

Comparison between subjective and quantitative methods for assessing the resolution limit of radiographic systems

Comparação entre métodos subjetivos e quantitativos na medida da resolução limite de sistemas radiográficos

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Abstract

The aim of this study was to compare two ways of measuring the resolution limit of radiographic systems, one subjective and one quantitative. To this end, nine images were acquired with different radiographic techniques using a pattern of bars and aluminum plates. With these images were acquired modulation transfer function (MTF) through the edge image obtained by the aluminum plate — the MTF 10% was measured on all images — and the variation of these points, which was faced with the evaluation obtained by the resolution limit of the standard bar. Although we have observed a greater variation between measurements obtained using the bar-pattern, the simplicity of this measuring technique favors the common use of the same. We concluded that, to optimize the quality control of radiographic equipment, it is suggested to measure the MTF at least in periods of time while the annual pattern of bars to be used in shorter time periods to measure changes in resolution of the system.

Keywords: optimization, quality control, radiography.

Resumo

O objetivo deste estudo foi comparar duas formas de aferição da resolução limite de sistemas radiográficos, uma subjetiva e outra quantitativa. Para tal, foram adquiridas nove imagens com diferentes técnicas radiográficas utilizando um padrão de barras e placas de alumínio. Com estas imagens, foram adquiridas a função de transferência modulada (FTM) através da imagem da borda obtida pela placa de alumínio — a FTM foi aferida 10% em todas as imagens — e a variação destes pontos — que foi confrontada com a avaliação da resolução limite obtida através do padrão de barras. Apesar de termos observado uma maior variação entre as medidas obtidas com a utilização do padrão de barras, a simplicidade de medição desta técnica favorece o uso corriqueiro da mesma. Conclui-se que, visando a otimização do controle de qualidade de equipamentos radiográficos, sugere-se fazer a medição da FTM pelo menos em períodos de tempo anuais, enquanto que o padrão de barras seja utilizado em períodos de tempo menores para a aferição de mudanças na resolução do sistema.

Palavras-chave: otimização, controle de qualidade, radiografia.

Introduction

In an x-ray imaging system, the detector properties are determinant for the apparent resolution in the radiological images¹. Spatial resolution is one of the parameters that are routinely checked during acceptance procedures and regular quality control measurements methods¹. The spatial resolution of a radiographic imaging device is most appropriately expressed in terms of its modulation transfer function (MTF), which indicates the decline of detector spatial resolution with spatial frequency^{2,3}. Traditionally used methods

of MTF measurement involve imaging either a narrow slit or a sharp edge to obtain the detector line spread function (LSF), whose frequency transform leads to the MTF³⁻¹¹. Over the last few decades, robust techniques for slit^{4,5,10,11} and edge⁶⁻⁹ measurements have been developed and used in imaging research. These methods provide the advantage of good accuracy over a near-continuous frequency domain. However, this accuracy is dependent on the alignment of the slit or edge targets with the radiation beam that typically requires a complex and time-consuming experimental setup. As a result, slit and edge measurements are difficult

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to perform and not suitable where spatial resolution has to be monitored routinely and quickly, as is typically the case in quality assurance (QA) measurements. To estimate the limiting spatial resolution of the system, the frequencies at which the MTF has fallen to 10% is commonly measured¹².

An alternative procedure to estimate the limiting spatial resolution of a radiographic device is to perform an exposition of a line-pair bar-pattern covering at least the range 1-5 line pairs (lp)/mm. The acquired image is examined according to the number of line pair that can be observed clearly, starting with the most easily resolved. The acceptable tolerance value of this test is the same used for the MTF²⁻¹².

In this work is presented a simulation study of the parameters involved in the MTF measurement followed by a study of the relationship presented between the measurement of the limiting spatial resolution using the MTF method and the line-pair bar-pattern method. Our aim was to compare the bar-pattern method with the MTF method and then to evaluate which method is better for the dairy quality control tests and when is appropriate to perform one test or other.

Material and methods

Data acquisition

Radiographies of a line-pair bar-pattern and an aluminum target were obtained with entrance surface expositions in the range of 0.9-200.9 uGy. An x-ray equipment Siemens 844002 and an AGFA CR-85X were used to obtain the images. The line-pair bar-pattern images were evaluated by three experienced medical physicists and the aluminum radiographies were used to obtain the MTF of the system and to measure data to simulate images with the same pattern. The aluminum images were obtained using a 4.5 cm sheet of polimetilmetacrilate (PMMA) with a 2.0 mm Aluminum foil placed above it.

