

Application of Oversampling to obtain the MTF of Digital Radiology Equipment.

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Abstract. Within the objectives of the project Medical Image Processing for Quality Assessment of X-Ray Imaging, the present research work is aimed at developing a phantom X-ray image and its associated processing algorithms in order to evaluate the image quality rendered by digital X-ray equipment. These tools are used to measure various image parameters, among which spatial resolution shows a fundamental property that can be characterized by the Modulation Transfer Function (MTF) of an imaging system [1]. After performing a thorough literature survey on imaging quality control in digital X-film in Argentine and international publications, it was decided to adopt for this work the Norm IEC 62220-1:2003 that recommends using an image edge as a testing method. In order to obtain the characterizing MTF, a protocol was designed for unifying the conditions under which the images are acquired for later evaluation. The protocol implied acquiring a radiography image by means of a specific referential technique, i.e. referred either to voltage, current, time, distance focus-plate (/film?) distance, or other referential parameter, and to interpret the image through a system of computed radiology or direct digital radiology. The contribution of the work stems from the fact that, even though the traditional way of evaluating an X-film image quality has relied mostly on subjective methods, this work presents an objective evaluative tool for the images obtained with a given equipment, followed by a contrastive analysis with the renderings from other X-film imaging sets. Once the images were obtained, specific calculations were carried out. Though there exist some methods based on the subjective evaluation of the quality of image, this work offers an objective evaluation of the equipment under study. Finally, we present the results obtained on different equipment.

1. Introduction

The field of Digital X-Ray Imaging has gained wide acceptance on the grounds of state-of-the-art advances, by incorporating new technologies that allow for readily obtaining improved images for medical diagnosis, as contrasted with traditional methods.

Indeed, due to the development of digital image treatment with information extraction and enhanced visualization technologies, along with greater software power to discern the reaches of any given parameter of interest, it is now possible to easily improve the diagnosis renderings of the medical specialist.

In spite of this significant progress, it is still necessary to evaluate the quality of images. According to a definition, quality is understood as the "Property or set of properties inherent to a given thing, which allows for judging its value". In the medical field, quality is associated to satisfying the expectations of the patient as regards diagnosis and treatment of his illness or condition, as performed by the physician, following the guidelines and rules established in national and international protocols, while trying to keep a reasonably lowest possible cost for the involved sanitary institution"[5].

In Medical Sciences, the subject of Medical Image Quality can be defined as the evaluation (objectively or subjectively) of the performance of a medical imaging system by means of measurement computations done on a given image. That is, it is technically possible to quantify and set values to image features with the aid of parameter data, e.g. spatial resolution, contrast, noise, and the like. Nevertheless, it is also possible to evaluate image quality by resorting to subjective estimations made on the overall performance of the X-ray



equipment. But, since this method relies on human capabilities for assessment, it may suffer from a certain variability degree on its conclusions. Therefore, it is sensible to seek an improved parameter definition that allows objectively defining the quality of X-ray imaging.

The concept of image quality is defined within the environment of medical diagnosis and consists of evaluating (objective or subjectively) the functioning of a generating system of medical images from measurements done on a resultant image. That is, technically it is possible to quantify or to value the characteristics of the image from parameters such as spatial resolution, contrast, and noise, between others. Nevertheless, it is also possible to evaluate the quality from subjective estimations of the global functioning of the equipment. This method of evaluation, dependent on human factor, presents certain degree of variability. Therefore it is important the parameters definition that characterize in an objective way the image quality.

Several authors[2] assert that image quality entails combining the effects of noise and spatial resolution. Therefore, if a straightforward, automatic analysis is made upon these parameters, the evaluation process will get free from both the object and the observer. This, in turn, will enable to do an unbiased quantitative and objective contrastive assessment among parametric characteristics of various detectors and technologies. Besides, when considering the current trend for incorporating digitally networked facilities into health centers, along with DICOM protocols capable of managing digitalized imaging, the conditions could then be optimally set for achieving faster and more reliable imaging analysis for improved diagnosis. In general, and in certain places, this renewal trend for digital X-ray equipment is being made progressively, but the need to re-design the image-quality control tests is an unquestionable fact.

