Optical analyze of electro-optical systems by MTF calculus

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ABSTRACT

One of the widely used methods for performance analysis of an optical system is the determination of the Modulation Transfer Function (MTF). The MTF represents a quantitative and direct measure of image quality, and, besides being an objective test, it can be used on concatenated optical system. This paper presents the application of software called SMTF (software modulation transfer function), built in C++ and Open CV platforms for MTF calculation on electro-optical system. Through this technique, it is possible to develop specific method to measure the real time performance of a digital fundus camera, an infrared sensor and an ophthalmological surgery microscope. Each optical instrument mentioned has a particular device to measure the MTF response, which is being developed. Then the MTF information assists the analysis of the optical system alignment, and also defines its resolution limit by the MTF graphic. The result obtained from the implemented software is compared with the theoretical MTF curve from the analyzed systems.

Keywords: Modulation Transfer Function, Optical Alignment, Fourier Transform, Optical Performance.

1 INTRODUCTION

Equipments incorporating optical, electronics and mechanics are increasingly disseminated and used in different applications such as medical, remote sensing and imaging systems. Examples are fundus camera, ophthalmological surgery microscope and infrared sensor. Such equipments should have a good optical performance, allowing the system to capture images with high resolution and contrast.

The Optical Transfer Function (OTF) became the most used function to evaluate image quality of optical systems. The OTF provides an evaluation of the structure of the image indicating the contrast for a sinusoidal object for a range of spatial frequencies. Therefore, the information obtained by the OTF can be used to build in detail an image [10].

The OTF is a complex function and is possible to calculate the modulus and phase of this function. The modulus value of OTF corresponds to the value of the MTF of the system. As discussed by Scaduto [9], there are different methods to perform the calculation of the MTF, the majority uses targets with sinusoidal patterns, point (pinhole), border type (Knife-edge), among others. Other tests are still based on interferometry method [11]. According to Samei [8] among the several existing techniques for the calculation of the MTF, the knife-edge target is actually the most used. One of the justifications for the use of the knife-edge target is its simplicity of construction. Moreover, when compared to other techniques, it presents a much higher flow of energy, making their detection more convenient [5].

A disadvantage of using the knife-edge target to calculating the MTF is the noise on the image to be marked during the calculation, when the spatial derivation is performed [1].

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This work uses a knife-edge target to perform the MTF calculation of the electro-optical analyzed systems. An infrared sensor is used primarily to allow the validation of the proposed method, and then the method is applied to fundus camera and to surgery microscope. A default target is used for all systems. What changes between one system to another is the position that the target is placed due to the focal length difference of each equipment. Each optical instrument mentioned has a particular device to measure the MTF response in the real time, which is being developed.

2 OPTICAL PERFORMANCE

The image formed by an ideal optical system should be an exact point-to-point reproduction of an object. However, imperfections are always present in a real optical system and can be caused by diffraction effects on the edges of the lens, aberrations and mistakes in construction [13].

One of the most used forms to evaluate the optical performance of a system is using the calculation of the MTF. To perform this calculation is necessary have knowledge about the Fourier Transform (FT) and the Optical Transfer Function.

2.1 Fourier Transform

The Fourier Transform (FT) is an important tool in image processing, which is used to decompose an image into sine and cosine components. The FT is used in a wide range of application, such as image analysis, filter for images, image reconstruction and image compression.

The result of Fourier Transform represents the image in the frequency domain, while the image is in the space. In the frequency domain, each point of the image represents a particular frequency. For analytical FT calculation it can be used Equation (1).

$$\int f(x) e^{-i.2.\pi.x.s} dx \tag{1}$$

But it can be approximated numerically by Equation (2).

$$\sum_{n=o}^{N-1} y_n e^{-ik\frac{2\pi}{N}n} \quad k \in [0, N-1] \tag{2}$$

In the Equation (1) and (2) f(x) and y_n represents the function which will be applied FT, x represents the frequency that varies in the range of frequencies and N represents the period, where the function is defined.

