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Comparison of Bar Pattern and Edge Method for MTF Measurement in Radiology Quality Control

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Resumo
A resolução espacial é um dos parâmetros rotineiramente verificado durante os procedimentos de aceitação e medições regulares de controle de qualidade. A resolução espacial de um dispositivo de imagem radiográfica é mais apropriadamente expressa em termos da sua função de transferência de modulação (MTF), o que indica a queda de um detector de resolução espacial com frequência espacial. Métodos tradicionalmente utilizados de medida da MTF envolvem a imagem de uma fenda estreita ou uma borda afiada para obter a função linha detector spread (LSF), cuja transformada de Fourier leva a uma estimação da MTF do sistema. Neste trabalho é apresentado um estudo sobre a medida da resolução espacial limitante utilizando o método MTF e o padrão de barras. Nosso objetivo é comparar o método de padrão de barras com o método de borda e, em seguida, avaliar qual método é o mais suitável para os testes de controle de qualidade rotineiros e inferir quando é melhor para executar um teste ou outro. Estes procedimentos de aquisição foram testados de acordo com a sua reprodutibilidade e variação devida ao ruído.
Palavras-chave: Resolução de sistemas radiográficos, testes de garantia de qualidade, controle de qualidade.

Abstract
Spatial resolution is one of the parameters that is routinely checked during acceptance procedures and regular quality control measurements. 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. 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 MTF. In this work is presented a study of the measurement of the limiting spatial resolution using the MTF method and the line-pair bar-pattern method. Our aim is to compare the bar-pattern method with the MTF method and then evaluate what method is the best for the dairy quality control tests and when is better to perform one test or other. These acquisition procedures were tested according to its reproducibility and variation due to noise.
Keywords: *Resolution of radiographic systems, Quality assurance tests, Quality control.*

1. Introduction

In an X-ray imaging system, the properties of the detector are determinant for the apparent resolution in the radiological images[1]. Spatial resolution is one of the parameters that is routinely checked during acceptance procedures and regular quality control measurements methods are used [1]. 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]. 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 MTF[1].

Over the last few decades, robust techniques for slit and edge measurements have been developed and used in imaging research[2-5]. 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 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[4]. To estimate the limiting spatial resolution of the system, the frequencies at which the MTF has fallen to 10% is commonly measured.

Originally bar patterns devices were used to measure the limiting resolution of screen film radiographic systems. With the advances made in radiology, digital direct and indirect systems are not difficult to find. The pre-sampled Modulation Transfer Function was first used by Fujita[3] which used a slit device to measure the Line Spread Function of the system. Samei[2] optimized Fujitas technique using an edge device, making the measures more easily obtainable. 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 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. Typically, a bar pattern containing several sets of such line-pair targets presenting several spatial frequencies may be also used to determine the MTF[1]. The fundamental advantages of this method are ease, simplicity, and quickness relative to the slit and edge techniques, as well as the fact that it provides direct visualization of imaging spatial resolution from the image of the line pairs[1]. Bar pattern measurements are limited mainly by the accuracy of the normalization at zero frequency, which has to be approximated from large areas of the bar, and by the need to correct for the presence of higher-order harmonics of the fundamental frequency of the line pairs that requires interpolation between the discrete spatial frequencies.

In this work is presented a study of the measurement of the limiting spatial resolution using the MTF method and the line-pair bar-pattern method. Our aim is to compare the bar-pattern method with the MTF method and then evaluate what method is the best for the dairy quality control tests and when is better to perform one test or other. These acquisition procedures were tested according to its reproducibility and variation due to noise.

2. Methods

2.1. Data Acquisition

Radiographies of a line-pair bar-pattern and an aluminum target were obtained with detector exposures of about 2.5 uGy. An x-ray equipment Multix B (Siemens®) and a CR-85X (Agfa®) were used to obtain the images.

The bar pattern used to evaluate the MTF is depicted in figure 1-left, their radiographies were evaluated as depicted in session II.D. A 10x10x1mm thick copper plate was used to evaluate the MTF by edge method, its radiography is depicted at figure 1-right.

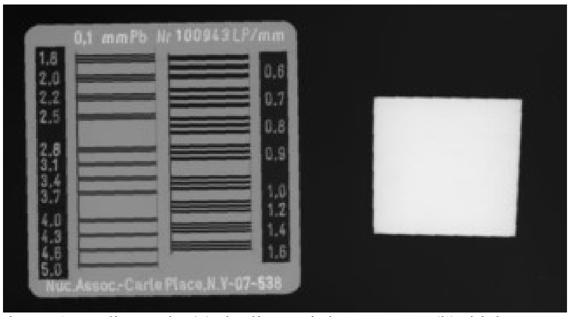

Figure 1. Radiograph: (a) the line-pair bar-pattern; (b) thick copper

To infer about the noise sensitivity of the techniques, three radiographies were obtained using the same detector exposure, but adding 3.0 cm and 6.0 cm of PMMA.

2.2. Geometry

The geometry used in the acquisition of the images is the recommended by the IEC62220-1 and the Xray beam used was the RQA5. The acquired images were within 512x512 pixel array, the edge transition was defined by a 0o straight line passing through the center of the image dividing it into two regions with different average values.

2.3. MTF Measurements

The developed algorithm used to compute the MTF is based on the algorithms developed by Samei and Carton A-K. Basically, this algorithm requires an image of an edge and the signal images must be linear with detector dose.

Step 1: A region of interest (ROI) centered around the edge is selected. This ROI is defined by a width W and a length 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 and edge angle of 0°.

Step 3: A Supersampled edge spread function (SESF) 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 algorithm the filter is applied in the reverse from the last point to the first point of the MTF.

In figure 2 are plotted an 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.

