). The IR system has the focal distance *f*=500 [mm], the aperture diameter D=125 [mm] and medium wavelength (λ) =4 [µm]. The turbulence coefficient for the image b is $C_n^2=10^{-15}[m^{2/3}]$ and for the c picture is $C_n^2=10^{-12}[m^{2/3}]$.

2. The approach, simulations and discussions

The work hypothesis is that the MTF variation between the two type of EO/IR systems is indistinguishable (practically) in normal ambient (laboratory conditions), but it is important if the ambient has severe conditions. More, the observation conditions became significant in these conditions (fig.9-10).

It is noteworthy also that in the undisturbed ambient conditions, under an precise montage and in laboratory conditions (lack of vibration, air turbulence and aerosols), any EO / IR with the same features and architecture (differentiated only by the quality of the montage (i.e. more and less precise, respectively), offers ovservation distances and MTF values better than in the case of a poor execution,e.g. with optical misalignments (fig. 9-11).

By introducing mechanical vibrations (fig. 10-13) in the same laboratory conditions, it can reduce the MTF, especially if the EO/IR system is deficient as precision montage.

The analysis of the fig. 11-12 shows that the MTF varies more if the EO system (with optical aberrations and defocused, so for a poor montage) is tested to mechanical vibration; quantitatively it can write the following (related to this figures): $\frac{0.54-0.14}{0.54}\cdot 100[\%]=74[\%]$.

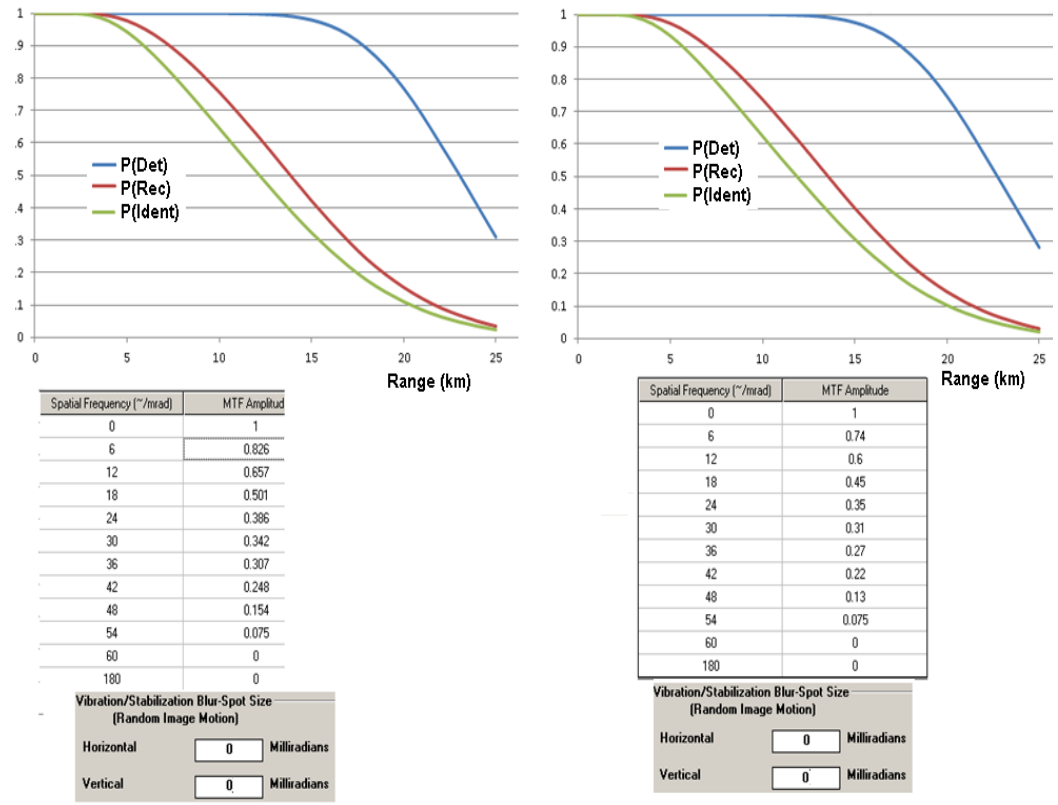


Fig. 9. The observation distances (detection, recognition, identification) in undisturbed ambient (left) for a given IR system with optimal MTF and, respectively, with MTF decreased (right) by 10% for all amplitudes (which simulates a more poorly fitted).