2.2 Optical Transfer Function

The OTF represents the resolution capability of an imaging system related to the spatial objects frequency, which demonstrates exactly degradation degree for all frequencies imposed by the system on the image production process [7]. Its equation is defined by Equation (3), where mtf(x,y) is the modulation transfer function of the system, ptf(x,y) is de phase transfer function (PTF) and x and y are the image coordinates.

$$otf(x,y) = mtf(x,y) * ptf(x,y) \tag{3}$$

Using the FT and the convolution theorem, the optical transfer function for a sinusoidal signal can be calculated according to equation (4), after applying the FT in all terms of the equation (3).

$$OTF(\varepsilon,) = MTF(\varepsilon,).PTF(\varepsilon,) \tag{4}$$

From the OFT can define the MTF and PTF as Equation (5) and (6) respectively,

$$MTF(\varepsilon,) = |OTF(\varepsilon,)| \tag{5}$$

$$PTF(\varepsilon,) = e^{-i2.\pi.\lambda(\varepsilon,)} \tag{6}$$

Since ε = 1 / X and η = 1 / Y where X and Y are the spatial periods in the x and y directions respectively.

For the images used in this article, will be examine only the MTF of the systems, therefore $OTF(\varepsilon,) = MTF(\varepsilon,)$.

2.3 Modulation Transfer Function

Although the equating of the MTF has been presented by the Equation (5), according to Holst [4] and Wolfe [12], the MTF can be given by the dimensionless relationship expressed by Equation (7).

$$MTF = \frac{Modulation\ of\ image\ signal}{Modulation\ of\ object\ signal} \tag{7}$$

The Figure 1 presents the relationship between input and output signals of an optical system, allowing calculation of the MTF.

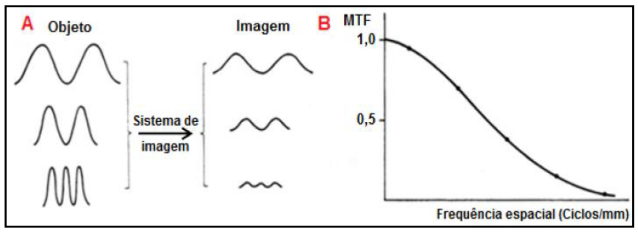

Figure 1 – (A) Relation between the intensity distribution of sinusoidal objects with same amplitude and different spatial frequencies and their respective images; (B) The corresponding system modulation transfer function (MTF) [7].

The graphic provided by the MTF can offer an analysis of the system resolution limit. This limit is given by the value of spatial frequency (cycles/mm) where MTF is zero [6]. The resolution of an optical system can be defined as the separation of two discrete points that can be easily discerned in angle of object-space or in distance of image-plane [1].

2.4 Methods for calculating the MTF

There are different methods for calculating the MTF of an optical system. The method used in this work use a standard target with known frequency. Such target provides a way to measure the MTF that eliminates the dependence of the measure with the position of the target, allowing obtaining an average MTF for a scene that occurs naturally. The test consists of capturing the target image produced by the system under test, using a CCD, and analyzes the spatial frequencies contained in the detected image [3].

This method can be used to test only an array of detectors as well as complete optical systems [2].

3 MATERIAL AND METHODS

This article can be divided into three stages: the first stage presents the implementation of the algorithm needed for the calculation using the implemented software, in the second stage SMTF is tested using a static image, with only one target for the infrared sensor and in third stage the MTF is calculated using five targets, as shown in Figure 2.

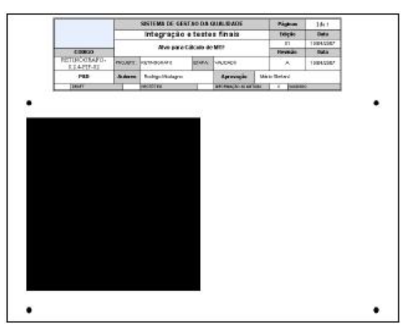

Figure 2 – Target for MTF calculation [5].

3.1 Algorithm of software for MTF calculating

Below is described the algorithm used to implement software SMTF using the programming language C + + and OpenCV library.

1. Vectors of input signals, derived from the input signals, and the FT module are created;
2. The amount of entries is represented by the amount of targets captured by the image;
3. The size of the input signal vector is defined by the signal line on the target;
4. Input signals are obtained. These signals are represented by lines positioned over areas of transition from black to white in targets;
5. The minimum value of the input signal of each line positioned on the targets;
6. Derivative signal is calculated by subtracting the signal shifted one position ahead of the original signal;
7. Maximum value of derivative is calculated. This value will be used so that only the transition of signal is considered, reseting the points with low derived;
8. Low derived values are zeroed. For this is determined threshold and reseting the points whose derivative is less than 10% of maximum value – this value was determined empirically;
9. Possessing the derivative of the step input. Then define the FT module.
10. Estimated FT maximum.
11. Is held the division of the FT module per calculated value, normalizing this way FT values.
12. Finally, it makes the input signal graphic and the FT module, which characterizes the MTF of the analyzed system.