Simulated images

The simulated images were within 512 x 512 pixel array, the edge transition was defined by a 0° straight line passing through the center of the image dividing it into two regions with different average pixel values. The values of these two regions were generated by a Gaussian distribution with mean and standard deviations obtained experimentally with values of 2,200+100 for the aluminum + PMMA region and 3,000+100 for the PMMA region. Finally, a low-pass median filter with dimensions of 2 x 2 was used to better simulate the visual aspect of the simulated edge.

In Figure 1A is depicted the real edge image in comparison with a simulated edge image, which is depicted in Figure 1B.

Modulation transfer function measurements

Described in the following is the algorithm used to compute the MTF. This algorithm is based on the algorithms

developed by Samei, Flynn and Reimann⁹ and Carton et al.¹. Basically, this algorithm requires an image of an edge and the signal images must be linear with detector dose. As illustrated in Figure 2, the process to calculate the MTF includes six steps, following.

Step 1: A region of interest (ROI) centered on the edge is selected. This ROI is defined by a width W and a length

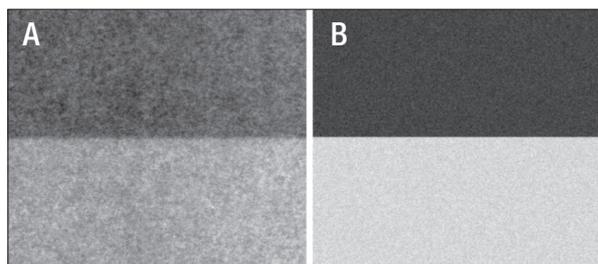


Figure 1. Edge images. (A) Real image obtained from the aluminum sheet. (B) Simulated edge image.

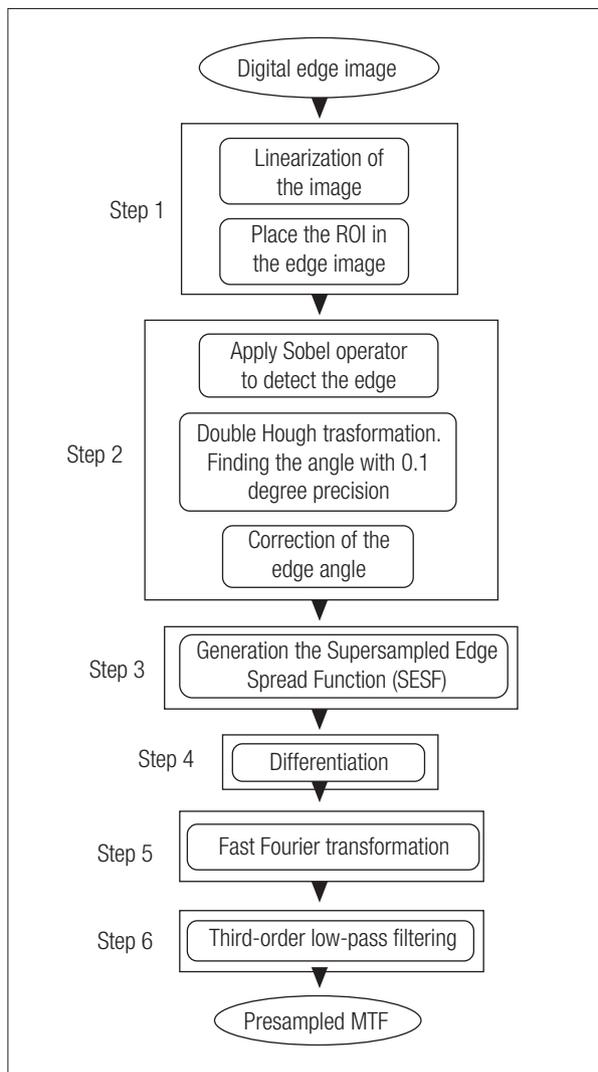


Figure 2. The processing steps applied in the digital edge image to calculate the modulation transfer function of the radiologic system.

L. W is the total number of rows used for the determination of the MTF. L is the length of the edge profiles.

Step 2: Sobel operator is applied to the image to detect the position of the edge and a double Hough transform is applied to the resulting matrix to estimate the angle of the edge. Then, the image is rotated to obtain an edge angle of 0° .

Step 3: A supersampled Edge Spread Function (ESF) is generated by using the pixel values of N consecutive rows across the edge: the value of the first pixel in the first row gives the first data point in the supersampled ESF; the first pixel in the second row gives the second data point, etc.; and the first pixel in the Nth row gives the Nth data point.