Among other means, one way to characterize objectively the performance of a digital imaging system is by using Modulation Transfer Function (MTF) as the evaluating parameter. In the literature, several measuring procedures can be found. However, in one such works, Neitze et al. have stated that the use of different evaluation routines may lead to sharp discrepancies in parameter determination, some of them reaching up to 30%, even when employing a single image for all measurements.

The early published works showed various image-quality evaluating methods that used, for example, bars patterns [11], and even a radio-transparent discs matrix [12]. In an effort to prevent the occurrence of calculation differences and to eliminate the variations among adopted methods, the International Electrotechnical Commission IEC 62220-1 [4] published a standard in 2003 that set the procedure to determine imaging-quality parameters by using the MTF of the digital detectors of X-ray imaging equipment. Through this standardization, it is thus possible to unify the measuring procedures and, consequently, to do reliable contrastive studies in this field.

This work framed within the larger project Medical Imaging Processing for image quality evaluation of X-ray equipment. The general objective is to design and develop a testing device having low cost and simple construction, for measuring standardized image quality parameters of digitalized X-ray equipment. The work continues into the development of an algorithm to calculate the MTF of a digital detector, following the above cited CEI standards, applied to images stored in DICOM-format files and using a protocol aimed at combining the conditions under which the images have been acquired for later evaluation.

1.1. MTF, Modulation Transfer Function.

MTF is a mathematical function that provides a measurement on how well an X-ray

imaging system transfers the contrast details of an examined object onto the X-film image. Otherwise expressed, MTF is directly related to quantifying the capability of the X-ray equipment to generate an image that accurately reflects the details of the explored object, with a scale ranging from 0 to 1 or 100 % as a maximum value [6]. MTF is considered the best index for measuring spatial resolution as well as a contrast index for different spatial frequencies. If the system were thought to be a filter (generally a lowpass filter) the MTF would represent its frequency response.

In practice, MTF can be obtained by means of three methods: the slit method [7], the edge method [8] and the grid method (grids used at different spatial frequencies). The typical option has been to use the image of a slit to obtain a MTF perpendicularly to the object. In order to improve the brightness estimation for a given system, the concept of Line Spread Function (LSF) is used. The LSF is a contour or profile of the image obtained from a very thin slit. The MTF is the Fourier transform of LSF (equation 1):

$$MTF(u) = |F[LSF(x)]| = \left| \int_{-\infty}^{\infty} [LSF(x) \cdot e^{-2\pi j \cdot x \cdot u}] dx \right| \quad (1)$$

being $TF(u) = (\text{output amplitude}/\text{input amplitude})_u$, where u is the spatial frequency.

The implicit difficulty of this method is that using slits requires precise manufacturing and alignment, are highly exposed to radiation to allow the transmission across the slit and a correction to take into account the small size of the slit.

Samei et al. [9] have concluded that the edge method provides a better definition of MTF fall at low frequencies. For this purpose an image of an edge phantom, called the Edge Spread Function (ESF), is obtained (Fig. 1).

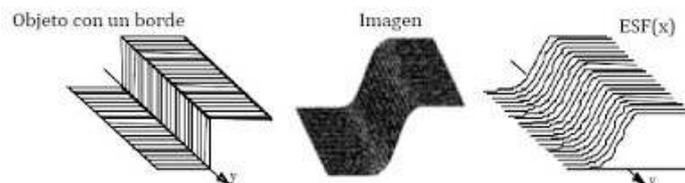


Figure 1. The ESF is the image of an opaque object having an edge.

Mathematically, LSF is the first derivative of the ESF, as stated in the following equation:

$$LSF(x) = \frac{d[ESF(x)]}{dx} \quad (2)$$

In practice, ESF can be easily obtained due to the simple form of the plate (←??) needed for the experience. Once the image is obtained, a perpendicular cut to the edge is made to obtain the ESF. Then, the LSF of the system is obtained by deriving the ESF. Now, Eq. 2 will be valid only when working on the linear range of the sensor.