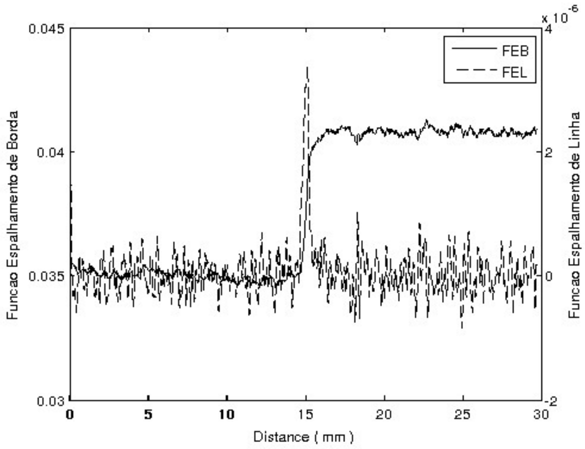

Figure 2. Real Supersampled Edge Spread Function (SESF) and line spread function (LSF) obtained from one of the radiographs used in this study.

2.4. MTF using line-pair bar-pattern

The line-pair bar-pattern used have line pairs/milimeter (lp/mm) in the range of 0.6-5.0lp/mm. The contrast difference between lead and acrylic was measured and normalized by the lower frequency present in the bar pattern (0.6lp/mm). An example of the measurement of the contrast for low, medium and high frequency is depicted at figure 3.

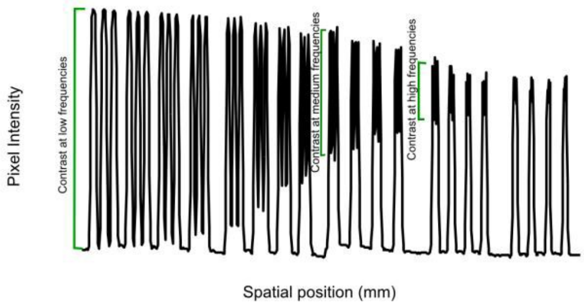

Figure 3. Contrast evaluation using the profile generated by the barpattern method.

2.5. Comparison of methods

The MTF obtained by the edge method was compared to the contrast measure obtained by the bar pattern. The MTF normalized at 0 lp/mm was renormalized at 0.6 lp/mm to evaluate the variation between both methods according to the addition of PMMA.

3. Results

Results of the MTF normalized at the 0 frequency is depicted at figure 4.

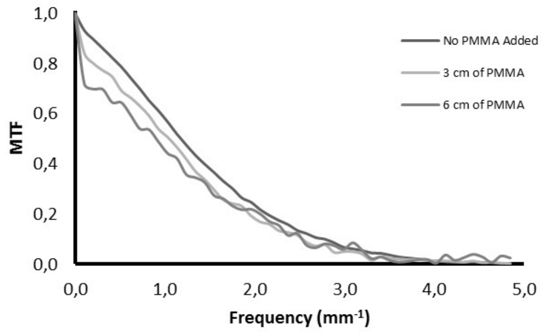

Figure 4. MTF by Edge Method

Figure 5 shows the (a) MTF normalized at 0.6lp/mm obtained using the edge method and (b) MTF obtained using the bar pattern.

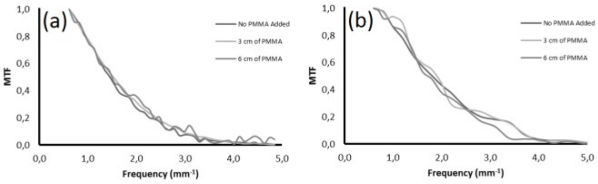

Figure 5. MTF obtained by (a) edge method and normalized at 0.6 lp/mm and (b) bar pattern.

In figure 6 is depicted the differences between the mean of MTFs obtained by the edge method normalized at 0 and 0.6 lp/mm and the bar method.

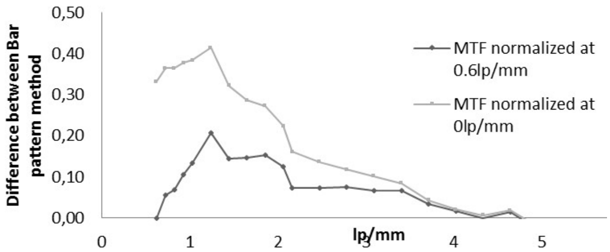

Figure 6. Difference between bar pattern and MTF normalized at 0 frequency and at 0.6 lp/mm.

Mann Whitney test was applied to the data and the three compared methods did not differ statistically with a p=0.402 and a Bland Altman LoA of -0.03 to 0.21 between the bar pattern and MTF normalized at 0.6lp/mm and a p=0.6 and Bland Altmann LoA of -0.07 to 0.49 between bar pattern and MTF normalized at 0 frequency.

4. Discussion and Conclusion

The MTF measures varied mostly at low frequencies. As show in figure 4, the MTF normalized at 0 frequency was the only method that was sensitive to the PMMA plates added.

There was not statistically significant difference between the methods. This is an indicative that the bar pattern is a simple method that can be used in the routine quality control to evaluate the reproducibility of the system for medium and high frequencies.

Another important aspect is, as show in figure 6, the limiting resolution of the system (approximate at 3.5-4.0lp/mm) can be inferred by all the methods since a small error was verified in that frequency.

It is very important to never use the MTF normalized at other frequency above 0 to infer about the Detective Quantum Efficiency. This will lead to an overestimation of the contrast, as shown by the Bland Altman values.

The error between methods is very dependent of the frequency, since higher frequencies and even the limiting resolution presented a small difference.

In contrast, for lower frequencies it were encountered errors in the order of 0.5, which is half the maximum amplitude of the signal.

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