3.2 Measures using the optical system of the infrared sensor

In order to implement the algorithm presented above, it was placed a target on a screen, perpendicular to the optical axis of the infrared sensor in the central region of the captured image. Using the infrared sensor, a few images were acquired, as shown in Figure 3, during the alignment of the optical system sensor.

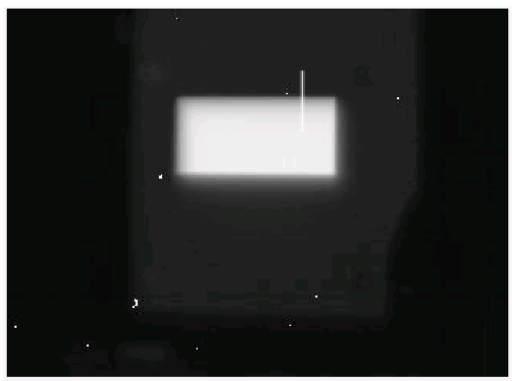

Figure 3 – Image captured by the infrared sensor to calculate the MTF.

After the image is captured it was necessary to indicate the beginning and end of a line, positioned in the transition from black to white part of the target. Once, it can determine the line, it is possible to calculate the MTF from the software SMTF and determine the graph of the MTF, as shown in Figure 4.

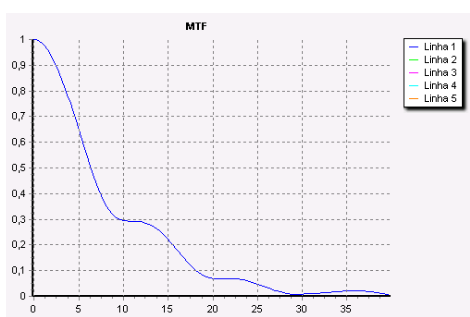

Figure 4 – Graph of the MTF for one target using the infrared sensor.

Following the calculations, it was made a comparison between the theoretical and calculated MTF.

Figure 4 and Figure 5 show respectively the calculated and theoretical MTF of the infrared sensor, after alignment.

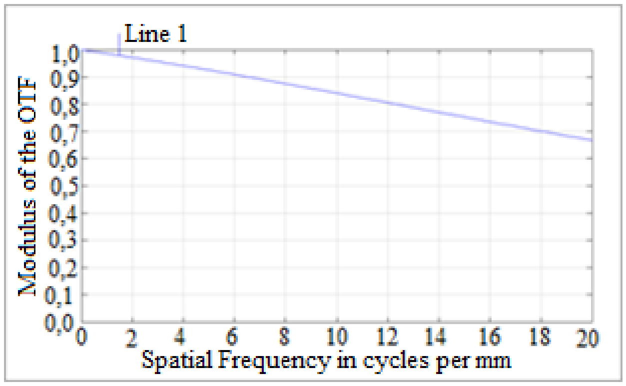

Figure 5 – Theoretical MTF graph for the infrared sensor.

Comparing the MTF graphic presented by the software and the theoretical values, it can be verified the sensor MTF was below the value expected (theoretical). This result is due to the failure of assembly and manufacturing of optical infrared sensor.

3.3 Measures using the Fundus Camera optical system

Five targets were used, one target in the center of the fundus camera optical axis and the other four targets are placed on the sides, which are equidistant from the central target.

For the fundus camera, the lines are drawn in the image that is being captured and the targets are placed where the lines coincide with the transition from black to white. Thus, once the targets are positioned correctly on the screen perpendicular to the fundus camera optical axis, it is possible to view continuously changes in the MTF, when there is any change in the optical alignment system. After that the alignment process is optimized.

Through this calculation is it possible to note, when it has a misalignment in the horizontal, then the values of the MTF graphic on the right side are different from the left side of the image. Now, when it has a vertical misalignment, the values of MTF graphic are different for target located at the bottom from the top.