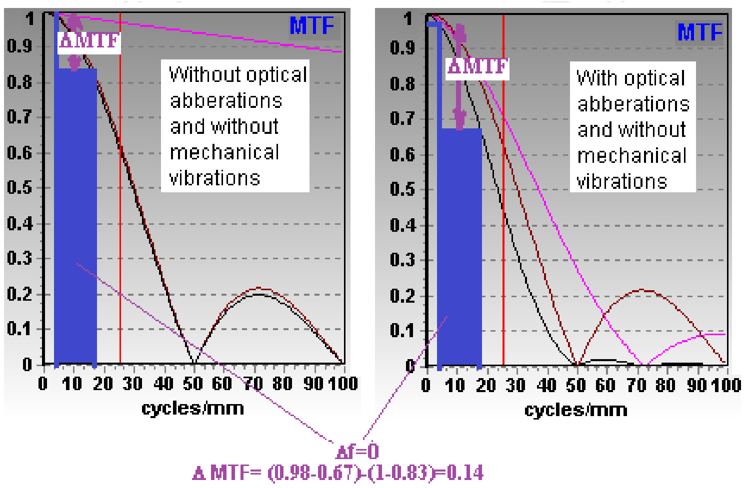


Fig. 11. The variation of the MTF for the same spatial frequency between 2-18 cy / mm with and without mechanical vibrations, for an EO/IR system without aberrations EO (left) and, respectively for a same system with optical aberrations and defocused (right).

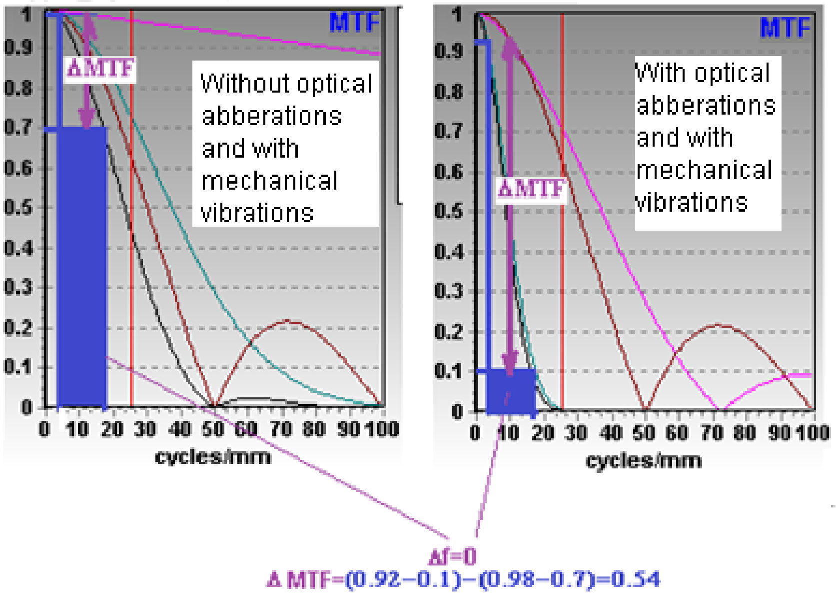


Fig. 13. The variation of the MTF for the same spatial frequency between 2-18 cy / mm with and without mechanical vibrations, for an EO/IR system without aberrations EO (left) and in the case of a same system with optical aberrations and defocused (right).

In the following relation for an EO/IR system [16]:

$$MTF_{EO/IR} = MTF_{atm} \cdot MTF_{turb} \cdot MTF_{Random} \cdot MTF_{optics} MTF_{sensor} MTF_{electr} MTF_{display} \cdot MT_{eye} \quad (1)$$

where

$$MTF_{Random} = e^{-2(\pi\sigma f)^2} \quad (2)$$

and σ has spatial frequency units

In the above figures it can be seen that the mechanical perturbations (vibrations and/or displacements) have a stronger effect for an image acquired than the atmospheric turbulence.

To highlight how an EO/IR system evolves concerning the MTF values, tested with mechanical vibrations at different amplitudes, it can use the rapport E:

$$E = \frac{1-R}{R} \cdot 100[\%] \quad (3)$$

where:

$$R = \frac{MTF_{1i}}{MTF_2} = e^{-2\pi^2 \cdot f^2 (\sigma_2^2 - \sigma_1^2)} = e^{-20f^2 \cdot \Delta\sigma(\sigma 1 + \sigma 2)} \approx e^{-20f^2 \cdot 2\sigma \cdot \Delta\sigma} \quad (4)$$

in which 1 represents the status of the EO/IR system with the vibration amplitude 1, for example 6 µm, and 2 represents the status of the EO/IR system with the vibration amplitude 2, for example 11 µm (Figure 14).