Step 4: The line spread function (LSF) is calculated by finite-element differentiation of the SESF using a convolution filter with a $[-1 \ 1]$ kernel.

Step 5: The modulus of the Fourier transform of the LSF is calculated, the result is normalized to its zero-frequency value $[MTF(0)=1]$.

Step 6: A third-order low-pass filter is applied to the MTF. To avoid distortion of the MTF, the filter is applied twice. A copy of the raw MTF data is made. On one array the filter is applied from the first point to the end. On the second array, the filter is applied in the reverse from the last point to the first point of the MTF.

In Figure 3 are plotted a super sampled ESF and a LSF obtained from real images using the algorithm above. The limiting resolution of the system was measured at 10% of the MTF in the images obtained.

Measurement using line-pair bar-pattern

In Figure 4 is shown a radiograph of the line-pair bar pattern used in this paper to measure the limiting resolution of the system by the medical physicists. The line-pair bar-pattern used has line pairs/millimeter (lp/mm) in the range of 0.6–5.0. The test is performed in the following way: the radiograph of the line-pair bar-pattern is viewed on the monitor of the available workstation with at least a 1:1 zoom factor and the number of line pairs that can be observed clearly is taken as the limiting spatial resolution of the system. This test was performed by three medical physicists to evaluate the differences encountered in the visualization of them.

Results

Simulated images

Noise and angulation were added in the simulated images in order to test the algorithm performance and to better understand some errors given in the development of the program. The results are shown below.

Noise

Noise was added to the edge image by improving the standard deviation of the Gaussian distribution that was used to fill the areas of the simulated radiographs. In the Figure 5 is depicted the MTF obtained for a standard deviation (in pixel values) of 5, 50 and 200.

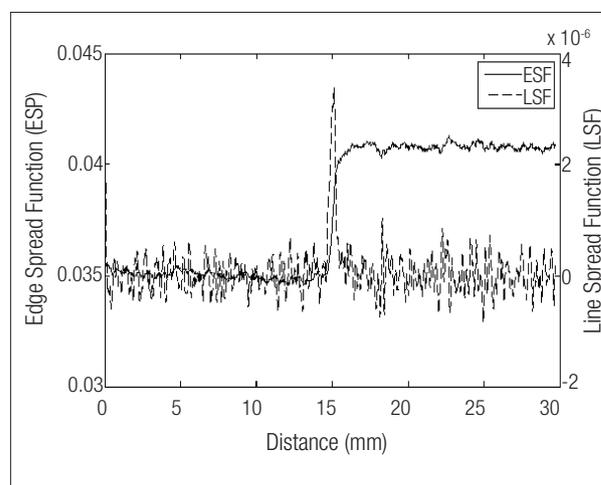


Figure 3. Real supersampled Edge Spread Function (ESF) and line spread function (LSF) obtained from one of the radiographs used in this work.

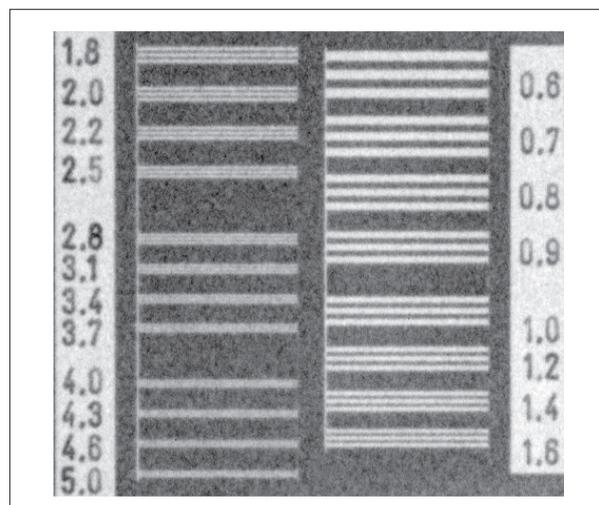


Figure 4. Radiography of the line-pair bar-pattern tool used in this study.