Various analytical and experimental methods have been used to obtain the MTF from the LSF and the ESF. Fujita and cols [7] designed an oversampling method applied to LSF. Samei and cols. [8] also worked with oversampling but combined it with other image processing techniques by using ESF.

Figure 2 shows a conceptual scheme of the MTF. Input signals to the system are represented by sinusoidal functions having different frequencies. Once they pass through the image system, the output signals show lower amplitudes than those of the input signals, but they

keep the frequency. It is also noted that greater input frequencies cause lower output amplitudes, which means that the output amplitude is affected by the image system, and that this effect is dependent on the spatial frequency. In the figure it can also be noted that, at lower values of spatial frequencies (corresponding to large objects), the signal is transferred almost entirely, with no significant loss in contrast of the output image. As the spatial frequency increases (smaller objects), the amplitude of the output signal (and therefore, the contrast) decreases. This effect confirms the low-pass characteristics that X-ray imaging systems have.

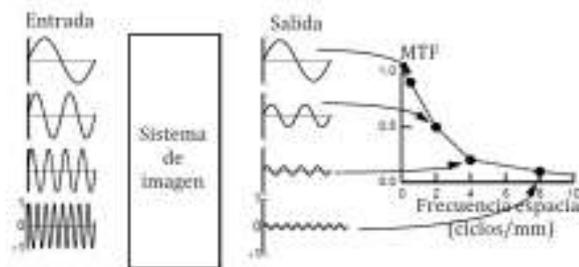


Figure 2. The MTF depicts how an X-ray system affects the details of an image.

2. Materials and Methods.

The method proposed for the obtaining of the MTF requires using a specific radiological technology, a normalized phantom and a set of algorithms for image processing. In this section, the characteristics of each one of these elements are described.

A. Description of the Radiological Technology.

The geometry established by IEC 62220-1 [4] for acquiring the MTF is defined by choosing a radiation quality 5 (RQA 5) under 70 kVp and 100 mA, as well as a thin focus in a 18x24 chassis. Images were taken without any anti-diffusive grid, and 1.5 m source-detector distance, as shown in Fig. 3.

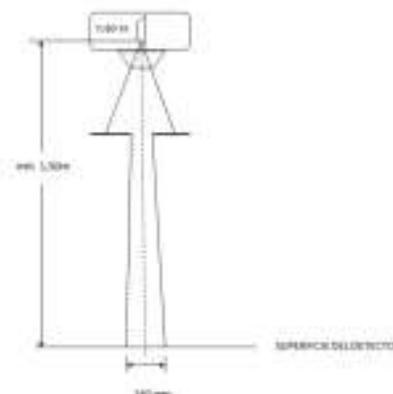


Figure 3. Standard geometry used in the test.

The Norm IEC 62220-1 [4] allows using other qualities, though it recommends using RQA5. The standard adopts the edge method, specifying the use of a radio-opaque object of tungsten of 1 mm of thickness with a straight edge and definite dimensions, as shown in Fig. 5.

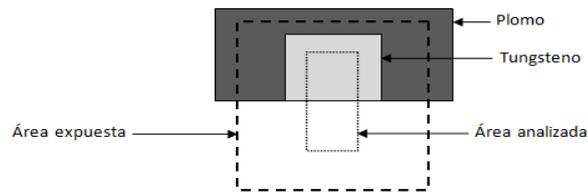


Figure 5. Phantom (specifications according to Norm IEC 62220-1:2003).

At present there are market-available edges, but, as Neitzelet al. [10] have demonstrated, a semitransparent edge may lead to an erroneous MTF estimation due to a small amount of ed diffused radiation coming through the back of the edge and that reaches the detector. But this can be adapted for evidence tests, because the precision of the method is not altered, just its accuracy. In addition, a semitransparent edge is light and easier to align.

The proposed phantom in this work (Fig. 6a) is built with a 1mm-thick copper plate (22,5% transmission, for an RQA5 bundle quality), sized 75x100 mm, with a precision edge, contoured with a 3mm-thick lead fringe, with which an “infinitely long edge” is simulated.