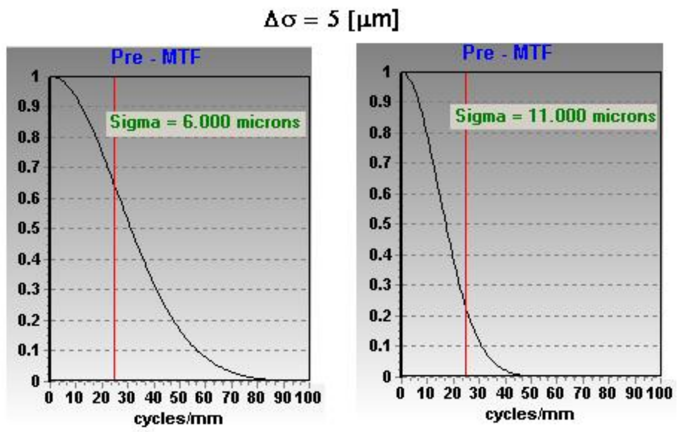
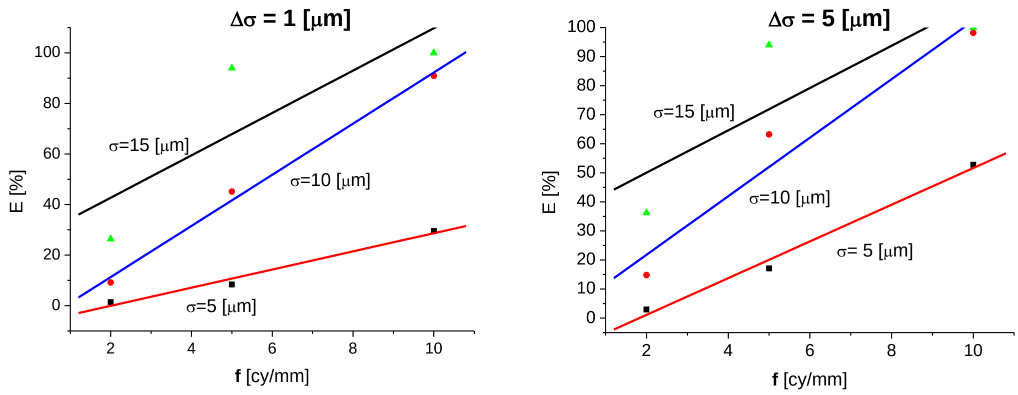


Fig. 14. The MTF diagrams corresponding to the two values of the vibrations amplitudes (6 microns and 11 µm, respectively), which means a difference Δσ = 5 µm.

We consider a significant variation for σ = 1 ... 20 [µm] and a variation between the status 1 and status 2 as Δσ = 1 ... 5 [µm]. The results are shown in fig. 15-16.



a) b)

Fig.15. The variation of the MTF difference with the spatial frequency f at different amplitudes σ [µm] and different amplitude variations Δσ [µm] between them.

By the analysis of the following diagrams it can see that, as the observed object is farther from the EO/IR system (the spatial frequency is higher), as the difference between MTF is higher; also, the difference in amplitude of vibration increases the difference between the MTF.

For the higher the vibration amplitude (σ), the difference between the two MTFs increases, so that under null vibration (without any ambient severity) there are virtually differences between the MTF. The difference increases with the increasing of the severity of the ambient.

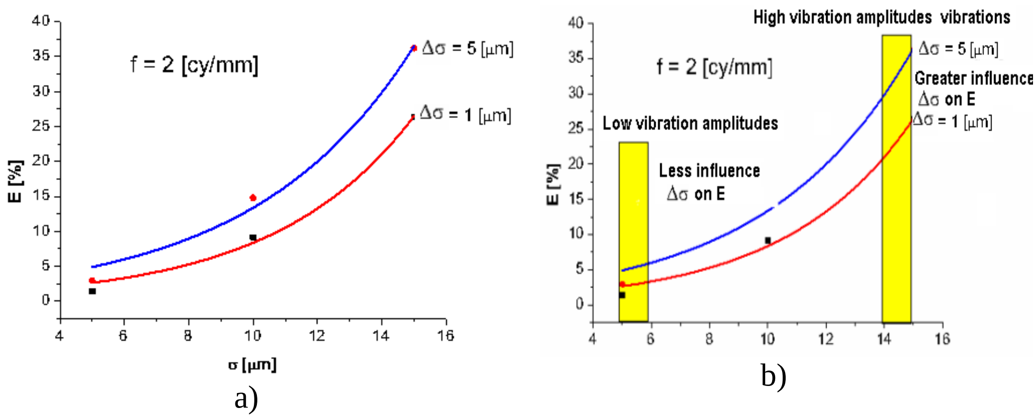


Fig. 16. Numerical simulations of the variation of the MTF with the σ [μm] and Δσ [μm] for a fixed spatial frequency *f*.

4. Conclusions

4.1 Two EO/IR systems with the same components and features, but with different accuracies of execution can be differentiated by analyzing the acquired image quality of each;

4.2 The behaviour of an EO/IR system can be estimated for different conditions of an ambient, especially for mechanical random vibrations.

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