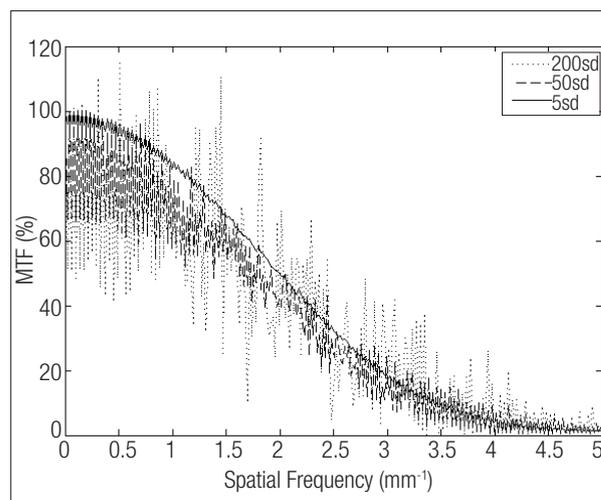


Figure 5. Three modulation transfer functions obtained by addition of the noise to the input image.

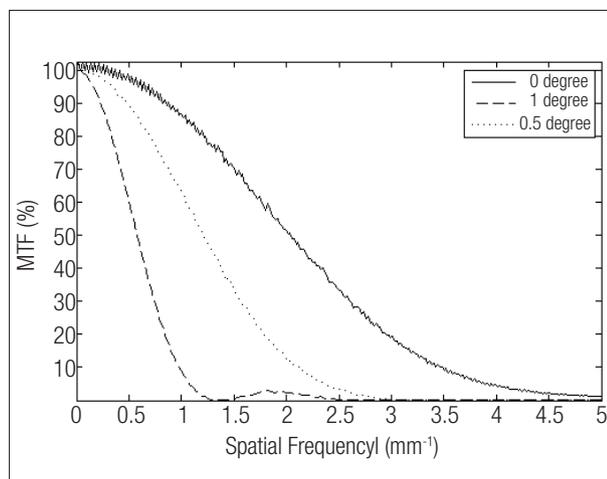


Figure 6. Three modulation transfer functions obtained by rotation of the input image by 0°, 0.5° and 1°.

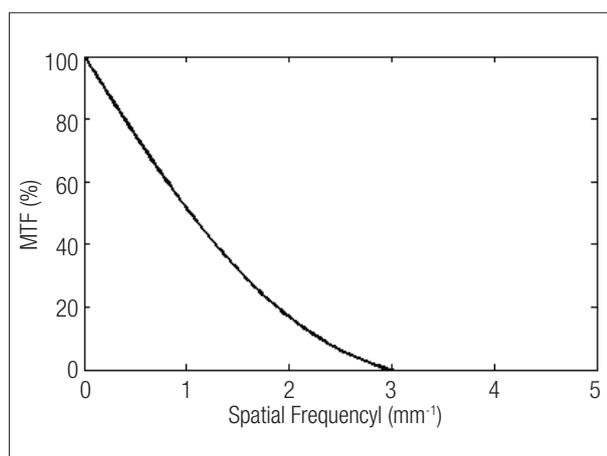


Figure 7. Modulation transfer function calculated from a real image.

Table 1. Reference points measured to each modulation transfer function calculated and the physicist readers' evaluation of the resolution limit.

Dose (uGy)	Reader (lp/mm)	MTF		
		50%	20%	10%
200.9	2.2±0.2	1.22	1.96	2.30
191.2	2.1±0.4	1.32	1.95	2.50
145.8	2.2±0.2	1.43	1.92	2.10
113.4	2.2±0.2	1.25	1.80	2.25
81.0	2.2±0.2	1.25	1.92	2.30
48.6	2.1±0.4	1.30	1.82	2.35
19.8	2.1±0.4	1.28	1.99	2.20
1.9	2.2±0.6	1.30	1.95	2.20
0.9	2.1±0.4	1.32	1.86	2.55
Mean±2SD	2.2±0.4	1.30±0.12	1.91±0.13	2.31±0.29

MTF: modulation transfer function; SD: standard deviation

Angulation

The angulation in the input image was proven to be one of the most important factors in the MTF acquisition. In Figure 6 is shown three MTF obtained with the angulation of the input image in 0°, 0.5° and 1°.

Real images

MTF obtained from the real images were measured in the points of 50, 20 and 10%. The points measured in 10% were used to compare the limiting resolution of the system while the others measured points were used to evaluate the performance of our algorithm/x-ray system. In Figure 7 is shown an example of a MTF obtained using our algorithm while in the Table 1 is depicted the measured points and the medical physicist readers' maximum resolution.

Comparison between the resolution limit measured by the modulation transfer function and the bar-pattern

In Figure 8 is plotted the resolution limit evaluated by three medical physicists and the resolution limit obtained by 10% of the MTF.