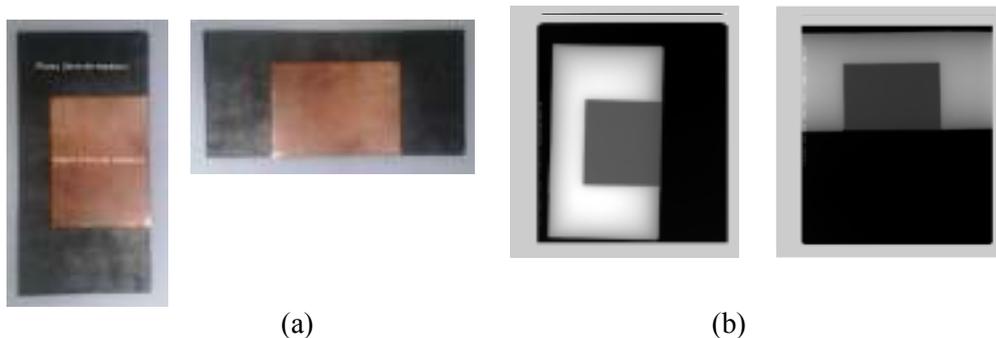


Figure 6. (a) Images of the constructed phantom. (b) Radiographic images of the constructed phantom.

The tungsten plate proposed in the standard is quite expensive; therefore, it has been replaced by a copper one, which is a material having very similar characteristics [13].

Since the edge must necessarily have a well-defined finish, a very precise cutting must be exercised. To this aim, the edge cut was performed with such care, and images were obtained through an Olympus microscope equipped with a 4x objective (Fig. 4a). Next, the cut was milled and polished (Fig. 7b), with images obtained with an Arcano 10x stereoscopic magnifying glass.

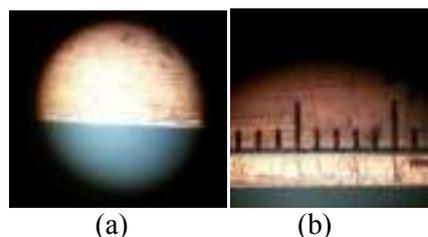


Figure 7. Images of the constructed edge.

The method consists on acquiring phantom images taken with a light camera angle (1.5°-3°) respecting the detector matrix, so as to obtain an over sampling profile that prevents any

digitalization effect (Figure 6.b). Images on a direction parallel to the columns of the detector were firstly taken; then, on the direction of rows. The edge's center was positioned coinciding with the center of the radiation bundle so as to prevent that any offsetting motion may alter the image.

The method consists of acquiring images of the phantom with a light camera angle ($1,5^\circ - 3^\circ$) with regard to the matrix of the detector, to obtain an oversampling profile that avoids the effects of the digitalization (Figure 6.b). First, images in a parallel direction to the columns of the detector were taken, and then in the direction of the rows. The center of the edge was placed at the center of the bundle of radiation to prevent that the displacements of it could modify the image.

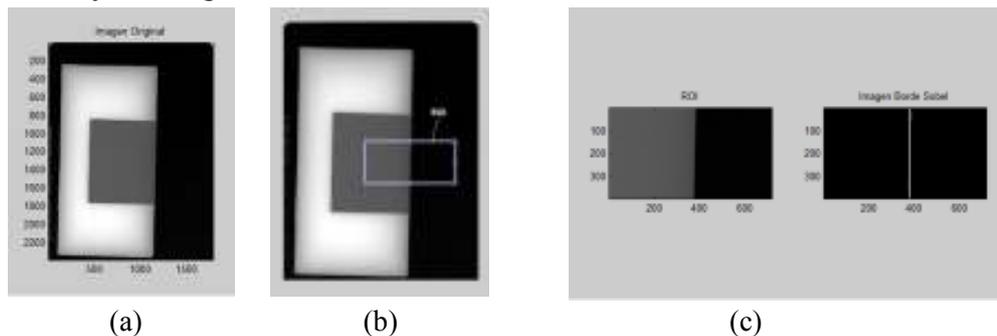


Figure 8. (a) Contours of the image. (b) Region of interest. (c) Determination of the edge.