The image captured by de fundus camera in shown in Figure 6.

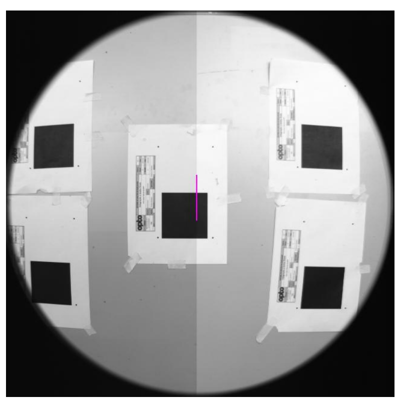

Figure 6 – Image captured by the fundus camera to calculate the MTF.

Figure 7 shows the resulting graphs from the MTF calculating for the five targets used. In fundus camera MTF graphic the lines correspond to the following targets: Line 1 corresponds to the upper left target, Line 2 to the upper right target, the Line 3 to the center target, Line 4 to the lower left target and line 5 to the lower right target.

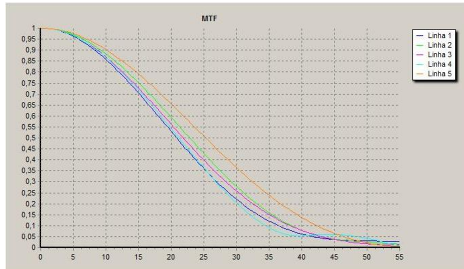

Figure 7 – Graph of the MTF for five targets using fundus camera.

Figure 7 and Figure 8 shows the theoretical and the calculated MTF graphic of fundus camera, respectively, after performing the alignment.

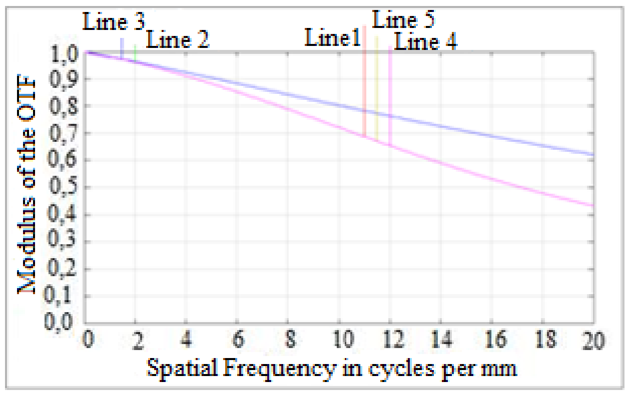

Figure 8 – Theoretical MTF graph of the fundus camera

From the theoretical fundus camera graph, it is possible verify that the MTF of the graphics on the both sides are equal and the best MTF is from the central target. Considering the MTF of the fundus camera, it can see the degradation of MTF system is due to a misalignment of the equipment imposed by the mechanical parts of the equipment and also optical aberrations.

4 CONCLUSION

During the implementation of the system proposed for calculating the MTF, it was verified that the target illumination affects directly the calculation of the MTF. For better use of the system, the targets must be illuminated homogeneously.

The software accomplished a good analysis of the optical system performance. This software allows good results for the alignment process of a fundus camera and an infrared sensor.

Using the SMTF of a static image can validate the operation process, but this form of analysis requires more time. Once in each picture the lines, which determine the signals to be analyzed, must be appointed manually for each captured image.

The software is operating in real time and when the targets are positioned correctly as described above, the calculation of the MTF occurs immediately. Any modification made in the alignment of the optical system is analyzed quickly and directly, facilitating the alignment process.

This work allows observing, in practice, it is not always the difference between the theoretical and calculated values of the MTF, the cause of alignment lack of optical system, but can help diagnose other problems, such as error in the manufacturing of lenses, assembling problems, or problems with the films present in some lenses, among others.

Tests will be conducted also with the ophthalmologic surgery microscope. This requires an optical system adapted to the microscope system in order to capture the image of the target by a CCD. After adjusting the CCD to the microscope, the MTF calculation is performed and the MTF curves are obtained by this software. The MTF curves are obtained on the optical axis and the bottom, top, right and left edges for each continuously magnification (5 to 30 times). The result is obtained by comparing the measured value with the standard Zeiss microscope. Will be used five targets distributed in the visual field of the microscope, that is on the optical axis and the four edges of the Cartesian axis.

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