Discussion and conclusions

This paper evaluated the performance of the resolution limit obtained by a quantitative and a subjective way. The first was performed calculating the MTF of the system and demonstrating that it can give a better understanding of the system spatial resolution than the subjective test. The subjective test was performed by the evaluation of the visibility of a radiography of a line-pairs bar-pattern. It has been shown that the quantitative way, although it presents a contrast response curve all over the frequency range, can be replaced by the subjective test in order to assess the maximum resolution of the radiologic system. Figures 5 and 6 present the effect of the noise and the angulation when assessing

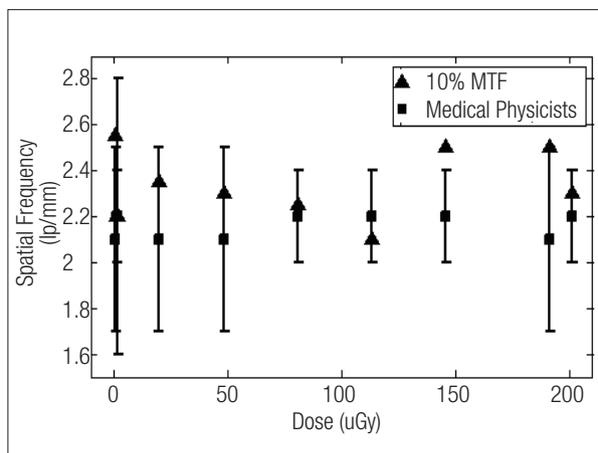


Figure 8. Comparison between the resolution limit measured by three medical physicists' evaluation and 10% of the modulation transfer function. The triangle indicates the measure of 10% of the modulation transfer function while the squares represented the medical physicists' opinion.

the MTF of the system. In agreement with Samei, Flynn and Reimann⁹, extra caution with the dose and the angle of the edge is needed when assessing the ESF in order to obtain the maximum MTF with less noise as possible.

Although the results obtained by the quantitative method showed fewer variations than the obtained by the subjective way, the caution need when placing the edge, the need of the linearization of the image and the need of digital image processing knowledge contributes to the difficulty of the calculation of the MTF. These factors favored the realization of the subjective test.

In this way, we conclude that it is advisable to perform the MTF test for an in-depth study of the contrast response of the system all over the frequency range. To check the resolution limit of the system, the bar-pattern imaging test should be sufficient.

References

1. Carton AK, Vandenbroucke D, Struye L, Maidment AD, Kao YH, Albert M, et al. Validation of MTF measurement for digital mammography quality control. *Med Phys*. 2005;32(6):1684-95.
2. Gopal A, Samant SS. Validity of the line-pair bar-pattern method in the measurement of the modulation transfer function (MTF) in megavoltage imaging. *Med Phys*. 2008;35(1):270-9.
3. Metz CE, Doi K. Transfer function analysis of radiographic imaging systems. *Phys Med Biol*. 1979;24(6):1079-106.
4. Rossman K. Measurement of the line spread function of radiographic systems containing fluorescent screens. *Phys Med Biol*. 1964; 18:551-7.
5. Dobbins 3rd JT, Ergun DL, Rutz L, Hinshaw DA, Blume H, Clark DC. DQE(f) of four generations of computed radiography acquisition devices. *Med Phys*. 1995;22(10):1581-93.
6. Judy PF. The line spread function and modulation transfer function of a computed tomographic scanner. *Med Phys*. 1976;3(4): 233-236
7. Cunningham IA, Fenster A. A method for modulation transfer function determination from edge profiles with correction for finite element differentiation. *Med Phys*; 1987; 14; 533-537.
8. Moy JP, Signal-to-noise ratio and spatial resolution in x-ray electronic imagers: Is the MTF a relevant parameter?. *Med Phys*, 2000;27(1), 86-93.
9. Samei E, Flynn MJ, Reimann DA, A method for measuring the presampled MTF of digital radiographic systems using an edge test device. *Med Phys*, 1998;25(1), 102-113.
10. Fujita H, Morishita J, Ueda K, Tsai D Y, Ohtsuka A and Fujikawa T. Resolution Properties of a computed radiographic systems. *SPIE Med Imaging*, 1989; 1090;263-275
11. Fujita H, Tsay DY, Itoh T, Doi K, Morishita J, Ueda K and Ohtsuka A, A simple method for determining the modulation transfer function in digital radiography *IEEE Trans Med Imaging*. 1992;11(1):34-9.
12. International Atomic Energy Agency (IAEA). Human health series n° 17: Quality Assurance Programme for Digital Mammography. Vienna: IAEA Press; 2011. 177 p.