The region of interest (ROI) used in finding the MTF is defined as a 50×100 mm rectangle of the transition edge, as shown in Fig. 8b. To determine the edge, it was proceeded to extract the image contour by applying the Sobel's method for computing the image's gradient of the image, as shown in Fig. 8c. The small angulation needed to acquire the images allows for applying oversampling techniques as we will see hereinafter. However, is it a fundamental requirement to know accurately the value of the angle Θ . For this purpose the Hough line transform is used, which consists of obtaining an image of the parameters space of the lines contained in an image. In order to do this, all the lines that can pass through a specific pixel are cumulated in every parameter and for every pixel of edge. In the Figure 9a the polar coordinate of the Hough transform is shown.

The region of interest (ROI) used for the determination of the MTF is defined as a rectangle of $50 \text{ mm} \times 100 \text{ mm}$, of the edge of transition, as Figure 8b shows. For the determination of the edge it begun with the extraction of the image contour, for this there was used Sobel's method that calculates the gradient of the image, as it appears in Figure 8.c. The small angulation needed for the acquisition of the images allows applying oversampling techniques as we will see hereinafter. However, is it a fundamental requirement to know accurately the value of the angle Θ . For this purpose the Hough line transform is used, which consists of obtaining an image of the parameters space of the lines contained in an image. In order to do this, all the lines that can pass through a specific pixel are cumulated in every parameter and for every pixel of edge. In the Figure 9a the polar coordinate of the Hough transform is shown.

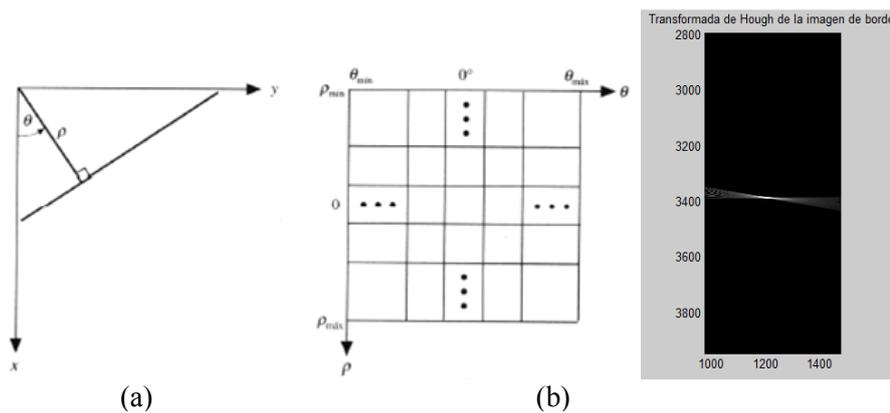


Figure 9. Hough Transform.

In Figure 9b appears the Hough transform of the image of edge where it can be appreciated a maximum corresponding to the parameters of the line of edge of the phantom [14]. Then, every pixel was projected along a perpendicular line to the edge obtaining the Edge Spread Function (ESF) or Edge Response Function (ERF). A scheme of the obtaining of the ESF is observed in the Figure 10a. Each of the columns of the image has been located in consecutive way forming a unique vector.

Due to the fact that the edge is perfectly straight and the levels of gray are changing gradually, it is possible to construct a function of edge with a precision defined by the quantity of rows that are needed to advance a pixel in the columns. For the example $N=4$. N is the nearest point to $1/\text{tg}\theta$. The standard indicates that the range of values of the measured angle must be between $1,5^\circ$ and 3° , which implies a value of N comprised between 40 and 20 respectively. It means that every N rows of the image is possible to obtain an $\text{ESFi}(x)$. If the image has a high of m rows it can be divided equally m/N times the $\text{ESFi}(x)$. It is necessary to bear in mind that before to the averaging it is necessary to do a displacement of each one of the functions (Figure 10b)

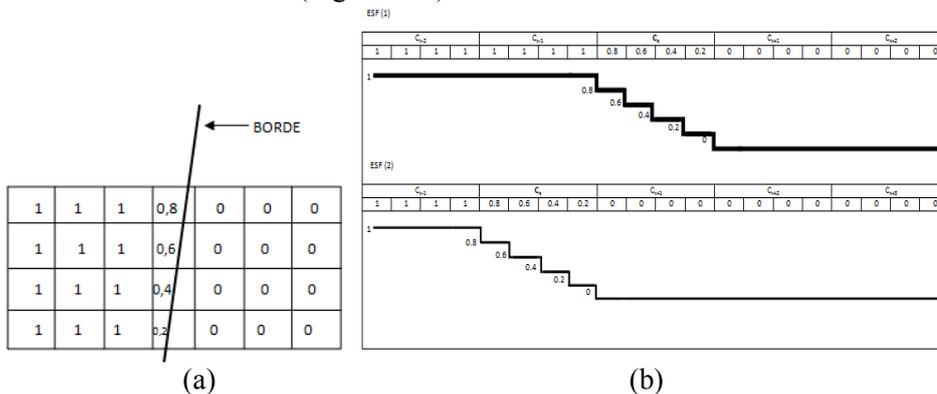


Figure 10. Edge Scheme of the ESF

The Line Spread Function (LSF,) calculated from Equation 2 is obtained in the digital domain by numerical differentiation of the ESF according to the expression:

$$\text{LSF}(x) = \text{ESF}(x-1) - \text{ESF}(x+1) \tag{3}$$

The $\text{LSF}(x)$ is a function with a high number of samples, superior to 18K samples. This causes noise in the $\text{MTF}(u)$ where it is not possible to evaluate the quality of the image. For it, the method proposed by [17] is used which consists in decreasing the quantity of samples according to the frequency resolution Δf needed and performing an apodization. It produces an $\text{MTF}(u)$ sharper.

To define the quantity of samples n a frequency resolution is assumed, expressed in pl/mm (couples of lines for mm):

$$\Delta f = 0,1 \text{ }^{\mu\text{m}}/\text{mm}.$$

Considering that Δf is defined from the Fourier Transform as:

$$\Delta f = \frac{1}{\Delta x \cdot n}$$

and the resolution of the ESF (x) is the quotient between the size of the pixel PS and N:

$$\Delta x = \frac{PS}{N}$$

then the quantity of samples n is defined for:

$$n = \frac{1}{\Delta x \cdot \Delta f} = \frac{N}{0,1 \cdot PS}$$

The apodization consists to apply a window to the LSF (x) where $LSF_a(x)$ is defined for:

$$LSF_a(x) = \begin{cases} 0 & x < -k \\ LSF(x) & -k < x < k \\ 0 & x > k \end{cases}$$

Finally MTF(u) is calculated using the equation (1) and it is normalized applying the following expression:

$$MTF_N(u) = \frac{MTF(u)}{\max \{MTF(u)\}}$$

B. Protocol Definition

The elaborated Protocol aims to analyze the quality of images of the equipments of digital radiology, by means of the MTF [4]. It needs the employment of a phantom, the RX equipment and software for parameters evaluation.

The tests are realized with the following conditions of reference: 70kVp, 100mAs, thin area (0.6mm), without antidiifusive grid at a photo-detector distance of 1,50 m and the quality of used radiation was the RQA 5.

The methodology of work proposed for the calculation of the MTF comprises the following steps:

- Annotate the code and the information of the movie in the "Data Schedule".
- Place the chassis in carries chassis.
- Places the phantom constructed on the chassis, inclined 1.5 - 3 degrees with respect to the axis of the detector to measure MTF.
- Realize two exposures (from two different positions of the phantom), one with the edge of the phantom orientated in a perpendicular direction to the axis anode-cathode (see Figure 11a), and other orientated in a parallel direction (see Figure 11b). Do the exposures with the reference conditions mentioned previously.
- Digitize the images.
- Process each digital image to evaluate the quality of it.
- Annotate the results in the "Quality index sheet".



Figure 11. Position of the phantom: a) perpendicular to the axis anode - cathode; b) parallel to the axis anode - cathode.

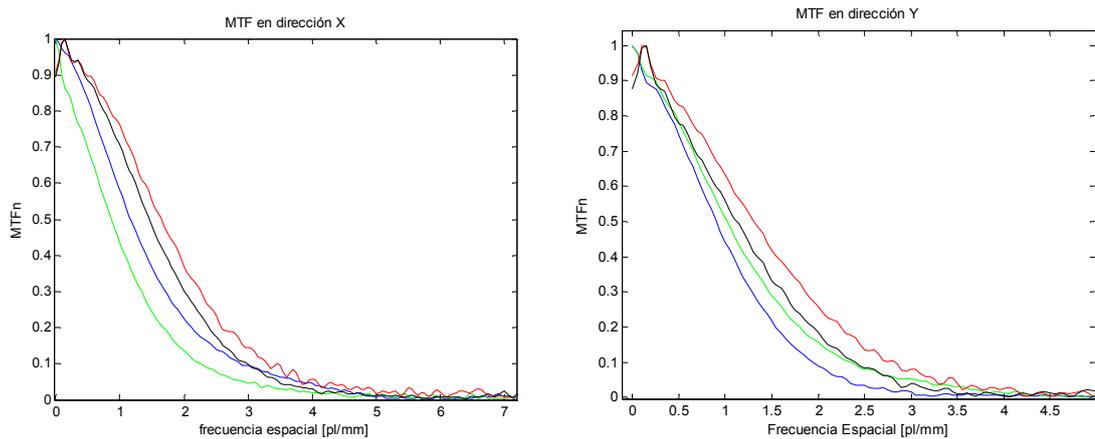
Results

The proposed methodology was evaluated on 4 computed radiology equipments. The KV, mA and time techniques described in the protocol were used. For each equipment 2 images of the phantom were obtained in parallel and perpendicular directions to the flow of electrons (cathode - anode).

In every image there was extracted the zone of analysis of 5cm x 10cm and the values of N, the average function of edge dispersion $ESF_{prom}(x)$, the function of dispersion of line apodized $LSF_a(x)$ and the MTFN (x) were calculated. In Table 1 and in the Figure 12 the results are presented.

	MTF (x)			MTF (y)		
	(frecuencia espacial en pl/mm)			(frecuencia espacial en pl/mm)		
	10%	50%	90%	10%	50%	90%
Equipo 1	2.8500	1.1500	0.3000	1.9000	0.9000	0.1000
Equipo 2	2.2000	0.8500	0.0500	2.3500	1	0.2000
Equipo 3	3.2500	1.6500	0.4500	2.8000	1.3000	0.3500
Equipo 4	2.9500	1.4500	0.4000	2.4000	1.1000	0.2000

Table 1.MTF's values.



Figures 12: MTFn for the axes X and Y

From the graphs the frequency values of the MTF(X) are obtained at 10 %, 50 % and 90 %. Due to the fact that there are no values of acceptance in the standard field, they have been compared with information published by [15] [16] [17], and it has been found an approximate error of 0.1 in the MTF at 50 %.

Conclusions

The previous sections have explained the theoretical aspects of the evaluation of the frequency response of a radiology system, which allows evaluating simultaneously aspects related to the contrast and to the resolution [18]. For this purpose the standard IEC 62220-1:2003 that describes the conditions for the acquisition of the image and then for the calculation of the Modulation Transfer Function. Though the standard describes the general characteristics for the obtaining of the function, different methods exist for its practical obtaining. In this work techniques of oversampling, frequency resolution restriction and the apodization are combined to obtain a quality graph.

For the evaluation of the method images of 4 equipments of computed radiology of different centers have been registered, obtaining in a complete and a clear way the MTF. Later these

values have been compared with values published of equipments of the same technology, obtaining similar values. The implemented method is part of the controls on radiology equipment that had been implemented in the Check and Calibration of Medical Equipment Laboratory of the GATEM-UNSJ. We expect in the future to integrate this measurement as a part of the protocols of valuation institutionally implemented.

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